NEURAL NETWORK MODELLING AND PREDICTION OF THE FLOTATION DEINKING BEHAVIOUR OF COMPLEX RECYCLED PAPER MIXES

by

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Declaration

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ABSTRACT

In the absence of any significant legislation, paper recycling in South Africa has grown to a respectable recovery rate of 43% in 2008, driven mainly by the major paper manufacturers. Recently introduced legislation will further boost the recovery rate of recycled paper. Domestic household waste represents the major remaining source of recycled paper. This source will introduce greater variability into the paper streams entering the recycling mills, which will result in greater process variability and operating difficulties. This process variability manifests itself as lower average brightness or increased bleaching costs. Deinking plants will require new techniques to adapt to the increasingly uncertain composition of incoming recycled paper streams. As a developing country, South Africa is still showing growth in the publication paper and hygiene paper markets, for which recycled fibre is an important source of raw material.

General deinking conditions pertaining to the South African tissue and newsprint deinking industry were obtained through field surveys of the local industry and assessment of the current and future requirements for deinking of differing quality materials.

A large number of operating parameters ranging from waste mixes, process variables and process chemical additions, typically affect the recycled paper deinking process. In this study, typical newsprint and fine paper deinking processes were investigated using the techniques of experimental design to determine the relative effects of process chemical additions, pH, pulping and flotation times, pulping and flotation consistencies and pulping and flotation temperatures on the final deinked pulp properties.

Samples of recycled newsprint, magazines and fine papers were pulped and deinked by flotation in the laboratory. Handsheets were formed and the brightness, residual ink concentration and the yield were measured. It was determined that the type of recycled paper had the greatest influence on final brightness, followed by bleaching conditions, flotation cell residence time and flotation consistency. The residual ink concentration and yield were largely determined by residence time and consistency in the flotation cell.

The laboratory data generated was used to train artificial neural networks which described the laboratory data as a multi-dimensional mathematical model. It was found that regressions of approximately 0.95, 0.84 and 0.72 were obtained for brightness, residual ink concentration and yield respectively.

Actual process data from three different deinking plants manufacturing seven different grades of recycled pulp was gathered. The data was aligned to the laboratory conditions to take into account the different process layouts and efficiencies and to compensate for the differences between laboratory and plant performance. This data was used to validate the neural networks and select the models which best described the overall deinking performances across all of the plants. It was found that the brightness and residual ink concentration could be predicted in a commercial operation with correlations in excess of 0.9. Lower correlations of *ca.* 0.5 were obtained for yield.

It is intended to use the data and models to develop a predictive model to facilitate the management and optimization of a commercial flotation deinking processes with respect to waste input and process conditions.

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GLOSSARY OF TERMS AND ABBREVIATIONS

ANN	Artificial neural network
Board	A paper typically of high thickness and high grammage
Brightness	Spectral reflectance at 457 nanometres.
Chemical pulp	Pulp fibres produced by chemical degradation of lignin.
Chromophore	A chemical structure which exhibits colour in the visible region of the electromagnetic spectrum.
COD	Chemical oxygen demand.
Consistency	Mass percent of solids in an aqueous pulp suspension.
Defibering	Separation of paper or paperboard into individual fibres.
Dissolving pulp	A chemical pulp with a high cellulose content.
ERIC	Effective residual ink concentration, measured by reflectance at 950 nanometres.
Filler	Minerals such as clay (kaolin) or calcium carbonate, which are added to a sheet of paper during manufacture to enhance the optical properties of the paper and to reduce the raw material cost.
Fines	Very small fragments of fibre and colloidal material, which occur in paper and pulp mill process water circuits.
Flakes	Small pieces of recycled paper that have not been completely disintegrated into fibres.
Furnish	The fibre and fillers that constitute the raw materials of a sheet of paper.
Grammage	The basis weight of a sheet of paper, expressed as grams/m^2, or gsm.
Lignin	Lignin is the substance that binds the fibre cells together in wood. It is an amorphous, glassy polymer of uncertain structure, comprising mainly phenolic monomeric units.
Lumen	The hollow centre of a fibrous wood cell.
Mechanical pulp	Pulp fibres produced by mechanical degradation of wood. Refer to "wood containing".
nm	Nanometers, or 10^{-9} meter.

Pareto analysis	Statistical analysis technique that uses the 80/20 Pareto Principle.
Pits	Small apertures in the cell wall of a wood fibre, to facilitate the transport of fluids from cell to cell.
ppm	Parts per million.
Pulp	A variably used term in the industry, referring to an aqueous suspension of wood fibres, but can also refer to the wood fibres themselves.
rpm	Revolutions per minute.
Reynolds number	A dimensionless number used in fluid mechanics to express the ratio of inertial forces to viscous forces.
SEM	Scanning electron microscope.
Shives	Small bundles of unseparated fibres, usually arising when wood is incompletely separated into fibres during pulping.
Specific energy	The ratio of energy input to mass flow of fibres. Common units are kWh/ton.
Stickies	Stickies arise when waste paper is recycled, and are formed from the resins and adhesives that are used in the manufacture of paper or board products.
Stokes number	A dimensionless number used in fluid mechanics to express the behaviour of particles suspended in a flowing fluid.
Utilisation rate	The percentage of recovered paper used as a raw material in paper production.
Virgin pulp/fibre	Fibre made from wood or other plant material, as opposed to recycled fibres.
Wood free	Refers to paper made from chemical pulps, essentially means that there is no lignin remaining in the fibres.
Wood containing	Refers to paper made wholly or in part from mechanical pulps, thus containing lignin.

CHAPTER 1: GENERAL INTRODUCTION

1.1 A global overview of paper recycling

In 2000 the global paper industry used an estimated 145 million tons of recycled fibre, only slightly less than the estimated 185 million tons of wood and non-wood pulp produced (World trade in waste paper, 2001). In 2007, 208 million tons of paper were recovered as opposed to an estimated total pulp production of 188 million tons (RISI, 2008a & 2008b). These figures show that today, recycled fibre constitutes a major proportion of the fibre used in the paper industry. In many parts of the developed world the paper industry would not exist without this valuable fibre resource. Even in countries which have abundant natural forest resources, recycled fibres are used in combination with virgin pulps in the production of many grades of paper. In the 1990's, the consumption of recovered paper grew at an annual rate of 6%, compared to the 3% annual growth in paper production and the 2% growth in the production of chemical pulp and mechanical pulp. (Goettsching & Pakarinen, 2000: 12-22)

This growth in the usage of recycled fibres has been encouraged by the growth in environmental awareness in the industrialised nations, coupled with stringent environmental legislation. The use of recycled fibre has been most successful in the densely populated developed countries, where recycling and collection efficiencies make recycled fibre a cost effective alternative to virgin fibre.

In developed countries, environmental awareness by the general public has driven the promulgation of environmental legislation, which aims to limit the amount of waste produced by domestic households and industrial operations. This has been necessary because of the growing mountains of waste material and limited landfill capacity, which has increased the costs and environmental burdens of waste disposal.

In the late 1950's the first flotation deinking plant was installed in the United States. Since then the production capacity has grown to exceed 30 million tons per annum in 2000. Most of this capacity growth has been in Europe (44%), with 25% each in the United States and Asia. The remaining 6% growth has occurred in South America, Africa and Oceania (Goettsching & Pakarinen, 2000: 12-22).

The amount of recovered paper used as a raw material is called the utilisation rate. This varies widely according to region and the grade of paper manufactured. In addition, the yields of the deinking processes also depend on the grade of paper produced. This yield loss is a consequence of the differing quality requirements of the end products. Based on statistics and estimates given by Goettsching & Pakarinen (2000: 12-22), the amount of recycled fibre in the different grades of paper in Germany in 1998 has been estimated in Table 1.1.

Table 1.1 Utilisation rates, process yields and amount of recycled fibre in different grades of paper, Germany, 1998.

Paper Grade	Utilisation rate %	Estimated yield of deinking process %	Estimated % recovered fibre in final product
Packaging and cardboard	96	90-95	86-91
Hygiene papers	70	60-75	42-52
Specialty papers	48	70-95	34-46
Graphic papers (including newsprint)	37	65-85	24-31
Newsprint	115	65-85	75-98

By contrast, the utilisation rates in the United States of America differ somewhat, as Table 1.2 shows.

Table 1.2: Utilisation rates in the USA, 2005. (Roberts, 2007)

Paper Sector	% Utilisation
Tissue	46
Boxboard	38
Newsprint	33
Container boards	24
Printing & writings	7

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As can be seen from Tables 1.1 and 1.2, the highest levels of recycled fibre are used in packaging papers and cardboard. For economic and technical reasons, the dark grey or brown colours of the final product do not require ink removal. The level of recycled fibre in tissue papers is more moderate, due to high yield losses in the recycling process. The average recycled fibre content of printing and writing papers is much lower, due to the high brightness requirements of many of the grades. In particular, Xerographic photocopy papers and other high quality grades do not allow high levels of recycled fibre addition. By contrast, the utilisation rates of newsprint have reached a very high level. This has been driven by the economic constraints on newsprint production and the development of deinking processes that produce an acceptable quality fibre that can be re-used at high levels.

The average global waste paper utilisation rate was projected to grow further, but at a lower rate. It was expected that a balanced utilisation rate of about 50% would be achieved by the year 2010 (Goettsching & Pakarinen, 2000 7: 12-22). This means that the average recycled fibre content of a paper or board product would be about 42.5% after recycling losses have been taken into account. However, recent figures have suggested that in Europe and America the waste utilisation rates have exceeded these expectations. In 2007, the recycling rate in Europe reached 64.3%, and the industry has set itself a target of 66% by 2010 ("European Declaration on Paper Recycling 2006 – 2010. Monitoring Report", 2007). In the United States of America, the recovery rate has increased from 33.5% in 1990 to 53.4% in 2006 ("2006 Recovered Paper Annual Statistics", 2006), with a goal of 55% by 2012 ("2007 Recovered Paper Annual Statistics", 2007). The international economic recession of 2008 to 2009 has impacted negatively on these projections, but indications are that the pre-recession momentum would be regained (Bureau of International Recycling, 2009).

1.2 Paper recycling in South Africa

In South Africa the situation is a little different from the rest of the world. There has historically been no legislation governing the re-use of recycled paper. With no supporting legislation, the major paper manufacturers have increased collections by aggressive promotion of recycling practices and the paying of good prices for recycled paper.

However, the National Environmental Management: Waste Act 59 of 2008 has been promulgated. This bill will change the way waste is managed in South Africa. Any material that can be recycled will not be classified as a waste, and will thus not be allowed to be dumped in landfill sites. The bill has set a target of a 70% reduction in waste dumped in landfills by 2022. This bill will thus boost the supply of recycled paper in South Africa (Pamsa, 2007).

Despite the lack of legislation, the recovery rate of recycled paper has grown from 29% in 1984 to 50% in the year 2003. Since then the recovery rate has fallen back to ca. 43% in 2008, with another increase expected in the years ahead. (South African Paper Recovery Information for 2008). The 2008 figure of 43% corresponds to about 1030 000 tons per annum. This indicates that the amount of paper recovered has increased considerably, even though its percentage of the total paper manufactured as decreased a little.

Table 1.3 compares the tonnages of the various types of pulps produced in South Africa. Recycled fibre is the second most important source of fibre in South Africa.

Table 1.3: Annual production of pulp in South Africa. (Pamsa, 2007)

PULP GRADE	TONS PRODUCED (000'S)
Mechanical pulp	238
Semi-chemical pulp	135
Chemical pulp	1489
Dissolving pulp	543
Recycled fibre	946
Total	3351

An analysis for 2009 by the Paper Recycling Association of South Africa (PRASA, 2009), showed that the total amount of paper available for recovery was about 1,639 000 tons. Of this amount, only about 943 000 tons (or 57.6%) was recovered. The remaining 43% consists of paper originating from domestic households. This represents the last available source of paper for recycling. Besides the difficulties associated with the collection of this paper, it will need extensive sorting into useable fractions. Even with sorting processes, the resultant grades of recycled paper are not uniform and will present challenges to the waste recycling plants, in terms of ever increasing variability of incoming raw material.

Figure 1.1 below represents an analysis by Hunt (2008) on the collection and use of recycled paper in South Africa. With the industry having to resort more and more to recovering household waste, which is a mixture of newsprint, magazines, office papers and packaging papers, it is evident that the grades of sorted waste available to recyclers in the future will be more variable.

It seems likely that newsprint manufacturers will have to take increasing quantities of mixed waste, and tissue (sanitary) manufacturers will have to take an increasing newsprint component in their waste mix. Packaging papers will also be a small component of these recycled streams.

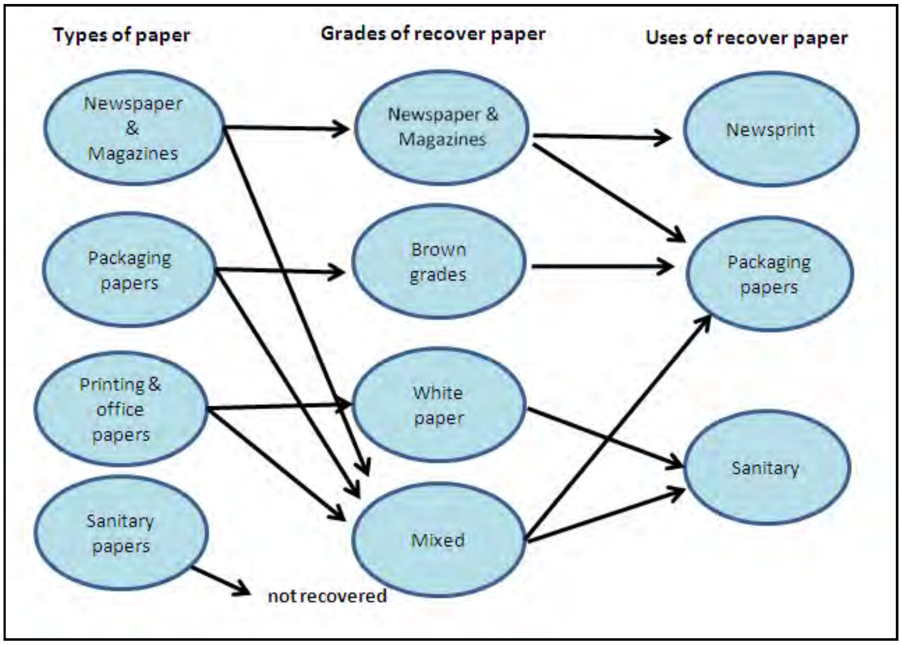


Figure 1.1: Grade mix of recovered papers. (Hunt, 2008)

1.3 Problem statement

A survey administered by the Forest and Forest Products Research Centre (FFPRC, a division of the Council for Scientific and Industrial Research) amongst the recycling industry in SA, indicated that most companies which engaged in deinking felt that the efficiency of their deinking processes needed to be improved. Accordingly funds were obtained to address this problem. (Andrew, 2007)

Discussions with the industry managers (Govender, 2008; Steyn, 2008) revealed that the performance of their processes was not adequate. This was attributed to the fact that the “quality” of the recycled paper supply had deteriorated over the years. It should be noted that poor “quality” referred to the *variability* in composition of the incoming recycled paper, rather than adherence to any particular property.

1.4 Scope and delimitation

The scope of this study was limited to the process conditions and raw materials used by a newsprint manufacturer (Mondi Shanduka Newsprint Ltd. Merebank mill) and a tissue manufacturer (Nampak Tissue) in South Africa.

1.5 Objectives and anticipated benefits

The objective of this project was to investigate the factors affecting the deinking processes at local plants with a range of recycled paper materials, with a view to developing an Artificial Intelligence based model for management control of such processes. This would allow for optimal adaption of deinking processes in response to changing incoming waste paper conditions.

This was accomplished by physically modelling the processes on a laboratory scale and then mathematically modelling the laboratory process, using an Artificial Neural Network technique. The laboratory based neural network model was then validated against plant data. The models developed in this work were consciously based on laboratory data, as it was not feasible to collect plant data over a wide enough range of operating values to successfully train a neural network. The plants have stringent quality and production targets with little room for experimentation. This situation also pertains in other parts of the world (Moe & Røring, 2001). Moe & Røring (2001) were able to monitor and model process conditions during the start-up phase of a new plant, where process conditions naturally varied to a greater extent than in an established plant.

It is intended to later use the validated model to develop a practical predictive model. This model would enable plant personnel to adapt to changing recycled paper composition and quality in a proactive manner. They would not have to rely on the usual method of process control by reacting to out-of-specification events. Better process control and more consistent final product quality would provide economic benefits to South African producers as they seek to compete in a globally very competitive industry.

CHAPTER 2: REVIEW OF UNIT OPERATIONS IN PAPER RECYCLING

2.1 Introduction

The major raw material for deinking processes consists of recycled paper. In addition to cellulose fibres, recycled paper consists of a wide variety of additional components necessary to manufacture paper products. These are typically substances such as:

- Additives used in the production of paper, which will include mineral fillers, coating components, dyes, sizing agents and process chemicals.
- Printing inks, adhesives, binders, plastic films and coatings.
- Miscellaneous foreign materials such as wire, stones, paper clips, staples and string.

It is important that the collection and storage processes do not further contaminate the collected paper. Recycled paper should be stored under cover and protected from the elements and should not be allowed to age for too long in storage. It has been found that as time passes, certain types of printing inks undergo ageing. These are oxidation processes induced by sunlight and atmospheric oxygen, which lead to further crosslinking of the ink binders. This makes them more difficult to remove from the paper, thus negatively impacting on deinking processes. This process has been called the “summer effect” (Haynes, 2008; Merza & Haynes, 2001).

High quality usable fibres must be separated from this complex mixture of materials described above and various waste streams need to be eliminated from the system. A variety of separation processes can be employed. These processes separate contrary materials based on their particle size, particle shape, particle deformability and surface chemistry. The main separation processes which are available to remove contaminants perform best in particular particle size ranges. These are summarised in Table 2.1 (Goettsching & Pakarinen, 2000: 91-94; Dash & Patel, 1997).

There is some overlap in the optimum efficiency ranges of the various separating processes. These processes make use of different particle properties to achieve separation. The flotation process relies on the surface chemical properties, whereas all of the other processes use physical properties such as particle size and density to achieve separation. However, surface chemistry does play a small role in the washing process. In addition, a number of secondary unit operations, such as pulping, dispersing, dewatering and bleaching are necessary to achieve adequate separation.

Table 2.1: Efficiency ranges for the main separation processes after pulping.

Contaminant size (mm)	Unit operation	Separation mechanism	Typical contaminants removed
> 1	Centrifugal cleaning	Density, size, shape	Metal, sand, plastics, large ink and sticky particles
0.1 – 1.0	Screening	Size, shape, deformability	Metal, sand, plastics, ink and sticky particles
0.001 – 1.0	Flotation	Size, surface properties	Inks, stickies, coating particles, fillers
0.0001 – 0.01	Washing	Particle size, shape	Very fine ink and filler particles

A more detailed description of the unit operations in paper recycling follows. The ideal combination of unit operations depends on the quality of the raw material and the final properties of the deinked pulp. Sometimes it is necessary to repeat individual unit operations in a number of stages to achieve adequate separation. However, the unit operations normally occur in the approximate order as given below, *viz.*
Slushing – cleaning – screening – flotation – cleaning – screening – washing/dewatering – dispersion – bleaching – storage.

2.2 Pulping or slushing

2.2.1 Introduction

The purpose of slushing or pulping is to break down the recycled paper into a suspension of fibres in water, which is termed a pulp. This produces a pumpable suspension and facilitates the addition of processing and bleaching agents. In addition, large solid contaminants are released in this process. Chemistry plays an important role in this process. Many chemicals are added at this stage and important ink dispersing, separation and stabilization process processes are initiated (Körkkö & Laitinen, 2008; Merza & Haynes, 2001). These are discussed more fully in Section 3.2.

In the South African plants only high consistency batch pulpers are used. The batch pulper is a cylindrical vessel with a large impellor and a perforated base plate, which holds back coarse contaminants and permits the passage of defibred pulp. The impellor or rotor is typically spiral in shape and located on the bottom of the vessel.

Water, recycled paper and process chemicals are charged into the pulper and the rotating impellor breaks the paper down into fibres, in a process termed defibering. It is necessary to wet paper fibres and to overcome the hydrogen bonding forces that bond the fibres together in the dry state (Körkkö & Laitinen, 2008).

2.2.2 Process parameters

The important process parameters for pulping are specific energy consumption, pulping time, temperature, pH or alkalinity and consistency. The extent of the pulping process is measured by the flake content. A *flake* is a small piece of undisintegrated paper. Deflaking rates of 98% are possible (Pescantin, Gu & Edwards, 1999).

The specific energy demand of the pulping process can vary from *ca.* 30 kWh/t in the case of high consistency pulping to over 100 kWh/t for low consistency pulping. Historically, batch pulpers have been favoured because of operating flexibility and the ability to put more energy into the slushing process (Merza & Haynes, 2001).

The time taken to completely deflake the recycled paper depends on the nature of the paper. Papers with a high wet strength require more energy and time to deflake. Typical pulping times for high consistency pulpers are in the region of 10 to 15 minutes, but can be as high as 55 minutes for wet strength grades (Pescantin, Gu & Edwards, 1999). Whilst long pulping times favour the complete disintegration of the waste paper, they also contribute to excessive ink fragmentation and lead to ink *redeposition*. One such redeposition process is *lumen loading*, whereby tiny ink particles enter the fibre cells through the pits, and reside permanently in the lumen, making it impossible to remove the ink particle. It is generally recommended to minimize the pulping time, consistent with efficient deflaking. (Körkkö & Laitinen, 2008; Merza & Haynes, 2001)

Pulping temperatures are typically in the region of 45^{o}C, but can be as high as 85^{o}C for certain grades. Increasing pulping temperature can increase the rate of defibering. However, this effect moderates at temperatures over 40ºC, with no practical benefits over 60ºC (Körkkö & Laitinen, 2008).

Pulping is normally carried out at high pH's. High pH is achieved by the addition of sodium hydroxide and/or sodium silicate. The high pH facilitates fibre swelling and ink removal (Körkkö & Laitinen, 2008), but also enhances the extraction of soluble and colloidal materials, which contribute to high chemical oxygen demand (COD) and hence water pollution. (Brouillette, Daneault & Dorris, 2001; Goettsching & Pakarinen

2000: 95-105). High pH pulping is the norm for wood-containing papers (newsprint and magazines), but neutral pulping is more usual for wood-free papers (Körkkö & Laitinen, 2008; Brouillette, Daneault & Dorris, 2001).

The initial repulping pH has a great effect on the wet tensile strength of the paper, and hence on the deflaking rate, as expressed in Equation (2) below (Brouillette, Daneault & Dorris, 2001).

Seasonal differences in deinking, known as the “summer effect”, have been widely reported on in the northern Hemisphere (Haynes, 2008; Merza & Haynes, 2001). As a result of the higher temperatures in the summer months, accelerated thermal drying of newsprint inks occurs. This leads to embrittlement of the ink and stronger attachment to the fibres. When pulped, greater ink fragmentation and redeposition occurs, with attendant deinking difficulties. These have been overcome by adding increased levels of sodium hydroxide and decreasing pulping times during the warmer months. However, this has not been reported to be a problem in South Africa, because of the milder climate and smaller differences in Summer and Winter temperatures.

Currently, high consistency pulping (13-18%) is almost exclusively used in the modern deinking process. High consistency offers better and faster deflaking, lower energy consumption and a higher deinking chemicals concentration for the same dry fibre mass addition rate (Körkkö & Laitinen, 2008). High consistency pulping can be achieved in a continuous drum pulper or in a batch pulper. Batch pulpers offer better opportunities to control the ink fragmentation through variations in consistency and pulping time (Merza & Haynes, 2001). Drum pulpers have a gentler defibering action, with resultant reduced fragmentation of contaminants. This allows the larger contaminants to be more easily removed in the screening stages (Merza & Haynes, 2001; Goettsching & Pakarinen, 2000: 106).

2.2.3 Models and fundamentals

The study of the mechanisms of the pulping process only started in the 1980’s, with significant work only being published after 1998 (Fabry, Carre & Galland, 2005). The pulping process can be divided into three distinct mechanisms: defibering, ink detachment and particle fragmentation (Körkkö & Laitinen, 2008).

2.2.3.1 Defibering or deflaking

Recycled paper, chemicals and water are charged to the pulper. Within about two minutes wetting occurs and the inter-fibre bonding forces are weakened considerably

(Goettsching & Pakarinen, 2000: 94). The input of mechanical energy via a rotor separates the paper into individual fibres. Higher strength papers generally need more energy to defibre, and pulping times approaching 60 minutes could be required for strong boards and wet-strength papers. Increasing pulping temperature increases the defibering rate (or reduces the pulping time). However, above about 40 °C, no substantial improvements have been noted (Körkkö & Laitinen, 2008). The addition of alkalinity (in the form of sodium hydroxide alone or in combination with sodium silicate) leads to fibre swelling and accelerated defibering. Rao *et al.* (1998) state that both mechanical forces (comprising shear and vibration) as well as chemical forces are required to efficiently detach and stabilise ink particles.

Bennington, Sui & Smith (1998) studied the kinetics of the defibering of recycled paper in repulpers. Defibering was found to obey a first order kinetic model of the form:

$$\frac{dF}{dt} = -kF \tag{1}$$

Where F is the TAPPI flake content, t is time and k is the rate constant.

The rate of deflaking was found to be dependent on the cumulative contact area between the pulp fibres and the rotor blades. By expressing the rate constant in terms of practical pulping parameters, Bennington *et al.* (1998) developed the following expressions:

$$\frac{dF}{dt} = -k'CBNG.exp\left(\frac{-T\pi BH}{KN_pD^4N^2\rho}\right).F \tag{2}$$

Where k' is the intrinsic rate constant, C is the volumetric concentration of fibre suspension, B is the number of impellor vanes, N is the impellor rotational speed, G is the area swept by a rotor vane, T is the wet tensile strength of the paper, H is the impellor height, K is a constant, N_p is the impellor power number, D is the impellor diameter, and ρ is the density, all in S.I. units.

For a given installation with fixed geometry and defined operating conditions, this expression simplifies to:

$$\frac{dF}{dt} = -k''exp\left(\frac{-T}{K'}\right).F \tag{3}$$

Where $k''$and K' are machine efficiency constants.

Equation (3) shows that the rate of deflaking in a practical situation depends on the wet tensile of the paper, *viz.* the type of paper being pulped. This model was shown to hold for a number of industrial rotors, operating speeds, consistencies and paper types. Validation of this model in industrial scale pulpers showed that almost complete deflaking had occurred after about 2 minutes. This suggests that most industrial pulping sequences are too long.

Fabry & Carré (2004) have demonstrated that the rate of defibering can be well explained by the volume energy consumption (the electrical energy input per *volume* of pulp, $kWhm^{-3}$) for a given type of pulper and initial chemical conditions. Similarly, Rao *et al.* (1998) have shown that the amount of energy inputted in the stirring system determines the initial rate of detachment. They also reported that the addition of alkaline chemicals increases the defibering rate and reduces the energy requirement.

2.2.3.2 Ink detachment

Ink detachment occurs simultaneously with defibering. Generally, more energy is required to detach ink particles, as the chemical bonding forces between ink and paper are higher than the hydrogen bonding forces between paper fibres. It is thought that fibre swelling, induced by high pH also facilitates ink detachment. In addition, chemicals such as sodium hydroxide and hydrogen peroxide could chemically break down ink binders, further enhancing ink detachment (Körkkö & Laitinen, 2008; Fabry & Carre, 2004; Carré, Galland & Julien Saint Amand, 1994).

Whilst ink detachment is a complex function of rotor speed, pulping time and chemistry (Rao *et al.,* 1998), Fabry & Carré (2004) found that the *volume energy consumption* well describes the detachment phenomenon. The volume energy consumption effectively summarises the forces involved in pulping, *viz.* the pulping time, rotor speed, consistency and the type of pulping device.

2.2.3.3 Particle fragmentation and redeposition

The continuing input of mechanical energy leads to further comminution of ink particles. Rao *et al.* (1998) found that non-ionic surfactants assist in the comminution process, whereas the soap/calcium system tends to agglomerate the ink particles. The production of large quantities of fine ink particles will lead to redeposition onto the fibre surface. The mechanical action also smears ink onto fibre surfaces (Carré & Galland, 2007), or even results in ink penetration into the fibre lumens via the pits, known as lumen loading. (Haynes, 2000).

Similarly, Fabry & Carré (2004) found that ink fragmentation depended on rotor speed, pulping time and chemistry, and reported that the volume energy consumption also describes the detachment phenomenon, although it does not predict the ink redeposition process.

Redeposition and lumen loading lead to irreversible brightness loss. This can be mitigated by the addition of surfactants, which stabilise the fine ink particles by rendering them hydrophilic (Körkkö & Laitinen, 2008).

In similar deflaking rate studies, Bennington & Wang (2001) also found that the rate of ink detachment followed first order kinetics, and depended on fibre suspension consistency and the cumulative contact area between rotor and suspension. Whilst the consistency affected the rate of ink detachment, it did not influence the final level of detachment.

Bennington & Wang (2001) found that after some time ink redeposition started setting in. Ink redeposition also followed first order kinetics, increasing as the concentration of detached ink increased.

The net effect of these two competing processes was that the residual ink concentration on fibres decreased with repulping time to a minimum at about 15 minutes, and thereafter increased steadily as ink redeposition started gaining momentum.

A comprehensive study of the effects of pulping parameters on deflaking, ink detachment and ink removal by flotation was carried out by Fabry, Carré & Crémon (2001). They found that the rate of defibering was accelerated by consistency, temperature, rotor speed and the introduction of chemicals conventionally used in pulping. The results suggested that the pulping times conventionally used in industrial pulpers were way too long. On the other hand, the effect of rotor speed, consistency and temperature on the residual ink concentration all showed *minima* with respect to the pulping time. This confirms the observations of Bennington & Wang (2001) that the rate of both ink detachment *and* ink redeposition are accelerated at the same time, resulting in an optimum repulping time. Continually increasing pulping times also lead to continually increasing ink fragmentation. The use of conventional pulping chemicals (*viz.* sodium hydroxide, sodium silicate, hydrogen peroxide and surfactants) greatly accelerated the deflaking and ink detachment and retarded the ink redeposition. Nevertheless, increasing pulping times still resulted in increasing ink redeposition with time (Fabry, Carré & Crémon, 2001).

The net effect of the abovementioned pulping conditions on ink removal by flotation was found to be as follows: longer pulping times, higher consistencies, higher temperatures lead to greater ink fragmentation and consequently to inferior ink removal by flotation. The use of conventional pulping chemicals also lead to a slightly lower ink removal (ERIC, see Section 3.5.5) by flotation (Fabry, Carré & Crémon, 2001).

In another study on the effect of pulping variables on ink removal from thermally aged newsprint, Haynes (2000) found that ink fragmentation increased (*viz.* Eric increased) with decreasing temperature, increasing pulping time, decreasing alkali charge, and increasing ratio of sodium silicate to sodium hydroxide. These results are at odds with those reported by Fabry, Carré & Crémon (2001) with respect to temperature, perhaps due to different types of ink.

2.2.4 Conclusion

The pulping process represents a compromise between two opposing processes: fragmentation processes (defibering, ink detachment and ink fragmentation) and redeposition processes. Too much fragmentation can result in ink particles being too fine for effective removal by flotation, and excessive redeposition results in lumen loading with very little possibility of ever removing the ink from the lumens. After defibering and detachment, the fragmentation and redeposition processes occur simultaneously. All of these processes are influenced by consistency, chemistry, temperature, and energy input. The ideal pulping conditions represent a compromise between the abovementioned processes. Thus, pulping is a process which must be optimised for each item of equipment and set of conditions As a result, various authors (Fabry, Carré & Galland, 2005) have recommended to drastically reduce the pulping times of 15 to 20 minutes normally employed in commercial deinking lines to only a few minutes.

The above conclusions apply mainly to recycled newsprint and magazine furnishes. In a study of the defibering-detachment-fragmentation-redeposition dynamics in wood-free recovered papers intended for tissue manufacture, Fabry, Carre & Galland (2005) found that ink redeposition was not a major negative factor, and that extended pulping times marginally improved ink removal by flotation. In recycled paper mixes of wood containing and wood free papers, it could be expected that ink redeposition would again appear as a negative effect.

2.3 Centrifugal Cleaning

Cleaners or hydrocyclones make use of centrifugal force and differences in relative density to separate undesirable particles from the water. Thus, dense particles such as sand and metal, and light particles such as shives and plastic material are easily removed by a cleaner. According to Table 2.1, cleaners are most effective at removing large, dense particles. (Goettsching & Pakarinen, 2000: 134-137).

Ink particles have densities close to that of water, and are not normally separated by cleaners. However, cleaners are known to remove very small dense particles of the type typically found in fillers (Goettsching & Pakarinen, 2000: 134-137). Fillers have different brightness to fibres, and their removal could influence the final, measured brightness.

Centrifugal cleaners are usually connected in a cascade arrangement, and are normally used in combination with screening to effect removal of contrary materials in a recycling system.

2.4 Screening and fractionation

The recycled fibre pulp is passed through a screen plate perforated with small holes or slots. A rotating rotor within the screen body produces pulsations and a pressure drop across the screen plate, thereby ensuring throughput and preventing fouling. Debris such as shives, coarse fibre, stickies and fragments of plastic are removed from the pulp stream on the basis of size, although particle shape and flexibility also play a role. Flexible or conformable particles will force themselves through even fine perforations.

Typical screen plate hole sizes are 1.2 to 1.6 mm in the primary screens, and slot widths as low as 0.1 mm are commonly used in the final stages. Screen design factors (screen profiles and rotor geometries) play a large role in the performance and efficiency of the screens. It is not possible to remove all the debris in one screening stage, and fibre losses always accompany screening. In order to optimise the screening efficiencies, multiple stage screening in a cascade arrangement is usually employed. (Goettsching & Pakarinen, 2000: 110-132).

Cleaning and screening removes high density and large solid materials, and do not remove significant quantities of ink. Pulping, flotation and washing have the overriding influence on ink removal (Beneventi, Deluca & Carré, 2004) Thus, it was assumed for the purposes of this modelling work that the change in brightness or ERIC was solely due to the pulping, flotation and washing processes.

2.5 Flotation

2.5.1 Introduction

The flotation process is one of two methods for removing ink from a recycled paper pulp. Fine air bubbles are injected into the fibrous pulp. The bubbles move upwards to the surface, and in the process attach to themselves hydrophobic particles such as ink, stickies, fillers and coating components. Typically, particles in the size range of 10-250 microns form stable structures with the air bubbles and are successfully removed. On the surface, the bubbles form a stable foam layer comprising the ink and other floated material. This foam bed is removed physically from the fibre suspension below (Goettsching & Pakarinen, 2000: 153-154).

2.5.2 Process equipment and parameters

Early deinking flotation cells were based on designs borrowed from the mineral flotation industry. Hines (Hines, P.R. 1933. US Pat. No. 2,005,742) was granted a patent for flotation deinking in 1935, but it was only in the early 1950's that the Denver cell, originally designed for mineral flotation, was first used in a deinking flotation installation in North America (Kemper, 1999). Only in the 1980's did waste paper recycling and flotation deinking come into common use. Since then a large amount of effort by many manufacturers has gone into the design of specialized deinking equipment. Flotation cell designs can be square, rectangular, cylindrical (horizontal or vertical), or elliptical, and some cells are even pressurised. High speed impellors provide agitation and fine air bubbles are introduced by aspiration or pumped in through fine nozzles. (Goettsching & Pakarinen, 2000: 158-165; McCool, 1993). Multiple flotation stages are necessary to achieve the desired pulp quality in modern installations.

Of interest in the South African market are the flotation cells produced by Sulzer Escher Wyss (CF/CFC), and the Voith E-cell and Voith Sulzer Eco-Cell. The details of these cells are discussed later in Chapter 9.

Flotation systems are generally operated at consistencies of 0.8%-1.5%, temperatures of 40℃-70℃, and pH's in the range of 7-9. A water hardness of about 200 ppm as calcium carbonate is required when using fatty acid surfactants as collectors. With surfactants other than fatty acid soaps, hardness is not required. The relative air volume (expressed as total air volume flow per total stock volume flow) is typically 300%, with some flotation systems operating at relative air volumes up to 1000% A secondary flotation stage is commonly used. The flotation foam removed from the primary stages is refloated in a secondary stage. The secondary stage further removes contaminants (ink, fillers, stickies), and the remaining fibres are returned to the inlet of the primary flotation cells. In this way the fibre losses are reduced. (Goettsching & Pakarinen, 2000: 153-158)

2.5.3 Theoretical models and fundamentals

2.5.3.1 Introduction

The physical flotation processes have been described using hydrodynamic and probability processes by various authors (Heindel, 1999; McCool, 1993; Schulze, 1991). The flotation process has been described as a combination of three main physical processes (McCool, 1993):

a. The probability of collision - dependent on the number and size of the air bubbles and ink particles.
b. The probability of attachment of air bubbles and ink particles - dependent on the surface chemistry of the various particles.
c. The probability of removal of the air bubble-particle complex from the system – dependant on the stability of the bubble-particle complex.

Steps a. and c. depend on process equipment design and process conditions such as consistency, temperature, agitation, retention time and flotation cell design. A more detailed treatment of theoretical models for the flotation process follows.

Flotation deinking processes have drawn many of the concepts and practices from the mineral flotation industry. However, the flotation of ink from a cellulose fibre slurry differs in many fundamental aspects from that of mineral flotation. These similarities and differences are summarized in Table 2.2:

Table 2.2: Comparison of deinking and mineral flotation. (Julien Saint Amand, 1999; Heindel, 1997; Pan *et al.,* 1996)

PROCESS PARAMETER	FLOTATION DEINKING	MINERAL FLOTATION
Particle surface energy	Varies from low energy hydrophobic adhesives and inks to high energy hydrophilic fibres and fillers.	More uniform, generally high energy hydrophilic minerals.
Particle size and shape	Broad distribution, 1 micron to 1 mm. spherical to fibrous to large flat.	Broad distribution, irregular and granular.
Particle density	Less than or equal to water, filler particles greater than water, very fine.	Generally higher than water.
Particle liberation	Slushing in the presence of a mix of chemicals.	Size reduction by grinding.
Pulp properties	Heterogeneous fibre network which tends to flocculate above 1% consistency, at relatively high temperature 40-60 ^{o}C. A blend of dissolved, colloidal and suspended particles.	More homogeneous 2-phase system with simpler rheology, lower temperature.
Characterization of final product	Qualitative or semi-quantitative brightness, dirt and adhesive content. Indirect measurement of ink content using a spectrophotometer.	Quantitative chemical analysis.
Impact of low efficiency on downstream plant	Reduced product quality, contamination of downstream equipment	Effects are mainly economic.

The net result of these differences is the lower separation efficiency of flotation deinking. Nevertheless, it is assumed that the fundamental processes occurring are very similar. Particle inertia effects are typically disregarded in flotation deinking, because of the lower density of particles involved. The modelling of flotation separation processes has tended to be grouped into a number of different approaches, as outlined below.

2.5.3.2 Multistage probability process models (Bloom and Heindel, 1997; Heindel, 1997)

In these models, the basic philosophy is that the overall flotation process consists of a number of sub-processes, each with their associated probabilities. The basic assumptions are: bubbles and particles are spherical, one particle interacts with one bubble, a non-turbulent flow environment is assumed, and the air bubbles are assumed to be "stiff", or inelastic.

The sub-processes are:

Step 1: Approach of particle and air bubble

As depicted in Figure 2.1, it is assumed that the particle is intercepted by the bubble within a capture radius R_c. Because of the low density of ink particles, inertial effects are neglected and it is assumed that the particle moves along a fluid streamline.

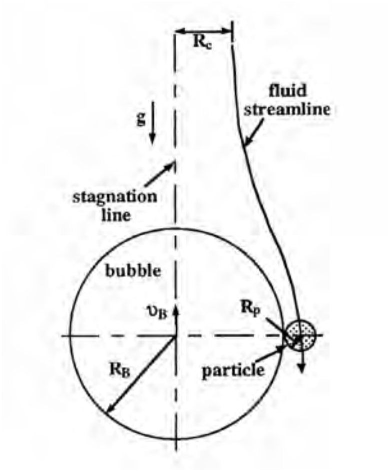


Figure 2.1: Approach of ink particle and air bubble. (Bloom and Heindel, 1997; Heindel, 1997)

Step 2: Interception of particle by the bubble

By taking into account the Reynolds number (Re_B) and Stokes number pertaining in a typical flotation cell, an expression for the probability of particle capture, P_c, has been derived (Bloom and Heindel, 1997; Heindel, 1997):

$$P_c = \left[\frac{3}{2} + \frac{4{Re_B}^{0.72}}{15}\right]\left(\frac{R_p}{R_B}\right)^2 \qquad (4)$$

Step 3: Attachment by sliding

The particles slides along the interface for some distance before attachment takes place. With reference to Figure 2.2, the probability of attachment by sliding, P_{asl}, can be expressed as:

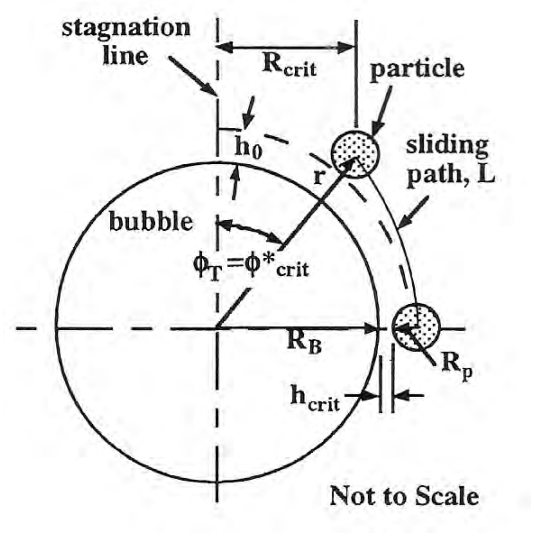


Figure 2.2: Schematic of probability of attachment by sliding P_{asl} (Bloom and Heindel, 1997; Heindel, 1997)

$$P_{asl} = \frac{R_{crit}^2}{(R_B+R_P)^2} \tag{5}$$

where R_{crit} is the limiting radius associated with the touching angle φ^*_{crit}.

Various expressions have been derived for this term, but its determination still depends on a number of immeasurable quantities. (Bloom and Heindel, 1997; Heindel, 1997)

Step 4: Film rupture and formation of three-phase contact angle

Once a particle is attached to an air liquid film, the film must rupture and a three-phase contact configuration must form. This is illustrated schematically in Figure 2.3.

It has been widely assumed that this probability is close to 1. Thus, the probability of three-phase contact $P_{tpc} = 1$ (Bloom and Heindel, 1997; Heindel, 1997).

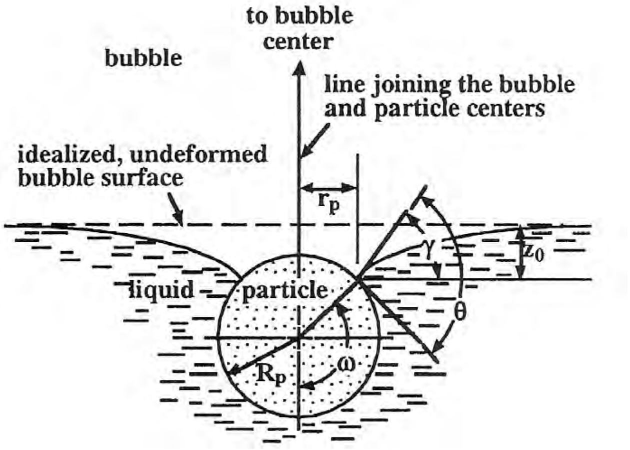


Figure 2.3: Formation of three-phase contact angle. (Bloom and Heindel, 1997; Heindel, 1997)

Step 5: Stabilisation of the particle-bubble complex and transport to the froth layer.

The particle-air bubble aggregate must remain stable as it is transported up to the froth layer. As it rises, the air bubble will experience stresses, which tend to destabilise the particle-bubble aggregate. A schematic of this situation is given in Figure 2.4:

Figure 2.4 can be a little misleading. In practice, as a bubble rises to the surface, the ink particles will most probably slide to the bottom of the bubble, as shown in Figure 2.5.

These forces are identified as gravitation F_g, buoyancy F_b, detachment by fluid drag F_d, force due to capillary pressure in the gas bubble F_σ, capliiary force F_{ca}, and the hydrostatic pressure force F_{hyd}. The net balance of these forces B is defined as:

$$B = \frac{F_{detachment}}{F_{attachment}} = \frac{F_g - F_b + F_d + F_\sigma}{F_{ca} + F_{hyd}} \tag{6}$$

and the probability of stabilisation P_{stab} is:

$$P_{stab} = 1 - \exp\,(1 - \frac{1}{B}) \tag{7}$$

Once again, expressions have been derived for the force balance (Bloom & Heindel, 1997; Heindel, 1997).

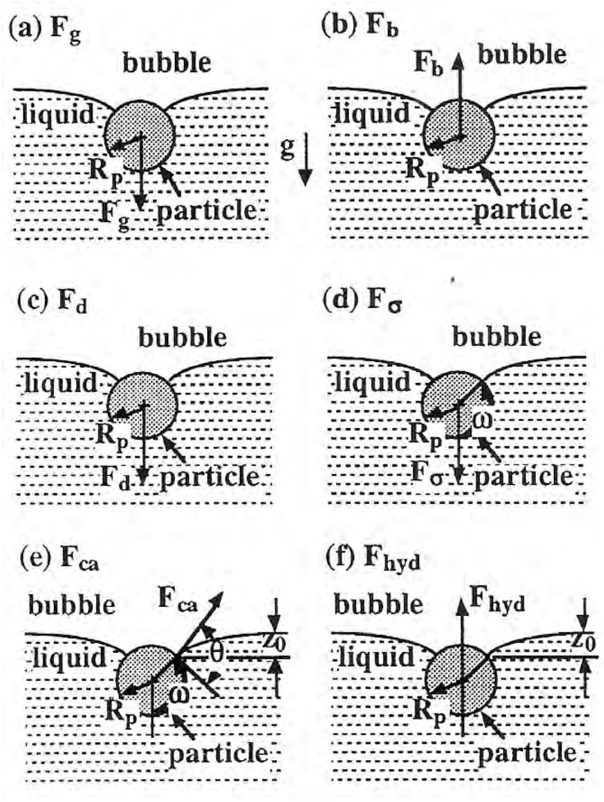


Figure 2.4: Stabilising and destabilising forces on a particle-bubble aggregate. (Bloom and Heindel, 1997; Heindel, 1997)

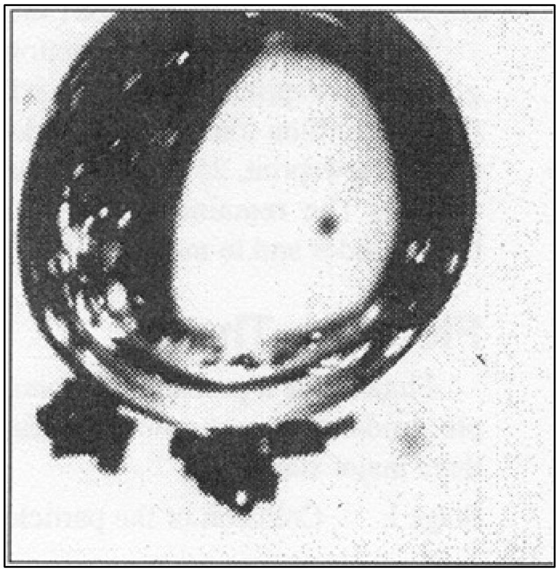


Figure 2.5: Photograph of rising air bubble with attached ink particles. (McCool, 1993: 142)

By assuming that the individual micro process probabilities are not correlated, the overall probability of separation by flotation becomes:

$$P_{overall} = P_c P_{asl} P_{tpc} P_{stab} = P_c P_{asl} P_{stab} \text{ approximately} \tag{8}$$

where P_c is the probability of particle capture, P_{asl} is the probability of attachment by sliding, P_{tpc} is the probability of three-phase contact (assumed to be ca. 1) and P_{stab} is the probability of stabilisation.

The calculation of these probabilities involves a large number of difficult-to-measure variables. As a result, the use of such models in practice is limited.

2.5.3.3 Reaction rate models

Another way of describing the flotation process is to consider it analogous to a first-order chemical reaction:

$$X(particles) + Y(bubbles) \rightarrow Z(floated\ particles) \tag{9}$$

where X, Y *and* Z are the number of objects. Assuming the concentration of the bubbles is constant and that the volume of the removed particles is negligible, the rate expression becomes:

$$\frac{dc}{dt} = -kc \tag{10}$$

where c is particle concentration and *k* is a rate constant.

Depending on the system studied, many different expressions have been developed for *k* (Heindel, 1997).

2.5.3.4 Population balance models

The basic kinetic model above has been extended by Bloom (1996), Heindel (1997) and Bloom and Heindel (1997) to a population balance model of the form:

$$\frac{dn_p^f}{dt} = -k_1 n_p^f n_B^f + k_2 n_B^a \tag{11}$$

where n_p^f = number of free particles per unit volume available for attachment,

n_B^f = number of bubbles per unit volume available for attachment, and

n_B^a = number of bubbles with particles attached.

Thus the term $-k_1 n_p^f n_B^f$ represents the probability of attachment and $k_2 n_B^a$ represents the probability of particle-bubble aggregates splitting to become unattached particles again.

This approach thus ties in with the probabilistic approach, where:

$$k_1 = Z P_c P_{asl} P_{tpc} P_{stab} \tag{12}$$

and

$$k_2 = 1 - P_{stab} \tag{13}$$

Solving these equations (Bloom and Heindel, 1997) yields the predicted flotation efficiency as a function of particle size for various particle diameters R_p, as shown in Figure 2.6. For particle diameters greater than 200 microns, the theory predicts that $P_{stab} < 0$. In this case $P_{overall}$ (equation 8) will be less than zero and flotation will not occur. In addition, very small particles (1 to 10 microns) will take an impractically long time to float.

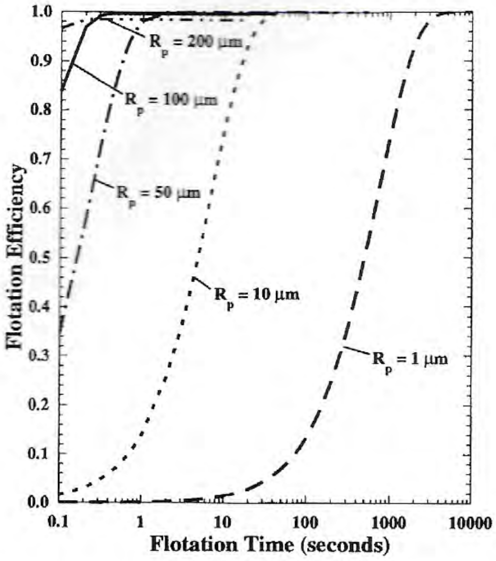


Figure 2.6: Flotation efficiency as a function of flotation time and particle size. (Bloom and Heindel, 1997; Heindel, 1997)

The findings of this model concur with what is known in practice: large particles of ink, as generated by electrographic inks, do not float well and very fine ink particles are also not removed by flotation.

The models outlined above were partially validated experimentally (Bloom, 2006), with the conclusions that the models showed “great promise” if the measurement of bubble particle size, stability parameters and the relationship between consistency and viscosity could be determined.

2.5.3.5 Hydrodynamic models

As above, the flotation process can be considered as a first order kinetic process:

$$\frac{\mathrm{dNp}}{\mathrm{dt}} = \text{-}\mathrm{zN_pN_bP_cP_aP_s} \tag{14}$$

where N_p and N_b are the number of particles and bubbles per unit volume, P_c, P_a and P_s are the probabilities of collision, attachment and stabilization respectively. Julian Saint Amand (1999) has taken a slightly different approach to the modelling of the flotation process. Equation 14 can be written as follows:

$$\frac{\Delta\mathrm{Np}}{\Delta\mathrm{t}} = \text{-}\mathrm{zN_pN_bP_cP_aP_s} = \text{-}\mathrm{kN_p} \tag{15}$$

where k is a flotation rate constant.

In order to increase the generality of such models it is useful to consider the concept of volume of air to pulp ratio, instead of flotation time to define rate constants. Thus, let air ratio = T and $\Delta T = N_b(\pi d^3/6)$, where d is the bubble diameter. An equation similar to Equation 15 can now be written:

$$\frac{\Delta\mathrm{Np}}{\Delta\mathrm{T}} = -KNp \qquad \text{or} \qquad \frac{\Delta N_p}{N_p} = -K\Delta T \tag{16}$$

where K is a flotation rate constant.

For small variations of $\frac{\Delta\mathrm{Np}}{\mathrm{Np}}$ and ΔT and after integration, one gets

$$\ln\frac{N_p}{N_{po}} = \text{-KT} \tag{17}$$

The flotation efficiency as a function of air ratio is given by:

$$E = 1 - \frac{N_p}{N_{po}} = 1 - e^{-KT} \tag{18}$$

Laboratory deinking studies, where $\log_e$ (number of particles per litre of pulp) is plotted against T, have confirmed this linear relationship for different ink particle sizes (Julian Saint Amand, 1999). An investigation into the effects of particle size, bubble size and turbulence agreed with the established theory for mineral flotation (Julian Saint Amand, 1999), *viz:*

- High ink removal efficiencies *and* high flotation losses are achieved with high air ratios,
- Lower flotation efficiencies for microscopic ink particles,
- Small bubbles are more efficient at removing particles.

2.5.3.6 Transport phenomena models

Beneventi, Benesse, Carré, Julien Saint Amand & Salgueiro (2007) started from a similar rate equation as above (Equation 14):

$$\frac{dNp}{dt} = -Z_{pb}P_cP_aP_s \tag{19}$$

where N_p is the number of particles per unit volume, P_c, P_a and P_s are the probabilities of collision, attachment and stabilization respectively and Z_{pb} is the particle-bubble collision rate. They considered particle and water transport phenomena in terms of semi-empirical equations for the three sub-processes of flotation, entrainment and drainage, thus:

<u>Flotation rate</u>

It has been shown that (Koh & Schwartz, 2003):

$$Z_{pb} = N_pN_b\left(\sqrt{\frac{8\pi E_T}{15\nu}}\right)\left(\frac{d_p + d_b}{2}\right)^3 \tag{20}$$

where Z_{pb} is the particle-bubble collision rate, N_p is the particle number concentration, N_b is the bubble number concentration, E_T is the turbulent dissipation rate, v is kinematic viscosity, d_p and d_b are particle and bubble diameters.

The bubble number concentration N_b is given by:

$$N_b = 6Q_g t_g / \pi d_b^3 S v_b \tag{21}$$

where Q_g is the injected gas flow, t_g is the gas retention time and S is the cross-sectional area of the cell, d_b is the bubble diameter, v_b is the bubble rising velocity.

By combining the above equations, the rate of particle removal reduces to:

$$\frac{dNp}{dt} = -(\frac{KQ_g}{S})\, N_p, \quad \text{where} \quad K = 6\frac{P_c P_a P_s t_g}{v_b}\sqrt{\frac{8E_T}{15\pi v}}\left(\frac{d_p + d_b}{2d_b}\right)^3 \tag{22}$$

In practice it has been found necessary to modify the equation slightly, by incorporating an empirical correction factor α:

$$\frac{dNp}{dt} = -(\frac{KQ_g^{\alpha}}{S})\, N_p \tag{23}$$

This equation has been used to simulate industrial flotation systems.

Particle entrainment

Hydrophilic particles such as fibre fines, fibres and fillers, whilst not adhering to the surface of air bubbles, can nevertheless be dragged up or entrained into the froth phase by the rising air bubbles. The transport rate of hydrophilic particles can be described by:

$$\frac{dNp}{dt} = -(\frac{\varphi Q_f^o}{V})\, N_p \tag{24}$$

where φ is the particle entrainment co-efficient and Q_f^o the water upward flow in the froth without drainage, and V is the pulp volume in the flotation cell.

Drainage from the froth

The froth structure is very dynamic. Particles and water drain back into the pulp slurry, and bubbles can coalesce or burst. This can result in particle fractionation in the froth layer. An empirical equation for the water volume fraction in the froth ε, has been developed to describe the water drainage behaviour:

$$\varepsilon = \varepsilon_o e^{-L_d t_r} \tag{25}$$

Where ε_o is the water volume fraction at the froth/pulp interface, L_d is the water drainage rate constant and t_r is the average froth retention time in the float cell. t_r is related to the froth height in a flotation cell, and is an often controlled parameter in industrial flotation cells. In research by Beneventi *et al.* (2006), the froth removal height was found to play an important role in water and solids losses and ink removal.

The particle downflow or drainage rate M_f (g/min) through the froth in the pulp due to drainage can be described by the following equation:

$$\frac{dM_f}{dt} = -\delta N_{pf} Q_d \tag{26}$$

where δ is the particle drainage co-efficient, N_{pf} is the particle number concentration in the liquid phase entering the froth and Q_d is the water drainage flow (m^3/h).

The equations for the transport phenomena of the three sub-systems (Equations 24, 25 and 26) were combined using mass and hydraulic balances into a model for a single flotation cell, as per the schematic in Figure 2.7.

This basic cell model, using transport coefficients obtained in the laboratory, was used to model a three-stage flotation system with "sufficient accuracy" (Beneventi, Benesse, Carré, Julien Saint Amand & Salgueiro, 2007), and in another study, to evaluate the effect of various alkaline deinking chemistries on flotation. (Beneventi, Carre, Hannuksela & Rosencrance, 2007).

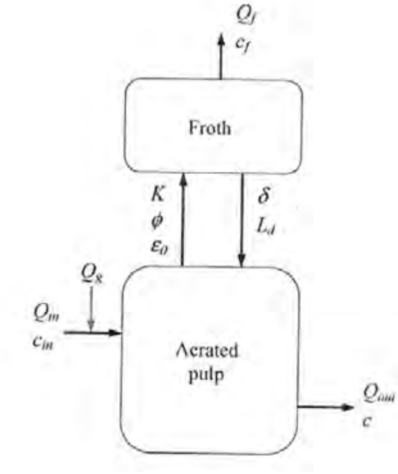


Figure 2.7: Schematic of combination of transport equations to simulate a flotation cell.
(Beneventi, Benesse, Carré, Julien Saint Amand & Salgueiro, 2007)

2.5.3.7 Statistical models

Pan *et al.* (1996 & 1994) proposed a very simple “Global Model” to predict the outcome of deinking flotation processes. It has only two parameters:

- The capture radius, which is the distance between centres of an air bubble and an ink particle, within which a particle will stick to an air bubble, and
- The bubble flux or flotation time.

The output of this model is defined as the flotation efficiency, which is the ratio of particles captured to the number originally present. The workers constructed various model systems in the laboratory, and report “excellent general agreement” with the global model (Pan *et al*., 1996). Unfortunately, the exact mathematical nature of the model was not disclosed in the publication.

2.5.3.8 Practical models

Scheldorf and Strand (1996) simulated ink removal in a newsprint deinking facility by using a combination of an existing modular simulation program known as WinGEMS with additional calculation blocks which were termed SPECSEP, BRIGHT and CONINK. SPECSEP was a model of the particle size distribution of ink removed in the pulper, BRIGHT was a model for the calculation of brightness from the Kubelka-Munk theory and the fractional composition of the pulp slurry, and CONINK converted a measured ink size distribution into an ink solids fraction. The results were described by the authors as “promising”.

2.5.4 Conclusions

Consideration of the overview of theoretical models presented above demonstrate that the modelling of a flotation system is extremely complex. Most of the attempts at modelling have been focused on the flotation process, although some models have been developed for the pulping process. It is probably not possible to develop a global first-principles model for the combined pulping and flotation processes, as they rely on fundamentally different physical processes, and the measurement of ink is not quantitative. An attempt will be made in this work to use artificial intelligence techniques to develop a global model for a deinking system.

2.6 Washing

Washing is a process of removing solid contaminants (including ink particles) by high dilution and filtration. The washing filtrate contains the contraries in the form of very finely dispersed particles such as fillers, fibre fines, stickies, fine ink particles, colloidal particles and dissolved organics. Washing is less selective with respect to ink particles than the flotation process, but removes a wider variety of contaminants (Goettsching & Pakarinen, 2000:176). Typical size ranges of particles encountered in a deinking system are listed in Table 2.3 (Goettsching & Pakarinen, 2000:176; Dobias, Klar & Schwinger, 1992).

Table 2.3: Typical size ranges of particles.

Solid particle	Size in microns
China clay	1-2
Kaolin	0.3-5
Calcium Carbonate	0.5-5
Titanium dioxide	0.2-0.5
Coating grit	<60
Ink particles	0.5-500
Fibre fines	<200
Short fibre fraction (length)	120-400
Long fibre fraction (length)	>400

The pore size of a fibre mat is initially that of the wire mesh on which the filtration is taking place (ca. 500 microns*)*, but decreases down to about 10 microns as the fibre mat builds up and consolidates on the filtration mesh. In practice, only particles smaller than 30 microns are successively removed by washing. Larger particles tend to become mechanically or electrokinetically entrained in the fibre mat during the filtration process (Goettsching & Pakarinen, 2000:176-180). The theoretical efficiency of a washing machine depends to a large extent on the consistency entering and leaving the washing unit, as shown in Figure 2.8.

Washing and flotation are often used in combination in many commercial deinking plants (McCool, 1993). Washing is more often targeted at removing fillers and fines, whilst flotation is used to selectively remove inks. For very finely dispersed flexographic inks, washing is the only practical means of ink separation.

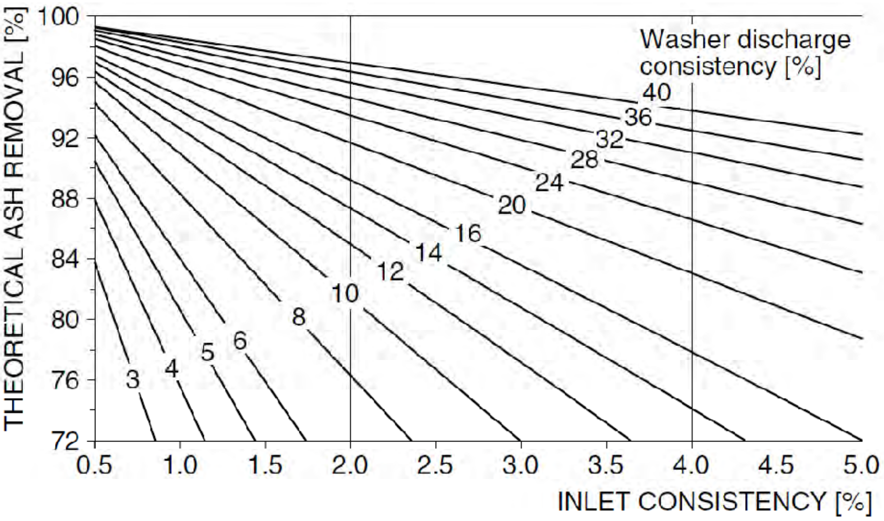


Figure 2.8: Effect of consistency on theoretical washing efficiency, as measured by ash removal. (Goettsching & Pakarinen, 2000:176)

Washing is normally carried out in dewatering machines, as described below. (Goettsching & Pakarinen, 2000:176-181)

2.7 Dewatering

Dewatering is a distinct unit operation in the processing of recycled fibres. Dewatering is the process of removing the water and water-soluble components of a fibre pulp from the solid (usually fibre) components.

Dewatering is usually done to adjust the consistency of a process into a range which is most efficient or cost effective. For example bleaching processes are more effective and use fewer chemicals at higher consistencies, and smaller storage volumes are required for high consistency pulp.

Dewatering allows for the removal of excess water in one area of the process to be utilised in other stages of the process in order to conserve process chemicals or process heat. Dewatering is also used to separate water systems. For example, an alkaline process could be separated from an acidic one, thereby eliminating expensive neutralisation steps.

Dewatering is essentially a filtration process carried out using belt, drum or disc filters. These machines can be vacuum or pressure assisted. The pulp feed consistency is typically 2-3.5% and water is removed to produce a fibre cake with a consistency ranging from 5% to 25%, depending on the machine (Figure 2.8). The resulting filtrate normally contains small quantities of fibre fines, colloidal and soluble materials. A filtrate consistency of 100 – 1000 ppm is typical. (Goettsching & Pakarinen, 2000: 168-175.)

The filtrate water from dewatering systems is recirculated for use at various points in the process. This is termed “back-water” in the industry. The result of this is that contaminants and process chemicals are cycled up and concentrated, which can have a significant disturbing effect on the process. It is advisable to remove such fines and colloidal matter from filtrate waters. This is usually done by using dissolved air flotation techniques.

2.8 Dispersing

Dispersing breaks up remaining ink and dirt specks into particles that are the correct size for further flotation or washing. In addition, it can also serve to disintegrate dirt specs until they are too small to be detected visually, thereby improving the appearance of the final paper. The visual detection limit for dirt specks is widely considered to be about 50 microns. In addition, dispersion can assist in removing ink particles still attached to the fibres and conditioning them for papermaking. In the dispersion process, high shear forces, which are in excess of the shear strength of the particles to be dispersed are applied to the stock. This is usually only achievable at high stock consistencies, of 20-30%. Dispersing can be carried out in disk dispergers or kneading dispergers. Disk dispergers are similar to pulp refiners, with specialised plates containing intermeshing teeth mounted on a static stator and a rotating rotor. The amount of energy, and hence the applied shear force is regulated by changing the axial spacing of the plates. Typical applied energy is in the range 50-80 kWh/t. Kneading is performed in tubular machines containing rotating shafts with specially shaped flights or impellors. The energy input into a kneader can be regulated by throttling the discharge from the machine. Energy inputs can range from 30-80 kWh/t. Dispersion is usually carried out at elevated temperatures of 60-130 ºC for disk dispergers and 40-95 ºC for kneaders. Disk dispergers are more effective at reducing dirt particle size, but also tend to affect fibre strengths and freeness. Kneading is gentler on the fibres. (Goettsching & Pakarinen, 2000: 185-192)

2.9 Bleaching

Bleaching in deinking involves the removal of yellowness of the fibres or other coloured components originating from printing inks. Bleaching chemicals can be added at various stages of the process. The chemistry of hydrogen peroxide bleaching is discussed in the Section 3.2.

The pulp bleaching industry has available to it a wide variety of bleaching agents. The commonly used oxidative bleaching agents include hydrogen peroxide (P), ozone (Z), oxygen (O), chlorine dioxide (D) and sodium hypochloride (H). The range of available reductive bleaching agents is more limited, and consists of sodium hydrosulphite (Y) and formamidine sulphinic (FAS) acid.

All of the oxidative bleaching agents can be used to bleach pulps which do not contain mechanical fibres. Chlorine dioxide gave the best destruction of fluorescent whitening agents (FWA), followed by potassium permonosulphate and peracetic acid. The reducing agents gave the best colour removal, followed by ozone, chlorine dioxide and sodium hypochlorite (Magnin, Angelier & Galland, 2000). Goettsching & Pakarinen (2000): 307 state that ozone is also very effective in removing FWA's.

However, the oxidative bleaching agents, with the exception of hydrogen peroxide, are not suitable in applications which contain mechanical pulps, as oxidative degradation of lignin occurs. This necessitates additional pulp washing stages and results in effluents high in COD. Thus in practice hydrogen peroxide and the reductive bleaching agents are used. These have the advantage that bleaching can be carried out in existing tanks and chests, without requiring dedicated bleaching and pulp washing plant. The reductive bleaches are most effective for colour stripping (removing the colour from dyes emanating from coloured papers and inkjet inks) and hydrogen peroxide is effective for the removal of fibre yellowing (Goettsching & Pakarinen, 2000: 308; Magnin, Angelier & Galland, 2000; Hach & Joachimides, 1991).

As a first bleaching stage, hydrogen peroxide is added into the pulper to counteract the propensity of fibres to yellow in an alkaline environment. A final, or post bleaching stage can also be applied at the end of the process in the storage chest. However, if really high brightness is required, a dedicated bleach plant might be necessary. The final bleaching is usually reductive bleaching with sodium hydrosulphite or formamidine sulphinic acid (FAS). If the highest possible final brightness is desired, then a multistage peroxide/hydrosulphite bleaching sequence is necessary (Hach & Joachimides, 1991).

Interstage bleaching with hydrogen peroxide has also been investigated by Carré, Galland, Vernac & Suty (1996). Peroxide bleaching can be performed in a kneading stage between two flotation stages, with similar results to that obtained by bleaching in the pulper. Similarly, pseudo-neutral pulping, followed by bleaching in the interstage kneader produced comparable results.

2.10 Process control of deinking plants

Paper recycling plants are typically controlled by measuring the final optical properties of the pulp. In particular the brightness is routinely measured, but the residual ink concentration and dirt concentration can also serve as secondary measures of deinking. The overall process yield is also monitored. These properties are discussed in more detail in Section 3.5.

These properties are usually measured by manual sampling at regular intervals and determining the optical properties in the laboratory. On-line measuring devices have come on the market in recent years to measure brightness (Gehr, Reinholdt & Koberi, 2000), specks (Julien Saint Amand, Perrin & Sabater, 1993), residual ink (ERIC) and fine ink particles (Carré & Galland, 2007). These devices aid in the control of the plants by providing timeous information to allow changes to be made to process parameters.

Waste recycling plants are normally set up to run at a standard set of conditions, which by experience have been shown to produce the desired final quality. Process parameters are not normally varied in response to changes in output quality or changes in raw material composition. The processes essentially fluctuate naturally about a process mean. The biggest challenge is that the improvements in brightness that can be achieved by manipulation of process parameters are always overshadowed by the effect of quality variations in the recycled paper feed (Carré & Galland, 2007).

Thus, the usual response is to change the recycled paper mix fed to the plant. However, the increasing variability of the recycled paper as foreseen in Chapter 1 makes this approach less viable in the future, and alternate control strategies are needed.

CHAPTER 3: REVIEW OF CHEMISTRY OF DEINKING

The main components of a typical deinking system are the fibres, water which functions as the carrier phase, the printing inks, the mineral fillers and various other process chemicals that are required to achieve deinking. A deinking system is very complex, because these components can interact with each other in difficult to predict ways. The various components will be considered:

3.1 Printing Inks

The main printing processes in use today are offset lithography, rotogravure and the flexographic processes. Offset lithography is commonly used for printing mass circulation newspapers, due to the high print quality and good economics of the process. The old letterpress process is no longer widely used. The rotogravure process is mainly used in the printing of high quality work, such as mass circulation magazines on coated or supercalendered paper. Flexographic printing of newsprint is used to a limited extent in countries such as the United States of America, England and Italy (Carré *et al.,* 2000), but not in South Africa. Flexographic printing is the most commonly used process for the printing of packaging papers (Goettsching & Pakarinen, 2000: 283 – 293; Aspler, 1991).

A printing ink consists of a vehicle, a binder, a colorant (pigment or dyestuff) and a variety of additives. The vehicle is a solvent that dissolves the binder and disperses the pigment. The binder is a polymeric material that on drying forms a film on the surface of the paper, thereby enveloping and adhering the pigments to the substrate. The colorants impart colour to the ink. The dominant pigment is carbon black as most inks are black, although coloured pigments (cyan, magenta and yellow) are used in colour printing. The compositions of printing ink vary, as printing inks are formulated according to the printing process used (Dobias *et al.,* 1992).

Typical compositions, applications and deinking behaviour of various types of ink are summarised in Table 3.1. (Carré & Magnin, 2004; Carré, Magnin & Galland, 2003; Carré *et al.,* 2000; Goettsching & Pakarinen, 2000:270-282; Dobias *et al.,* 1992).

Table 3.1: Typical composition and applications of printing inks. Deinking behaviour relative to unprinted paper.

Printing process	Application	Binders	Carriers	Deinking behaviour
Web-fed cold-set Offset	Newsprint, mass circulation papers.	Hydrocarbon resins	Mineral oil	Deinks well, ca. 15% ISO brightness drop
Offset	High quality printing on coated stock, forms, magazines, inserts etc.	Drying oils, alkyd resins, colophony resins, hydrocarbon resins	Mineral oil	Deinks well, ca. 15% brightness drop. Affected negatively by ageing
Rotogravure	Mass circulation high quality work eg. magazines, inserts	Colophony resins, hydrocarbon resins	Toluene	Deinks better than offset inks, especially on coated papers
Flexographic and rotogravure	Packaging printing	Cellulose nitrate, polyvinyl acetate, polyamides	Alcohols, ethyl acetate, benzene	Not deinked
Water-based flexographic	Newsprint (UK, Italy, USA) and packaging	Acrylic resin dispersions	Water	Poor, ca. 30% ISO brightness loss. Better removed by washing & neutral deinking
Non-impact or electrostatic (Xerographic)	Office copiers and printers, using toner inks	Styrene acrylic, styrene butadiene, polyester or epoxy resins	Toner inks do not contain solvents	Form large ink particles not easy to float – specks in the sheet
Ink-jet printing	Home/office printers, text and colour graphic prints	Azo dyes bound by soluble polymers	Water ethylene glycols	Not floatable, dye-based inks can be colour stripped.

In the printing process the ink is applied to the surface of the paper. The vehicle evaporates and penetrates into the paper, allowing the binder to form a tightly adhering film on the paper surface. The drying process is a purely physical process for binders such as high-boiling hydrocarbon resins or colophony resins. Such resins never harden or dry, but remain adhering to the paper surface. On the other hand, binders such as alkyd resins and drying oils undergo chemical cross-linking and solidifying reactions to form hard, brittle and tightly adhering films on the paper surface. The cross-linking processes can be either oxidative drying or initiated by heat, UV light or electron beams. The nature of the drying processes and the chemical nature of the printing ink binders and pigments determine the ease with which the ink can be removed. It has been found that binders and solvents that are covalently bonded; uncrosslinked; alkaline insoluble and wet pigments are easy to remove. In contrast, solvents and binders that are polar; crosslinked; alkaline soluble and wet pigments poorly are difficult to deink (Goettsching & Pakarinen, 2000: 274). This second class of inks do not fragment well on repulping and typically form large coherent ink particles which can't be easily emulsified and hence removed (Read, 1986).

With the passing of time and the action of heat and oxygen, the binders crosslink, thus becoming more brittle and firmly attached to the fibres. These inks are more difficult to remove from the fibres and fragment more during processing, both resulting in greater deinking difficulties. This is referred to as the "Summer effect" in the northern Hemisphere. (Carré, Magnin & Galland, 2003; Le Ny *et al.,* 2001; Goettsching & Pakarinen, 2000: 293; Olson & Letscher, 1992).

Water-based flexographic inks, which are bound by acrylic resin dispersions, form very fine particles when pulped. These particles are too small for removal by flotation, and are best removed by washing (Carré & Magnin, 2004).

The inks used in office copiers and printers (electrophotographic or "Xerographic" printing processes) do not contain a carrier. These "dry" inks are termed toners. The dry toner ink (consisting of fine plastic particles (*ca.* 20 microns) and carbon black pigment) is applied electrostatically to the paper surface and then fused at elevated temperatures onto the paper. The fused particles adhere tightly to the paper surface. (Johnson & Thompson, 1995)

Toners can be detached from fibre surfaces in the pulping process, but tend to break down into a wide range of particle sizes, varying from 10-20 microns up to large particles of around 500 microns. A large number of toner particles remain attached to fibres, forming "hairy particles" (Berg, Johnson & Thompson, 1997; Johnson & Thompson, 1995). These larger particles are difficult to remove by flotation, and impossible to remove by washing. This results in a bright pulp with visible (> 50 microns) dirt specks. Additional energy has to be applied to break down the large particles into floatable sizes (Carré & Magnin, 2004; Goettsching & Pakarinen, 2000: 278). The particles are broken down using kneaders or dispersers, usually at elevated temperatures. Kneaders can successfully break down particles into the 20-100 micron range, which can then be successfully removed by subsequent flotation stages (Borchardt & Lott, 1996). As was the case for offset inks, the conditions under which the office papers were printed affect the deinkability of toner inks. A study by Hladnik *et al.* (2006) showed that the printing drum voltage had by far the greatest effect on the deinkability of digitally printed papers.

The other main type of printing in the office environment is ink-jet printing. The inks used in ink-jet printing are essentially solutions of water soluble dyes which dry onto the fibre surfaces. They detach from the fibres as very small particles, which are difficult to remove by flotation or even by washing. However, they can be removed by "colour stripping" using reductive bleaching agents (Carré & Magnin, 2004; Goettsching & Pakarinen, 2000:281).

As a recent development, pigment based ink-jet inks are finding more and more applications. These are proving to be almost impossible to deink, as the very fine particles behave similarly to water-based flexographic inks. Also, the pigment particles cannot be decolourised by bleaching (Carré & Magnin, 2004).

Ink particles in a deinking system are actually agglomerates of the pigment and the binder system used to manufacture the ink. As the binder envelopes the pigments, it is actually the nature of the binder that determines the surface chemistry of the ink particle, the ultimate particle size distribution and consequently the ease with which it can be removed (Read, 1991 & 1986).

In order to be recycled, the paper must be re-pulped and the ink must be separated from the fibre substrate. This takes place in the first stage of the deinking process, the pulper. The subsequent separation of ink particles from the fibre slurry takes place in the flotation or washing processes.

3.2 The chemistry in the pulper

3.2.1 Chemicals added into the pulper

The pulping process consists of charging water, recycled paper and a variety of chemicals to the pulper and mixing together for 4 to 60 minutes, at temperatures of 45 ^{o}C to 60 ^{o}C and a pH of 9.5 to 10.5. The higher temperatures ensure faster reactions and increased solubility of the process chemicals (McCormick, 1990).

The water used to repulp the recycled paper is filtrate normally drawn from one of the dewatering stages downstream in the process. This means that colloidal matter, salts, surfactants and other process chemicals and containments in the filtrates are recycled, unless they have been removed by some filtrate cleaning process such as dissolved air flotation.

The pulping process has to fulfil a number of functions: convert the recycled paper into a pumpable fibrous suspension, separate the ink from the fibres and finally stabilise the ink particles to prevent their re-deposition onto the fibres. The separation of the ink is essential for successful deinking. If the ink is not separated from the fibre or re-deposits onto the fibre, its subsequent removal by flotation will not be possible.

Ink can redeposit onto the fibres in three ways:

- In lumen loading tiny ink particles migrate through the pits in the fibre wall into the hollow centre of the wood fibre, known as the lumen. Once in the lumen, the ink particles can never be removed (Ben & Dorris, 2000).
- Ink particles can be re-adsorbed via surface chemical interactions onto the fibre surfaces in a process termed chemical redeposition.
- Ink particles can be mechanically entrapped by irregularities on the fibre surface.

In order to prevent redeposition from occurring, both the fibres and the ink particles must be stabilised by ensuring that their surfaces are hydrophilic. Hydrophobic surfaces will lead to immediate re-deposition (Goettsching & Pakarinen, 2000:244; Section 2.2.3).

The separation of the ink from the fibres is brought about by fibre-to-fibre friction and mechanical action in the pulper (Rao *et al.,* 1998; Borchardt, 1997 & 1993; Schriver, 1990). The ink removal mechanism has been likened to a laundering process. Laundering is facilitated by high alkalinity and the presence of surfactants and complexing agents (Borchardt, 1993; Larsson, 1987).

The chemicals that are commonly added to a newsprint/magazine deinking system are: sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), chelating agents, sodium silicate, surfactants and collectors. This mixture has a pH in the region of 9 to 11. On the other hand, the deinking of mixed office waste is normally undertaken under *true neutral* or *low* alkali conditions (Hannuksela & Rosencrance n.d.). Under true neutral conditions the pH is 6.8-7.2, and sodium hydroxide, sodium silicate and hydrogen peroxide are not added. Under low *alkali* or *pseudo-neutral* conditions the pH is 7.2-8.8, with a low addition rate of chemicals.

Tayler *et al.* (2006) have reported on the successful use of sodium sulphite in a near-neutral environment to deink newsprint. The final ERIC values were similar but the brightness values were slightly lower.

3.2.2 The effect of temperature

In addition to the hydrodynamic effects of temperature, discussed in Section 2.2, temperature also has an effect on the chemistry of the pulping process. The pulping temperature should be close to the cloud point of the non-ionic surfactant in use (Pirttinen & Stenius, 2000). Borchardt & Lott (1996) found that pulping temperature had some influence on the deinking results, but the trends were unclear. Renders, Chauveheid & Dionne (1996) reported a small negative trend of brightness as a function of temperature for newsprint/magazine mixes and a small positive trend for mixed office waste furnishes. Pulping temperature will also affect the rate of the bleaching reactions.

3.2.3 Sodium hydroxide

Sodium hydroxide is commonly used to adjust the pH of the pulping system into the alkaline region of 9.5 to 10.5. At high pH's the fibres swell by absorbing water and they become more flexible. This swelling action assists in detaching the ink from the fibres. Printing ink binders containing drying oils or alkyd resins are thought to be partially saponified in this alkaline environment (Ferguson, 1992a; McCormick, 1990) according to reaction (1):

$$\text{R-CO-O-R'} + \text{NaOH} = \text{R-CO-}\ \text{O}^{-}\text{Na}^{+} + \text{R'-OH} \qquad (1)$$

The saponified ink resins have enhanced alkaline solubility and would carry a negative charge in solution. However, this was contested by Johansson & Ström (1999), who found that very little saponification of the ester group occurred. Only minor oxidation and limited polymerisation of the fatty acid chains was found to take place.

Cellulose fibres exposed to a high pH environment tend to yellow or darken in a process known as ''alkali darkening'' (Ferguson, 1991 & 1992a). Alkali darkening is caused by the formation of chromophores in the lignin molecules remaining in the fibres. The yellowing effect increases as more caustic soda is added, and is more pronounced in fibres originating from mechanical pulping. Ferguson (1991) reported that at a pH in excess of 10.2 the pulper brightness of a 70:30 newsprint/magazine furnish started to deteriorate.

Another side effect of high pH is the softening of adhesive materials such as stickies. This makes their removal by mechanical screening more difficult, as discussed in Section 2.4.

3.2.4 Hydrogen peroxide

As a consequence of alkali darkening, it is necessary to add the bleaching agent hydrogen peroxide to the pulper. Caustic soda is used to "activate" the hydrogen peroxide. The activation reaction with caustic soda at pH 10.0-11.5 and 40-80 °C is:

$$H_2O_2 + NaOH = HOO^- + Na^+ + H_2O \tag{2}$$

The perhydroxyl anion (HOO^-) is the active species in the bleaching reaction (Ferguson 1992a). The concentration of NaOH can influence the concentration of the perhydroxyl anion (reaction 2) and hence the bleaching reaction. Thus, the concentrations of both sodium hydroxide and hydrogen peroxide need to be optimised for effective bleaching (Ferguson, 1992a). Goettsching & Pakarinen (2000) suggest an optimum ratio of hydrogen peroxide to sodium hydroxide, dependant on the level of hydrogen peroxide (Figure 3.1). Renders (1993) suggested that an optimal alkalinity level is 0.5% on dry fibre, independent of the amount of sodium silicate added. The optimum alkalinity was however dependent on the addition level of hydrogen peroxide (Renders, Chauveheid & Dionne 1996). Alkalinity was defined as:

$$\%TA = [NaOH] + 0.112[Silicate] \tag{3}$$

Where NaOH is as 100%, sodium silicate as 38ºBé (see Section 3.3.6.1), all concentrations as % on dry fibre.

This optimum alkalinity manifested as a pH in the pulp of 8.5 to 9 (Renders, Chauveheid & Dionne, 1996). A 10% excess of hydrogen peroxide must be present to prevent reversion or yellowing. Increasing addition levels of hydrogen peroxide result in increasing brightness levels, up to a maximum of about 3%. In addition, increasing levels of bleaching agent will increase the COD of the process effluent. Thus, a 2% addition rate is considered economical (Goettsching & Pakarinen, 2000:315).

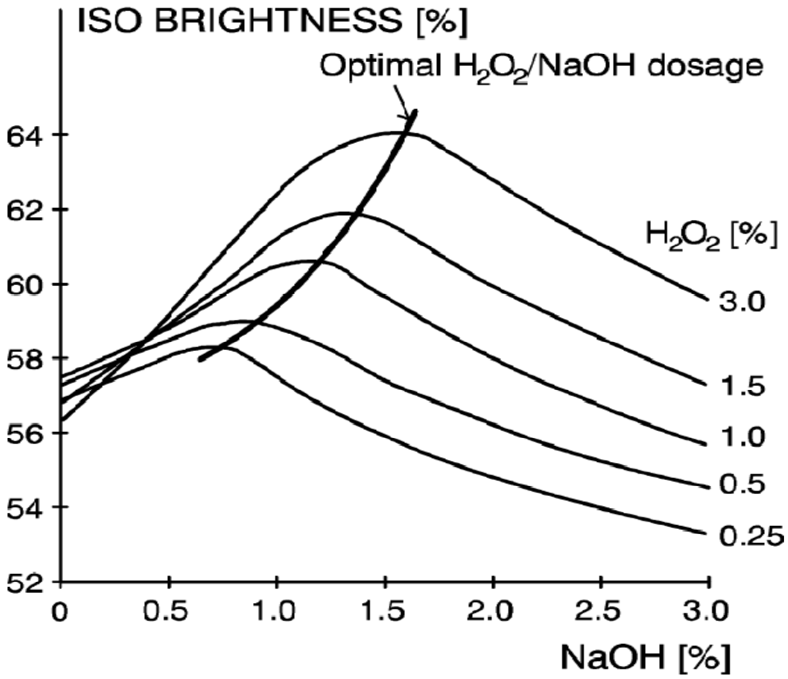


Figure 3.1: Brightness dependence on H_2O_2/NaOH ratio. (Goettsching & Pakarinen, 2000:315)

As a general rule, hydrogen peroxide brightness response improves with consistency (Renders, Chauveheid & Dionne, 1996). Higher consistencies result in a greater concentration of bleaching agent relative to fibre, and a relatively lower concentration of interfering substances. Dedicated bleach plants target a consistency as high as possible (*ca.* 30%), but in a recycled fibre pulper bleaching application, Marchildon *et al.* (1993) found that 15% was an optimum consistency.

In addition to consistency, higher reaction temperatures and long retention times also favour the bleaching response. In practice temperatures of 40-70 ºC and 1-3 hours are used (Goettsching & Pakarinen, 2000:321-2).

The high contaminant load of a deinking system results in a number of side reactions occurring. Heavy metal ions such as Fe^{2+}, Mn^{2+} and Cu^{2+} can catalyse the decomposition of hydrogen peroxide according to reaction (4) below:

$$H_2O_2 = \frac{1}{2} O_2 + H_2O \tag{4}$$

The oxygen produced by this reaction is responsible for the yellowing of the pulp again (Marchildon *et al.,* 1993).

Chelating agents such as the sodium salts of DTPA (diethylenetriaminepentaacetic acid) or EDTA (ethylenediaminetetraacetic acid) are commonly added to the pulper to inactivate the metal ions and prevent the decomposition of hydrogen peroxide. It has been shown that certain printing inks can be a significant source of heavy metals (Ferguson, 1991).

Bacteria commonly occur in the process water of a recycling plant. Certain types of bacteria can produce an enzyme called *catalase* that can decompose the hydrogen peroxide (Sundblad & Mattila, 2001; Goettsching & Pakarinen, 2000:243). Shock dosing with hydrogen peroxide or the addition of enzyme inhibitors are sometimes necessary to combat the problem.

A small residual concentration of hydrogen peroxide should be maintained after pulping. This will ensure that reversion does not take place and that hydrogen peroxide is not overdosed.

3.2.5 Sodium silicate

Sodium silicate is a versatile chemical which has a number of functions in the deinking system. The general chemistry of sodium silicate is discussed more fully in Section 3.3.6, and the chemistry relevant to pulping is discussed below.

Sodium silicate is commonly used in the deinking industry in the form of a 41.6 ^{o}Be (see Section 3.3.6.1) solution.

Firstly, sodium silicate is strongly alkaline in aqueous solution and acts as a pH buffer, according to reaction (5):

$$Na_2O.SiO_2 + 2H_2O = 2Na^+ + 2OH^- + H_2SiO_3 \qquad (5)$$

This reaction reaches equilibrium at pH 11.3 (McCormick, 1990). Reaction (5) indicates that sodium silicate will interact via the common ion effect with the sodium hydroxide present in the system.

Secondly, it is known that sodium silicate has a stabilizing action on hydrogen peroxide and thereby improves the peroxide brightening response. Ali *et al*. (1988) reported that sodium silicate reduced the extent of peroxide decomposition (Reaction (4)) and hence the rate of alkali darkening, and that an extra 2 to 7 brightness points were achieved by the use of sodium silicate in the bleaching process. The actual stabilizing mechanism is unclear, but is thought to involve the formation of a colloidal structure with heavy metal ions (Ferguson, 1991 & 1992a).

Thirdly, Ali *et al.* (1994) reported that the addition of sodium silicate in a deinking system yielded higher brightness after pulping and flotation. This mechanism has been the subject of much debate (Section 3.3.6), but has been attributed to the dispersing action of sodium silicate (Ferguson 1991). This mechanism has been investigated by Pauck (2003), whose research suggested that sodium silicate influenced the chemistry through its sequestering effect on calcium and hence increasing the activity of the soap. Whatever the mechanism might be, the net result is that sodium silicate improves the brightness, as shown in Figure 3.2.

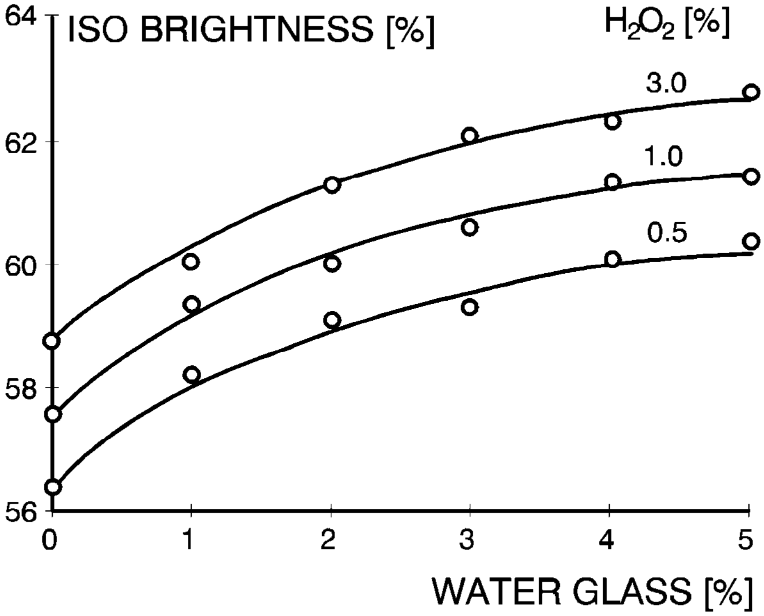


Figure 3.2: Effect of sodium silicate on deinking brightness.

(Goettsching & Pakarinen 2000: 317)

Sodium silicate should not be overused, as this will lead to a build up of silicates in solution. High levels of silicate can interfere with paper machine retention aid systems (McCormick, 1990) and cause deposits and scale formation on process equipment.

3.2.6 Surfactants

The mechanical action of the pulper impellor alone will not completely detach all ink from to the fibres (Rao & Stenius, 1998; Section 2.2.3). Surfactants are commonly added to a pulping system to assist with the wetting of the recovered paper, the dispersion of ink and the stabilisation of ink particles (Schriver, 1990). The surfactants used are usually non-ionic ethylene oxide - propylene oxide block copolymers (Rao *et al.*, 1999; Ferguson, 1991), discussed more fully in Section 3.3.2. Surfactants, if used in combination with the soap/calcium flotation system, will tend to stabilise the calcium-soap particles and ink particles and thereby reduce the flotation efficiency

(Johansson & Ström, 1999). Table 3.2 summarises various aspects of the numerous deinking agents the can be added into pulpers.

Table 3.2: Comparison of deinking agents. (Merza & Haynes, 2001)

Fatty acids	Surfactants	Fatty acid/surfactant emulsions	Surfactant/fatty acid blends
Poor detergency	Strong detergency, over disperse inks	Combined effect	Combined effect
Good ink collector	Average collector, prevent ink redeposition	Combined effect	Combined effect
Make-down equipment required	Liquid – easy handling	Liquid – easy handling	Make-down equipment required
High dosage 0.5-0.7%	Low dosage 0.1-0.25%	Medium dosage 0.3-0.5%	Depends on process
Requires 150-200 ppm hardness	No hardness required	Requires 80+ ppm hardness	Requires 150-200 ppm hardness

Fatty acids have a similar ink dispersing action to the non-ionic dispersants (Rao & Stenius, 1998; Borchardt, 1997; McCormick, 1990). However, the fatty acid soap will only be effective as a dispersant if there are an excess for free soap anions, which will depend on the pH of the solution (reaction 6) and the concentration of calcium in the pulper (Rao & Stenius, 1998). High hardness in the pulper will precipitate the free fatty acid, rendering it ineffective as a dispersant (Pauck, 2003; Weigl *et al.*, 1987). This could lead to an increase in the ink particle size by agglomeration in the pulper (Pirttinen & Stenius, 2000).

3.2.7 Pulping pH

Alkaline deinking has been found to be essential for the successful deinking of offset printing inks, particularly if the printing ink has aged somewhat. Caustic soda in the pulper has been found to improve ink detachment and reduce ink fragmentation, but hydrogen peroxide has no effect on ink detachment. The negative effect of alkaline pulping is the increase in soluble organic materials in the process water, which manifests as high levels of chemical oxygen demand (COD). High COD's have implications for effluent water treatment and discharge (Galland, Vernac and Carré, 1997a). Ackermann, Putz & Goettsching (1999) have also found that neutral deinking results in inferior quality of deinked offset papers.

In neutral deinking, the amount of sodium hydroxide in the pulper is greatly reduced, and sodium silicate and hydrogen peroxide are eliminated. For newsprint and magazine blends, this results in less alkaline yellowing but also reduced ink release and more ink fragmentation, with resultant reduced ink removal efficiency and lower consequent brightness. This can be overcome by more aggressive post-flotation bleaching, which however has to be done under alkaline conditions, therefore negating the previous benefits. The net effect is reduced chemical consumption and lower COD loading of the effluent, but reduced output quality. (Vahlroos, Körkkö, Rosencrance & Niinimaki, 2007; Moe & Røring, 1998).

Azevedo, Drelich & Miller (1999) found that mixed office waste pulped under alkaline conditions resulted in larger ink particles and inferior flotation removal. Neutral pulping resulted in a toner particle size more amenable to removal by flotation, together with the simultaneous flotation of filler particles. The neutral deinking of newsprint has been investigated by Lakshmana Reddy, Nayak & Vasanthakumar Pai (2008) using a new deinking surfactant. The results were comparable to that of alkaline deinking, with reduced COD load in the effluent.

On the other hand, water based inks, such as flexographic inks, become highly dispersed and fragmented in alkaline pulping systems, resulting in them being very difficult to remove. Neutral pulping results in less fragmentation and some success can be achieved with removal by flotation. The advantage of neutral deinking is that much lower levels of COD are produced in the process water. Thus, for the deinking of mixtures of different recycled paper grades, multistage processes are often essential. A neutral first stage followed by an alkaline second stage has been found to be effective. (Galland, Vernac and Carré, 1997a)

In the neutral deinking of recycled office papers, the reduced ink fragmentation is actually an advantage, allowing the easier removal of toner inks by flotation. Better stickies control and lower chemical costs are also advantages of neutral deinking. (Vahlroos *et al.,* 2007; Moe & Røring, 1998).

The deinking of recycled office papers to produce high quality recycled pulp also requires a multistage process. In this case a neutral first stage followed by either neutral or alkaline second stage is effective. Interstage bleaching with hydrogen peroxide or reductive bleaches further enhances the brightness (Galland, Vernac and Carré, 1997b).

3.2.8 Conclusion

At the conclusion of the pulping process, the fibres should be well dispersed in the process solution with no flakes remaining. The ink particles should be separated from the fibre and well dispersed and stabilised to ensure that no re-deposition occurs. The yellowing that was induced by the high pH environment has been reversed by the hydrogen peroxide.

This pulp is now passed through various physical screening and cleaning processes (as described in Sections 2.3 and 2.4 above) before it is pumped to the flotation cell. The physical separation processes tend to remove larger and denser or lighter particles, which tend not to affect the brightness of the pulp. Prior to flotation the fibre suspension is diluted with backwater to a consistency of ca. 1% and the pH is adjusted to the required level. If a soap/calcium system is being employed, then at this point collector soap and sufficient calcium chloride to obtain a calcium hardness of *ca*. 250 ppm as $CaCO_3$ is added. In the flotation cell air in the form of fine bubbles is forced through the fibre suspension. The air rises to the surface and forms a layer of foam on the surface of the pulp. This layer of foam, laden with ink particles, fibres, fines and filler is mechanically removed from the system.

3.3 Chemistry in the flotation cell

3.3.1 Surface chemical mechanisms of flotation

The pulping process is a process based on fragmentation and dispersing actions. In contrast, flotation processes require the agglomeration of dispersed inks to an ideal particle size range of 10 to 100 microns. In order for agglomeration to occur, the ink particles must be hydrophobic (Ferguson, 1992b). Opinions vary as to the ideal size range of the ink particles. Goettsching & Pakarinen (2000: 245) state that 20-40 microns is ideal, whilst Borchardt (1997) quotes a range of 30-80 microns. Hydrodynamic studies by Julien Saint Amand (1999) suggest an upper limit of 100 microns for the ink particle size.

The ink particle of correct size must then attach itself to an air bubble that is rising through the fibre slurry. To facilitate this attachment, it is necessary to add chemicals called collectors. The collectors most widely used in newsprint deinking systems are commercial fatty acids. The fatty acids are available in a number forms: solid soap pellets, liquid soap or the free fatty acid. A certain amount of preparation is needed to enable the fatty acid to be conveniently added into the system (Section 3.3.2). The soap must be converted to the calcium salt of the fatty acid according to reactions (6) and (7) below, for it to function as a collector. (Johansson & Ström, 1999; Johansson *et al*., 1996; Ferguson, 1992b)

$$\begin{array}{lcccccc} \mathrm{RCOOH} & + & \mathrm{NaOH} & = & \mathrm{RCOONa} & + & \mathrm{H_2O} \\ \text{Fatty acid} & & & & \text{Sodium soap} & & \end{array} \tag{6}$$

$$\begin{array}{lcccccc} \mathrm{2RCOONa} & + & \mathrm{CaCl_2} & = & \mathrm{(RCOO)_2Ca} & + & \mathrm{2NaCl} \\ \text{Sodium soap} & & & & \text{Calcium soap} & & \end{array} \tag{7}$$

The sodium soap is sparingly soluble in water at low concentrations. The calcium soap on the other hand is insoluble, and precipitates out of solution as a fine white precipitate. Above pH 7, the concentration of free sodium oleate has been estimated to be only *ca.* 2 x 10^{-7} M (Rao *et al.,* 1998). The calcium level required for effective collector activity is widely accepted to be about 200 ppm of calcium hardness ($CaCO_3$) (Ferguson, 1992b).

The calcium is added to the system as a calcium chloride solution. The addition of extra calcium might not be necessary in areas where the water is naturally hard or the recycled paper contains large amounts of calcium carbonate filler.

There are many schools of thought as to the mechanisms of interaction between ink particles, surfactants and air bubbles. Beneventi & Carré (2000) have reviewed mechanisms by Schweizer (Schweizer, G. 1965. Wochenblatt fuer papier Fabrikation 93(19):823-880), Bechstein (Bechstein, G. 1975. Oesterr. Papier 12(4):16-19), Ortner (Ortner, H.E. 1981. Tappi Press. Atlanta, GA), Hornfeck (Hornfeck, K. 1982. Wochenblatt fuer Papier Fabrication. 110(5):542-544), Larsson (Larsson, A., Stenius, P., Odberg, L. 1984. Svensk Papperstidning No. 18, pp158-164) and Putz (Putz, Schaffrath & Goettsching 1993).

Goettsching & Pakerinin (2000), Linck (1990), McCool (1993) and Schriver (1990) also refer to the work of Larsson *et al*. (Larsson, A., Stenius, P., Odberg, L. Sv. Papperstidning 88(3),R2(1985) and 87(18),R165(1984)).

The Larsson mechanism is considered by Beneventi & Carré (2000) to be “state of the art”, and is discussed below as an example. The Larsson theory suggests that in alkaline medium, the ionised fatty acids stabilise the ink particles. Calcium ions will precipitate the soap according to reaction (7) as very small particles, or micro-precipitates (Ferguson, 1992b) onto the surface of the ink particles. Larsson (1987) reported that this layer of sub-micron calcium soap particles was visible under a scanning electron microscope. This layer of calcium soap precipitate will render the ink more hydrophobic and leads to agglomeration of the ink into larger particles. The soap-coated particles also enhance the adhesion of the ink to the air bubbles and facilitate their removal from solution. Figure 3.3 depicts this process:

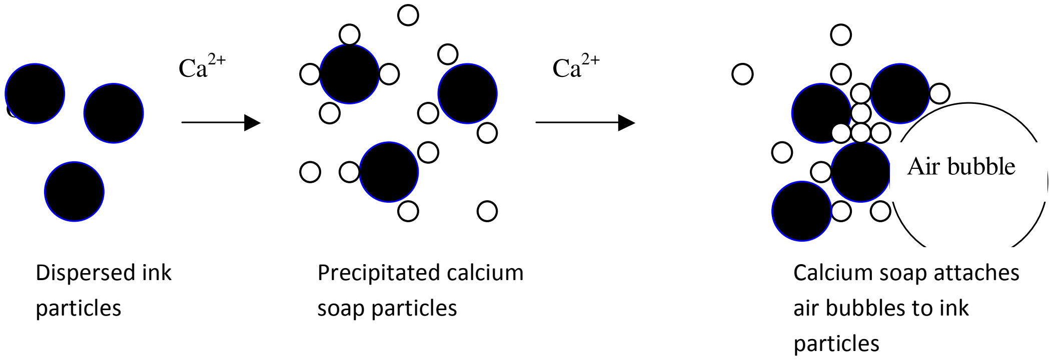


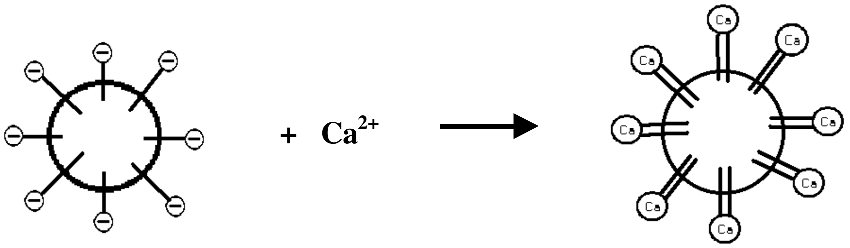
Figure 3.3: Collecting mechanism of calcium soap. (Larsson *et al*., 1987)

McCormick (1991) has proposed an alternate theory: The soap molecules are adsorbed onto the surface of the dispersed ink particle, and impart a negative charge to the ink surface. The calcium ions react with the soap molecules according to reaction (7). The negative charge on the soap particle has now been neutralised and the ink particle is more hydrophobic. However, because the soap molecules are adsorbed onto the surface of the ink particle, the soap/calcium salt takes on a strained configuration. When two ink particles collide, a re-arrangement of the adsorbed calcium soap molecule takes place, and the calcium ion now acts as a bridge between two ink particles. This process can repeat itself to form larger and larger ink agglomerates. In a similar way, the calcium soap stabilises the air bubbles by adsorbing at the interface between air and water. When such a stabilised air bubble collides with an ink particle, a similar calcium soap re-arrangement takes place and the ink particle is attached to an air bubble, *via* the calcium link. This mechanism is shown in pictorial form in Figure 3.4.

Putz, Schaffrath & Goettsching (1993) have postulated that a “hydrate cover” acts as a barrier between the ink particles and the air bubbles. Surfactants adsorb onto the surface of the ink particle and disrupt the ‘’hydrate cover’’. The removal of this hydrate cover facilitates the attachment of the ink particle to the air bubble and ink removal by flotation can take place.

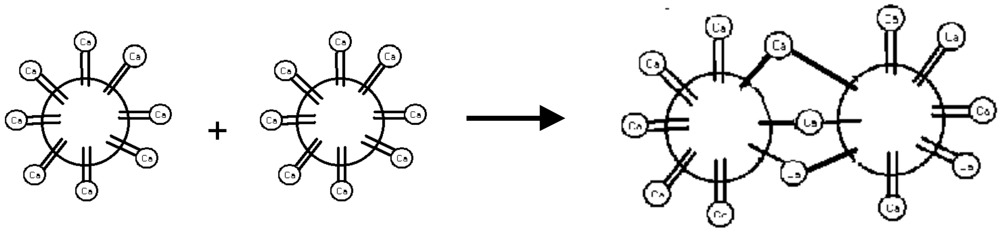
Based on studies of the equilibrium concentrations of the oleate-calcium system and agglomeration kinetics, Rao *et al.* (1998) have concluded that the agglomeration of ink particles is *preceded* by the agglomeration of calcium soap particles. This lends support to the Larsson mechanism, and they suggest that there is no evidence to support the bridging mechanisms of Ortner and McCormic.

The models are all confusingly similar, and mostly refer to the calcium – soap system. In essence, they all seek to describe the complex interactions occurring between soap, ink particle and air-water interface.

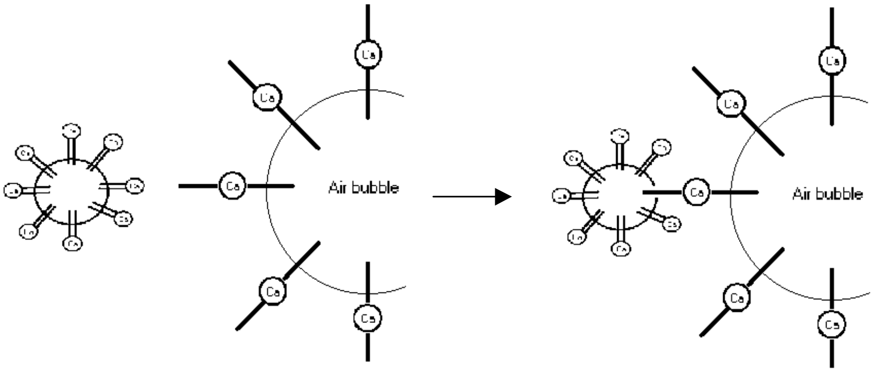


Soap stabilised ink particle, negatively charged.

Calcium neutralises negative charges on ink particles.



Ink particles collide: Calcium acts as a bridge between the soap molecules.



Collision between ink particle and air bubble: Calcium acts as a bridge between the soap molecules.

Figure 3.4: Mechanism of ink agglomeration and flotation. (McCormick, 1991)

3.3.2 The soap and surfactants

Surfactants play three main roles in the flotation process, summarised in Table 3.3:

Table 3.3: Role, nature and effects of surfactants in deinking. (Zhao, Deng & Zhu 2004)

Surfactant role	Typical surfactants	Effect in the process
Dispersant	Non-ionics such as alcohol ethoxylates, alkyl phenol ethoxylates, fatty acid ethoxylates, and polyethylene oxide alkyl ethers.	Liberation of ink from fibres, dispersion and stabilisation of ink particles.
Collectors	Fatty acid soaps, polyethylene oxide-polypropylene oxide copolymers, ethoxylated fatty acids.	Agglomeration and aggregation of small ink particles into ideal particle size ranges for flotation (10-100 microns)
Frothers	Non-ionic surfactants	Generate a stable foam layer to carry and remove ink particles.

Most surfactants however can play multiple roles and can interact in complex ways with other components of the deinking system. Surfactants are characterised by their hydrophile-lipophile balance (HLB value), their cloud-point (non-ionic surfactants) or Krafft point (ionic surfactants) and the critical micelle concentration (CMC). The cloud point should be at least 5ºC higher than the flotation temperature, and an HLB value of 14-15.5 has been found to be optimum. However, there are many other factors influencing the performance of surfactants in deinking, so these factors should not be the sole basis of surfactant selection. The selection of surfactant depends greatly on the conditions prevailing in any one deinking plant (Theander & Pugh, 2004; Zhao, Deng & Zhu, 2004).

Fatty acids are the most commonly used surfactants in the deinking of newsprint. They have good dispersing and foaming properties and are easily biodegradable (Goettsching & Pakarinen, 2000: 254). Fatty acid soaps are sensitive to water hardness and pH, according to reaction (7). However, as outlined in Section 3.3.1, hardness is an integral part of the collecting mechanism.

The optimum fatty acid chain length for newsprint flotation is reported to be C16 (Mak & Stevens, 1993). The ideal degree of unsaturation depends on the water hardness. Fatty acids with higher iodine values need higher water hardness to perform well (Mak & Stevens, 1993). The flotation efficiency of fatty acids decreases in the order stearate>palmitate>oleate (Rao *et al.,*1998).

Commercial fatty acids are blends of C16 to C18 saturated and unsaturated carboxylic acids such as stearic (C18:0), oleic (C18:1), palmitic (C16:0), linoleic (C18:2), linolenic (C18:3) and palmitoleic acids (C16:1).

Fatty acid soaps are waxy solids at room temperature. They need special preparation and storage measures to convert them to liquid form to effectively dose them into a system. The free fatty acid is liquid but would need to be converted to the soap *in situ*. Liquid solutions need to be kept hot and constantly stirred. In order to avoid these practical difficulties and associated housekeeping issues (Turvey, 1990), a number of synthetic surfactants or fatty acid/surfactant blends have been developed, which allow easy handling and are not sensitive to water hardness (Table 3.2).

Synthetic collectors commonly used in the industry are the non-ionic surfactants of the following types: ethylene oxide (EO) propylene oxide (PO) copolymers, ethoxylated fatty alcohols and ethoxylated fatty acids. Anionic surfactants have higher solubilities than non-ionics, and tend to cycle up in process water systems, resulting in higher yield losses due to high foaming tendencies. The poor biodegradability of particularly the ethoxylated nonyl-phenols has precluded their use in recent years (Goettsching and Pakarinen, 2000: 255; Dash & Patel, 1997). In order to address the concerns about biodegradability and renewability, researches have investigated surfactants based on natural sources, such as sugars and proteins. These have proven to be viable replacements for conventional petroleum based surfactants (Spence, Venditti & Rojas, 2009).

Fatty acid ethoxylates are thought to work by means of a hydrolysis mechanism. In the esterified form (mid to lower pH ranges) they function as dispersants, and disperse the inks. After some time in alkaline conditions they hydrolyse to fatty acids, and then function as collectors via the fatty acid-calcium coagulation mechanisms discussed in Section 3.3.1 (Theander & Pugh, 2004).

In a comparative study of a number of different surfactants, it was found that fatty acid based systems out-performed all other types (Mak & Stevens, 1993). In order to combine the superior collecting properties of fatty acids and the handling properties of synthetic surfactants, semi-synthetic fatty acid emulsion products have been developed. The final choice of surfactant for deinking is determined by many practical factors, which might outweigh the considerations of deinking efficiency alone.

Kanhekar *et al*. (2005) found that, depending on the nature of the soap/surfactant, ink removal either reaches an optimum and then decreases, or it increases steadily with surfactant dosage. Licht & Leighton (1991) found that the deinking reagent did not have a significant effect on brightness. On the other hand, Spence, Venditti & Rojas (2009) found a definite positive correlation between surfactant addition and ink removal efficiency.

3.3.3 Temperature, pH and surface tension

The pH of the solution has a profound effect on the calcium soap equilibrium, and the maximum efficiency of flotation of both mineral-oil and vegetable-oil based offset inks occurs between pH 7 and 11 (Rao *et al.,* 1998). In a review of flotation chemistry, Theander & Pugh (2004) state that a pH range of 8 to 10 is optimal for flotation. Flotation efficiency falls off above pH 10. This can be ascribed in part due to the more negative surface charges (zeta potentials) and hence greater repulsive forces at higher pH.

Substances naturally occurring in pulps or used in the paper making process, such as lignosulphonates, starch, carboxymethyl cellulose (CMC) or additives to coating mixes, tend to act as dispersing agents in a deinking system. Such materials all have a negative effect on flotation. (Rao *et al.,* 1998)

The hydrodynamics of flotation discussed in Section 2 showed the importance of air bubble size. From a surface chemistry point of view, the size of a *stable* air bubble depends on the surface tension of the liquid, according to the Young-Laplace equation (8):

$$\Delta P = \frac{2\gamma}{r} \tag{8}$$

Where $\Delta \mathrm{P}$ is the pressure difference between bubble gas and solution, γ is the surface tension and r is the bubble radius. The nature of the surfactant, including its hydrophilic/lipophilic balance and concentration will determine the surface tension and hence the stable bubble size (Rao *et al.,* 1998). The creation and destruction of air bubbles in a flotation system is a very dynamic process, often taking place within very short periods of time. Hence, the diffusion rate of surfactant molecules to the surface can also play an overriding role in determining the surface tension (Theander & Pugh, 2004).

Practically, flotation deinking processes run at temperatures ranging between 40 and 60ºC, although office paper recycling plants sometimes run at temperatures up to 90ºC. The work of Pletka *et al.* (2000) clearly showed an increase in brightness as the flotation temperature exceeded 60ºC. However, researchers are not unanimous on the effect of temperature on deinking, some reporting better ink removal at higher temperatures and others reporting the opposite. Many secondary parameters such as surfactant solubility, bubble size, froth structure and solution viscosity are affected by temperature, so that it is very difficult to isolate the effect of temperature alone (Theander & Pugh, 2004).

3.3.4 The role of the calcium Ion

The important role that the calcium ion plays in the ink collecting mechanism has been discussed in Section 3.3.1. The calcium ion also interacts with other components of a deinking system.

The hardness of a flotation system influences the amount of fibre that is lost during flotation (Turvey, 1987; 1990 & 1991). Fibre loss constitutes a loss of yield in the process, with negative economic consequences. Turvey (1990) reported a fibre loss of 7 -10% at a hardness of *ca*. 280 ppm calcium, which suggested that the calcium ions can interact with the fibres in some way. Schwinger & Dobias (1991) reported that the calcium cation adsorbs onto the surface of the fibre. Cellulose fibres normally exhibit a negative charge in solution, and adsorbed calcium ions reduce the negative surface charge to almost neutral. This renders the fibres hydrophobic and thus floatable. Turvey (1991) suggests that the calcium cations are held onto the fibre surface by the carboxylic acid groups that occur on a fibre surface in an alkaline environment, as per reaction (9). Furthermore, Turvey (1991) suggested that small ink particles are capable of interacting with calcium ions, and will deposit onto a fibre *via* the calcium half-salt reaction (9).

$$\text{Fibre-COO}^- + \text{Ca}^{2+} = \text{Fibre-COOCa}^+ \tag{9}$$

It could be expected that free calcium ions could precipitate as calcium hydroxide in the alkaline deinking environment, as per reaction (10).

$$Ca^{2+} + 2OH^- = Ca(OH)_2 \qquad (10)$$

However, Oliveira & Torem (1996) and Froass *et al*. (1997) state that this reaction does not occur to any extent below pH 12.

Calcium will also react with sodium silicate to form insoluble calcium silicate, as in reaction (11).

$$Ca^{2+} + Na_2O.SiO_2 = CaSiO_3 + 2Na^+ \qquad (11)$$

Froass *et al*. (1997) have determined that the critical precipitation concentration for calcium in a silicate solution corresponds to *ca.* 56 ppm of calcium at pH 9.2, 60°C and *ca*. 2340 ppm SiO_2. Thus, a 1% (10 000 ppm) addition of sodium silicate would exceed these values, indicating that such reactions are probable. These calcium silicates are known to form deposits on process equipment.

However, Turvey (1991) reports that the adsorption of calcium onto the fibre predominates the above reactions under alkaline conditions, and is responsible for the flotation of fibres.

Mineral fillers such as kaolin (aluminium silicates) usually carry a negative surface charge. Calcium ions adsorb onto the surface of the mineral filler, partially neutralising the negative charge (Liphard *et al*., 1991).

3.3.5 Fillers

Fillers are commonly used in the manufacture of various grades of paper. Newsprint can contain from less than 5% to over 10% filler, depending on world region (Brouillette *et al*., 2010). Office papers can contain *ca.* 20 % filler, as can uncoated and coated magazine papers. Thus, one of the major components in a deinking system will be the mineral filler. The filler most commonly used in making paper is clay or kaolin, although talc and calcium carbonate are also used (McCormick, 1991). Kaolin will originate from the magazine papers and the recycled office paper will contribute calcium carbonate to the recovered paper mix. The use of calcium carbonate has increased in recent years with the rise in alkaline paper making. Although calcium carbonate is not used in newsprint or magazine furnishes, it is increasingly being used as a pigment in coating formulations, so it too can find its way into newsprint/magazine deinking systems.

Newsprint is usually deinked in combination with recovered magazine papers in a typical blending ratio of 70% newsprint to 30% magazine, although this can vary depending on geographical region and availability. This is primarily to boost the brightness, but it has also been found that it is difficult to deink newsprint on its own (Schriver *et al*., 1990; Zabala & McCool, 1988). Some newsprint-only deinking operations have reportedly been adding fillers to the deinking cell to improve the deinking efficiency (Schriver *et al*., 1990; Zabala & McCool, 1988).

Clay particles normally exhibit a plate-like structure with a negative surface charge, and Zabala & McCool (1988) have hypothesised that the ink particles adsorb onto the surface of the filler, thereby producing larger, more easily floatable particles. Liphard *et al*. (1991) and McCormick (1991) have suggested that the negatively charged clay particles will associate with the weak positive surface charge of the calcium on the ink particle surface, thereby forming a protective filler layer.

Similarly, Grant & Blain (1995) have shown that filler clays or talc absorb ink mineral oils and go on to form ink-coated mineral particles. These particles are stable to shear forces and adhere well to air bubbles, and will thus float well. Shen, Abubakr & Springer *et al*. (1995) found that the addition of clay to a laboratory flotation cell significantly reduced the fibre losses from the cell, without negatively affecting the flotation deinking performance.

Schriver *et al*. (1990) have shown that the best fatty acid-based deinking performance was obtained from calcined filler clay, followed by talc and a low surface area zeolite. A scavenging mechanism was proposed. In contrast, calcium carbonate did not appear to enhance deinking.

However, Letcher & Sutman (1991) and Mahagaonkar, Stack & Banham (1998) found no evidence to support the theory that fillers assists ink removal.

It is sometimes necessary to remove the fillers in addition to inks, in cases where the final product does not require fillers, *eg.* newsprint or tissue paper. It has been found that fatty acid collectors remove a small quantity of filler, but special collectors are necessary to remove the fillers efficiently. This is normally accomplished in a dedicated second flotation stage (Liphard *et al.*, 1991).

3.3.6 Sodium silicate

The final major chemical additive to an alkaline deinking system is sodium silicate. Sodium silicate is used in a number of different fields, such as detergents, oil drilling, mineral flotation and bleaching. The chemistry of the soluble silicates relevant to deinking is discussed below:

3.3.6.1 The general chemistry and properties of soluble silicates

The soluble silicates are a combination of silica and an alkali metal oxide. The general formula can be written: x $SiO_2:M_2O$, where M is Na, K or Li, and x is the molar ratio. Molar ratios of 2:1 are termed ‘’alkaline’’ and ratios of 3.3:1 are referred to as ‘’neutral’’. The sodium silicates find general application, whereas the lithium and potassium salts are used in specialised fields.

The sodium silicates are commercially available as solid powders or as viscous aqueous solutions. For reasons of convenience, solutions are used in the industry. The density of such solutions is expressed as degrees Baume’ (^{o}Bé) or degrees Twaddle (^{o}Tw) at 20 ^{o}C. These are defined in terms of the specific gravity (SG) according to equation (12):

$$^{o}\text{Bé} = 145(1 - 1/\text{SG}) \text{ and } ^{o}\text{Tw} = 200(\text{SG} - 1) \qquad (12)$$

The specific gravity and viscosity depend on the molar ratio and the concentration in solution (Crosfield, 1993). Conventionally, 3.3:1 molar ratio, 38% solids, 79 ^{o}Tw (^{o}Bé 41) sodium silicates are used in deinking.

As already mentioned, solutions of sodium silicate are strongly alkaline (reaction 5), with a buffering ability similar to that of sodium hydroxide, but at a lower pH.

$$Na_2O.\ SiO_2 + 2H_2O = 2Na^{2+} + 2OH^{-} + H_2SiO_3,$$
$$\text{or } Na_2O + H_2O = 2NaOH \qquad (5)$$

At high concentrations, the silicates form insoluble silicate complexes with multivalent metal ions such as calcium, aluminium and magnesium to. At lower concentrations the silicates can sequester iron and manganese ions. This sequestering action is employed in water treatment processes and in the detergent industry, where silicates react with the calcium and magnesium ions to reduce their activity and enhance surfactant performance (Crosfield, 1993; Falcone, 1982).

The high alkalinity of silicate solutions will saponify the ester bonds in organic oils and fats. The soluble sodium soaps thus formed contribute to the overall detergent action of the silicate. The silicates are more efficient emulsifiers than conventional alkalis such as sodium hydroxide (Crosfield, 1993).

The silicate solutions are only stable at high pH. At pH's below about 9, insoluble silica gels are formed. This occurs rapidly in a concentrated solution, but can take many hours in dilute (less that 1% SiO_2) solutions. (Crosfield, 1993)

3.3.6.2 The effects of sodium silicate in deinking

The effects of including sodium silicate in a deinking formulation have been investigated by a number of researchers. In this section the results and conclusions of the various workers are summarised.

In a comprehensive study by Ali *et al*. (1994) of a 70/30 blend of newsprint and magazine, deinked by washing and flotation and measurement of brightness, lightness (L*), yellowness (b*) and particle size distribution by image analysis, it was reported that:

- The brightness of the final pulp increased as sodium silicate dosage increased from 0% to 5%.
- Silicate enhanced the removal of ink by forming larger, more floatable particles.
- Sodium silicate appeared to prevent suspended ink particles from re-depositing on the fibre surface.
- Sodium silicate had a stabilising action on hydrogen peroxide.
- Sodium silicate removed more ink than caustic soda alone.
- Sodium silicate reduced alkali yellowing of the pulp.

Numerous other researchers (Mahagaonkar *et al*., 1997; Mahagaonkar *et al*., 1996; Borchardt, 1995; Ferguson, 1992a and Read, 1991) have reported on experimental work that demonstrates that sodium silicate leads to higher brightness and reduced ink speck counts when used in the deinking of newsprint. The reasons advanced were that sodium silicate demonstrates wetting, detergency, peptization, ink dispersion, alkalinity, pH buffering, peroxide stabilisation and sequestering actions.

In contrast to the proposed dispersing action of sodium silicate, a number of researchers have presented evidence that sodium silicate actually has an agglomerating or collecting action. (Santos *et al.*,1996; Renders *et al.*, 1996; Renders, 1993 & Dionne, 1994)

The sequestering action of sodium silicate is utilised in detergent formulations, where it complexes water hardness salts and protects the surfactants. In the field of crude oil recovery, Krumrine (1982) reports that sodium silicates enhance recovery yields relative to sodium hydroxide due to the interaction of the silicate with hardness ions. The sequestering action of sodium silicate has support in the deinking field (McCormick, 1990). Weigl (1987) reports that the precipitation of fatty acid soap by calcium ions in the pulper leads to higher surface tensions and reduced emulsification of inks, with resultant increased ink redeposition. Research by Pauck (2003) supports the view that sodium silicate sequesters calcium in the pulper and enhances soap activity.

Mathur (1991) discounts the role that the surface active properties of sodium silicate play in ink removal. Instead, he ascribes the higher brightness observed with the use of sodium silicate to the chelation of metal ions such as Fe^{2+}, Mg^{2+}, and Cu^{2+}, and the attendant stabilisation of hydrogen peroxide.

Mak & Stevens (1993) studied the characteristics of fatty acids in deinking, and found that sodium silicate did not have a significant influence on deinking performance. Zabala & McCool (1988) were able to replace sodium silicate with a metal chelant in a commercial deinking system with no negative effects on brightness.

Other effects of sodium silicate have also been reported. Sodium silicate has been shown to reduce the fibre losses during deinking (Ackermann *et al.*, 1999; Liphard *et al.*, 1991) and to suppress the flotation of fillers (Ackermann *et al.*, 1999; Mathur, 1994). This mirrors the function of sodium silicate as a suppressant in the flotation of minerals such as chromium, copper, tin, fluorspar and phosphates, where it selectively adsorbes onto the surface of unwanted gangue minerals such as silica or iron oxide, thereby rendering them hydrophilic and depressing their flotation. (Crosfield, 1993)

Observations of the effect of sodium silicate in a South African newsprint deinking operation showed that attempts to eliminate sodium silicate from the process resulted in an immediate fall-off in deinking efficiency and loss of brightness (Crosby 1999).

In order to consolidate the divergent views on the role of sodium silicate, a summary is presented below.

- pH Buffering action and saponification
- Peroxide stabilisation
- Prevention of yellowing
- Ink agglomerator or collector
- Ink dispersant
- Calcium sequestering action

3.4 Final bleaching

The final bleaching of pulp, after all ink removal processes have taken place, is also called post-bleaching. After deinking, the pulp is dewatered and stored in a storage chest. If a second stage of hydrogen peroxide bleaching is required, the pulp is thickened to as high a consistency as possible (30-40%) and subjected to similar chemical additions and process conditions as discussed in the Section 3.2 on pulper chemistry.

Post-bleaching can also be achieved using reductive bleaching alone, depending on the final brightness required. The two commonly available reducing agents are sodium dithionite (a.k.a. sodium hydrosulphite) and formamidine sulphinic acid (FAS). A tabulated comparison of the practical bleaching conditions of the two reductive bleaching agents is given in Table 3.4. The factors mentioned in the table naturally interact, so optimisation for each plant is necessary.

Both reducing agents are susceptible to decomposition by oxygen in solution, so practical steps need to be taken to reduce aeration of the pulp and bleaching solutions. The bleaching times are quite short, so bleaching can be accomplished in storage chests or even “in pipe”.

Post-bleaching in a tower has been shown to be more efficient than pulper bleaching. This is because of the higher consistencies that can be achieved in a post-bleaching operation and the presence of fewer contaminants that could be involved in side reactions with hydrogen peroxide (Renders, Chauveheid & Dionne, 1996).

Table 3.4: Comparison of reductive bleaching agents. (Goettsching & Pakarinen 2000:326-334)

Property	Sodium dithionite	FAS
Chemical formula	$Na_2S_2O_4$	$C(NH_2)(NH) – SO(OH)$
Reduction bleaching reaction	$Na_2S_2O_4 + H_2O \rightarrow \mathbf{NaHSO_2} + NaHSO3$ (**active agent** in bold)	$\mathbf{C(NH_2)(NH) – SO(OH)} + NaOH \rightarrow CO(NH_2)_2 + NaHSO_3$ (**active agent** in bold)
Bleaching consistency	3 – 5%	5 – 20% (C)
Bleaching time	5 - 10 mins	15 – 60 mins
Bleaching temperature	*Ca.* 60 ºC	40 - 90 ºC (T)
pH	6 - 7	*Ca.* 9
Addition rate	0.5 – 1.0%	0.2 – 0.8% (F)
Typical brightness increase	4% - 7% ISO	$R_{457} = 55.05+0.08T-0.12C+5.7F-F^2$ for wood containing pulps

Additional bleaching can also be performed in dispersers or kneaders. Dispersers are placed in deinking lines after flotation and washing but before final storage. Temperatures and consistencies are high in dispersing units, and they thus provide ideal conditions for bleaching. The brightness naturally drops through the dispersion process, due to the further break up of ink particles. Hence, addition of bleach into the disperser can counteract this brightness drop. (Renders, Chauveheid & Dionne, 1996)

3.5 Measurement of deinking efficiency

The main criteria of deinking efficiency are the optical properties of the pulp and the yield or output of the process. There are three aspects to the optical properties: the brightness, the colour and the dirt content, which together determine the appearance of the final pulp to the human eye (Haynes, 2000). In a practical situation, pulp strength is also important for the final application of the pulp in the making of paper. However, pulp strength cannot be influenced by the recycling process, other than by varying the incoming recycled paper mix, so it is not normally considered as something to be monitored in a recycling plant.

3.5.1 Yield

The efficiency of the deinking process can be measured in two ways. Firstly, the efficiency of the process is determined by measuring the yield, which is defined as:

$$\%\,Yield\ =\left(1-\frac{removed\ mass}{input\ mass}\right)\times\ 100 \tag{13}$$

v*iz.* pulp mass remaining after the deinking process as a percentage of the mass of recovered paper fed to the process.

It has been estimated that ink constitutes ca 2-5% and filler 10-40% of the recycled stock (Hannuksela & Rosencrance, n.d). The deinking process typically removes ink, some fibres, and mineral fillers such as clay or calcium carbonate. A single flotation deinking stage normally has a yield of about 85-90%, and a single washing stage has a yield of 75-85% (Goettsching & Pakarinen 2000: 295). Spence, Venditti & Rojas (2009) reported lower yields with increasing ink removal efficiency (coupled with increasing surfactant addition). Thus, a lower yield generally means a higher quality final product due to better deinking, but with negative economic implications. The yield is therefore a compromise between quality and cost as it is very difficult to achieve both high yield and high ink removal efficiency (Le Ny, Haveri & Pakarinen, 2001). In addition, in a commercial operation other solid contaminants such as plastic, staples, grit *etc.* will also be removed. This is also a yield loss, but has nothing to do with the flotation yield. Flotation deinking plants are designed to optimise both these factors.

Another way of looking at the efficiency of the deinking process is to consider the reject rate. The reject rate is the amount of material rejected by the deinking process relative to the amount of feed, and is really the converse of the yield as discussed above.

3.5.2 Brightness

The brightness of the pulp is defined as the spectral reflectance at 457 nanometers (R_{457}), relative to a magnesium oxide standard. The two main methods are the TAPPI standard method and the ISO standard. The TAPPI method utilises an incident beam at 45^0, and the ISO method uses diffuse incident light. The methods give similar results (Goettsching & Pakarinen, 2000: 296).

The brightness is the standard and widely used method to measure the efficiency of deinking systems, but it has some limitations which need to be taken into account when interpreting brightness data. The brightness of a sheet of recycled paper is the composite effect of the intrinsic brightness of the fibres, the brightness of fillers and the amount and particle size distribution of the ink. The reflectance at 457 nm of ink is low, and fillers and bleached fibres have high brightness. The removal of ink will result in an increase in brightness, but the removal of filler may result in a decrease in brightness, even though ink has been removed as well. In addition, bleaching of a recycled pulp will result in a higher measured brightness, even if no ink has been removed. Thus there is no direct correlation between brightness and ink content, and small ink particles have a lower brightness than an equivalent amount of larger ink particles (Carré, Galland & Julien Saint Amand, 1994; McCool, 1993).

3.5.3 Colour

Reflectance at 457 nm is measured in the blue region of the visible spectrum, and will not describe the optical appearance of a coloured sheet of paper. The response of the human eye to colour has been simulated and quantified in a system called the CIELAB colour system. This system makes use of a set of three colour co-ordinates in a three dimensional colour space to describe a colour. The co-ordinates are L* which denotes the lightness, a* denotes the red-green axis and b* denotes the yellow-blue axis. (Goettsching & Pakarinen, 2000: 296)

In practice the colour is not used to assess the degree of deinking of a recycled pulp, but can however be useful in measuring the effectiveness of bleaching or colour stripping operations.

3.5.4 Dirt content

The human eye cannot detect particles less than 50 microns in diameter (Goettsching & Pakarinen, 2000: 269). Particles greater than this are detected as individual specks. This is commonly referred to as “dirt” or conversely “cleanliness” in the recycling industry. Particles below the visibility limit, whilst not individually visible produce a grey appearance in the pulp.

The ink size population between 10 and 100 microns has little impact on brightness or ERIC (particles too big) or on final paper cleanliness (particles too small). With the help of image analysis techniques, the number of ink specks in this size range can be analysed quantitatively and the efficiency of deinking can be measured more directly (Haynes, 2000; Anderson, 1993; McCool, 1993). However, each image analysis system has a lower size limit below which it can't detect ink particles. This is usually about 2-3 microns (Carré, Galland & Julien Saint Amand, 1994; McCool, 1993). In addition, image analysis as a technique is complex to perform with high repeatability. Carré, Galland & Julien Saint Amand (1994) reported an accuracy of about 25% only, with a large number of measurements being required. Image analysis is thus not routinely used to control process plants.

3.5.5 Effective residual ink concentration (ERIC)

This technique was introduced by Jordan and Popson (1994), and involves the measurement of the reflectance of a sample pad of pulp in the infrared region (950 nanometers) of the spectrum, where only the black printing inks absorb light (Goettsching & Pakarinen, 2000:268). This measurement is thus not sensitive to the influences of bleaching or other coloured materials (Carré, Galland & Julien Saint Amand, 1994). The attenuation of the incident beam gives a direct measure of the amount of printing ink on the surface of the pulp pad. The measurement is expressed as ppm. However, the variability of the method is greater than that of brightness determination. In a comparative study of ink measuring methods, Carré, Galland & Julien Saint Amand (1994) reported a coefficient of variation of 4% for ERIC measurements, compared to less than 2% for brightness. In another study, Carré, Galland, Vernac & Suty (1996) found comparative variability of 5% and 2% respectively.

As for the brightness, the ERIC measurement is a spectrophotometric method, and is thus also dependent on the particle size distribution of the ink (Carré, Galland, Vernac & Suty, 1996). Sub-visible ink particles, less than *ca.* 10 microns in diameter have the greatest effect on the ERIC measurement. On the other hand, ink particles greater than 10 microns and coloured inks have a negligible effect on the measured ERIC. Thus ERIC is a direct measurement of the ink particle size range that also determines brightness (Haynes, 2000).

Moreover, one cannot obtain a direct correlation between ERIC and brightness, as brightness is also influenced by the underlying brightness of the fibres. Thus a deinked newsprint pulp and a deinked office paper pulp might have the same residual ink concentration, but would have vastly different brightness, as the office paper contains no mechanical pulp and is inherently much brighter than newsprint.

Correlations between ERIC and brightness will only exist for a particular grade of recycled paper and bleaching conditions.

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3.5.6 Conclusion

Depending on the requirements of the deinked pulp, the above methods can be used alone or in combination to evaluate the final appearance of the deinked pulp. Therefore, the brightness could be used as an overall measure of deinking efficiency, and ERIC or image analysis could be used to determine more specifically the amount of ink removed. (Haynes, 2000)

CHAPTER 4: REVIEW OF ARTIFICIAL NEURAL NETWORKS

4.1 Introduction

Artificial Neural Networks (ANN's) were inspired by the vast interconnected network structure of nerve cells found in the human brain. ANN's were initially developed in an attempt to understand the structure and functioning of the brain, but have developed to become useful tools in scientific and engineering applications such as pattern recognition and classification. Typical pattern recognition applications include visual image classification, speech recognition and medical diagnosis. Classification applications would include the modelling of complex process systems. (Dayhoff, 1990)

4.2 Structure of biological networks

Traditional computing applications rely on sequential or serial processing. A silicon chip operates in the nanosecond range (Haykin, 1994:1), and a computer CPU can perform millions of operations (adding, subtracting, loading, shifting etc.) per second. These operations are performed one at a time, in sequence. By contrast, a Neural Network is a highly interconnected parallel processing structure. Relatively few operations are performed within this structure, but because of its interconnectedness, it is able to perform complex modelling functions (Dayhoff, 1990: Chapter 1). A schematic of a typical biological nerve cell, also known as a neuron, as found in the human brain is shown in Figure 4.1.

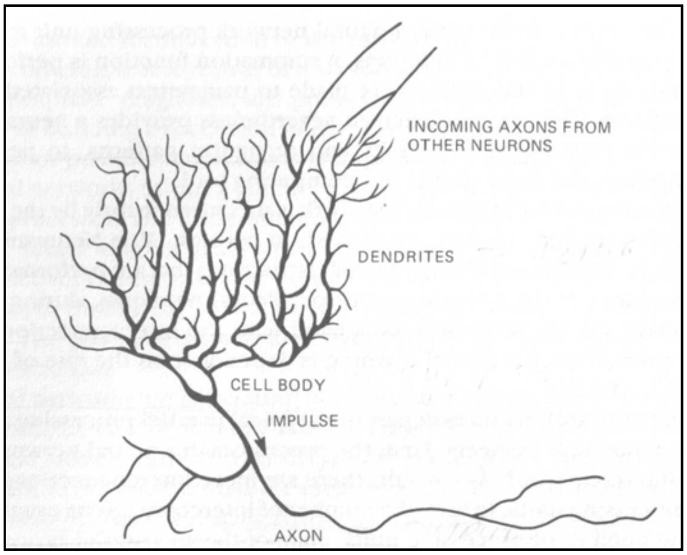

Figure 4.1: Schematic of a biological nerve cell. (Dayhoff 1990: Chapter 1)

A neuron receives a series of inputs from the axons of preceding neurons, through interconnecting fibres called synapses. Based on the inputs received, the neuron will fire an impulse down its own axon to other neurons downstream. Information processing speed in biological neurons is in the millisecond range (Haykin, 1994:1), much slower than that of a silicone junction. However the brain is a network of millions of interconnected neurons, *viz.* a massively interconnected parallel processing structure. It has been estimated that the brain contains 100 billion neurons, and each neuron is connected to ca. 10000 other cells. Thus the human brain has an estimated storage capacity of 10^{14} interconnects and a processing speed of 10^{16} interconnects per second. (Dayhoff, 1990: Chapter 1).

4.3 Structure of artificial neural networks

The structure of artificial neural networks (ANN's) has been modeled on that of the biological systems. Haykin (1994:2) defines an artificial neural network as "…..*a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use. It resembles the brain in two respects:*

1. *Knowledge is acquired by the network through a learning process.*
2. *Interneuron connection strengths known as synaptic weights are used to store the knowledge."*

The structure of a typical processing unit in an ANN, also called an artificial neuron or *peceptron*, (Tarasenko, 1998), is shown in Figure 4.2.

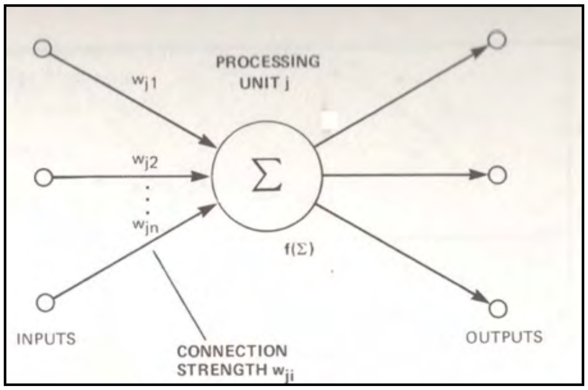

Figure 4.2: A processing unit in an artificial neural network. (Dayhoff 1990: Chapter 1)

Multiple inputs, each with its associated connection strength or weighting (w_{ji}), are fed into the processing unit, or neuron. The neuron sums the weighted inputs and computes an output via a threshold function $f_{(\Sigma)}$. The output is then sent on to the target neurons. These processing units are interconnected to other, similar units in the manner shown in Figure 4.3.

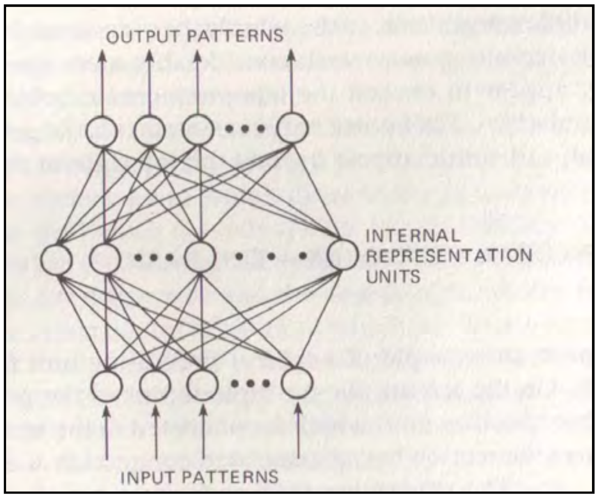

Figure 4.3: Interconnection of artificial processing units. (Dayhoff, 1990: Chapter 1)

Figure 4.3 depicts a network which has three layers. The first layer consists of input units. Data is inputted into the network in the form of an input vector. The inputs can take the form of images, speech patterns, financial data, diagnostic information, sensor outputs or process data. The input layer takes on the values of the input vector. The middle or hidden layer takes on the *features* of the input layer. There is sometimes more than one hidden layer, depending on the complexity of the input pattern. The last layer forms the output of the network. As is evident from the diagram, each input neuron is connected to every middle layer neuron, and every middle layer neuron is connected to every output neuron. Each connection is characterized by a weighting, or connection strength. These weightings are summed and operated on by the threshold function, before being passed on to the next layer. The values of the connection weights are obtained by the process of *training* the network. In *supervised training*, the network is presented with a series of input vectors and associated *target answers.* In response to the inputs and target outputs, various mathematical techniques are applied (see Section 4.4.2) in which the internal parameters are adjusted so that the output of the network matches or closely approximates the target answers. In this way a neural network *learns* by example. In the process of training the network, choices have to be made with respect to the internal size and structure of the network, *viz.* the number of processing units and the nature of their interconnections. The process of learning involves the adjustment and optimization of these internal structures. Various *learning paradigms* have been developed to achieve this, depending on the application: *back error propagation, competitive learning, Kohonen feature maps, and counter propagation.* If no target answers are available, a process of *unsupervised training* occurs, in which the network classifies the inputs into similarity categories. (Tarassenko, 1998: Chapter 2)

4.4 Mathematical basis of neural networks

4.4.1 Early history

An artificial neuron, or perceptron, was defined mathematically, with reference to the schematic in Figure 4.4, by equation (1), as follows:

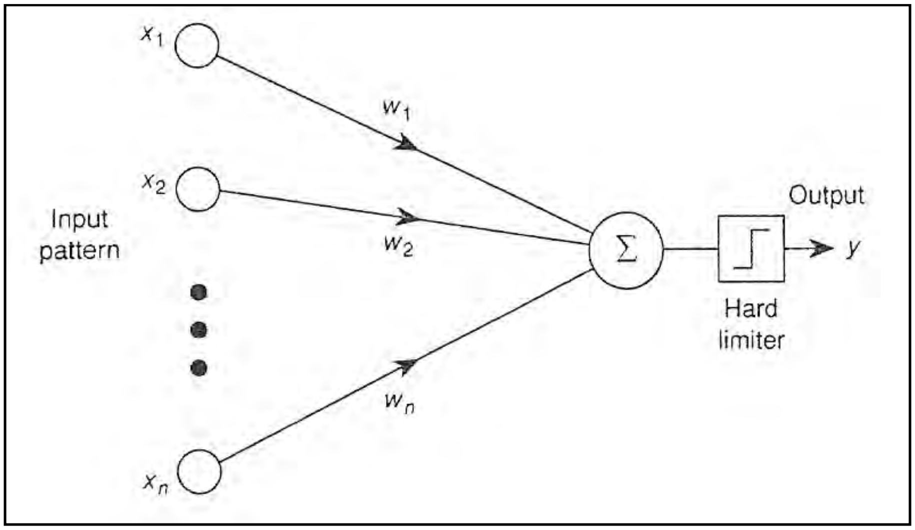

Figure 4.4: Schematic of an artificial neuron. (Tarasenko, 1998:7)

$$Y = f_h(\sum_{i=0}^{n} w_i \ x_i) \tag{1}$$

In the early perceptrons, the *activation* function f_h was a hard-limiting function which gave an output of +1 whenever $\sum w_i x_i$ was greater than some threshold value (usually 0), or -1 whenever the sum was less than or equal to the threshold value. Learning was the process of adjusting the values of w_i until the neuron performed the classification successfully. More complex patterns were solved by using a number of neurons in parallel.

Returning to the analogy with biological systems, the weights w_i would be referred to as synaptic weights. However, the structure of the neurons, as well as the learning processes are gross over-simplifications of the biological systems.

In the early years of study, ANN's were applied to pattern recognition problems. However, the perceptron structures as detailed above were not able to learn the simple task of how to determine the parity of a binary input pattern *viz:* to return a value of +1 for an odd number of 1's and -1 for an even number of 1's. It was eventually found that the problem could be solved by construction of a *multi-layer* perceptron, but no learning algorithms for multi-layer structures were available at the time. It took a few decades and the development of modern computing power to achieve viable learning algorithms. Currently, ANN's find use in applications of pattern classification, regression (prediction of continuous variables from input vectors) and time series prediction. In this work, an ANN will be used in the role of regression. (Tarassenko, 1998: Chapter 2)

4.4.2 Multi-layer networks and error back-propagation

A more modern model of a neuron is shown in Figure 4.5.

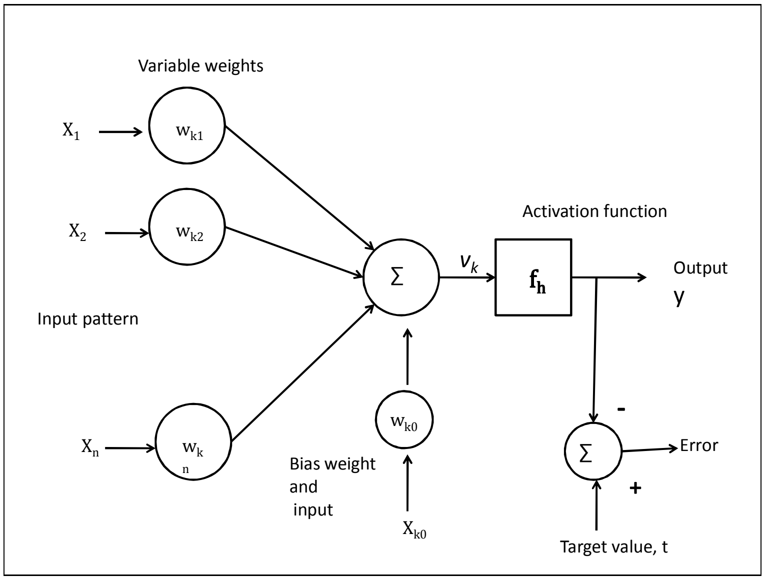

Figure 4.5: Nonlinear model of a neuron.

In this case an externally applied *bias* or *threshold*, w_0 has been added. The bias has the effect of increasing or decreasing the input to the activation function (Tarassenko, 1998; Haykin, 1994). The equation representing the k_{th} neuron now becomes:

$$Y = f_h(\sum_{i=0}^{n} w_i \ x_i + w_0) \tag{2}$$

where x_0 = +1 or -1, and here w_0 is the bias weight or offset.

The early activation functions were step or threshold functions, of the form:

$$f_h = \begin{Bmatrix} 1, v \geq 0 \\ 0, v \leq 0 \end{Bmatrix} \tag{3}$$

This was known as the McCulloch-Pitts model (Hajek, 2008).

The activation function can also be a piecewise linear function (equation 4):

$$f_h = \begin{Bmatrix} 1, & v \geq 0.5 \\ v + 0.5, & -0.5 < v \leq 0.5 \\ 0, & v \leq -0.5 \end{Bmatrix} \tag{4}$$

However, modern multi-layer neural networks make use of sigmoid (or logistic) activation functions (equation (5)) or hyperbolic tangent functions (equation 6) of the general form (Hajek, 2008):

$$f_h = \frac{1}{1+\exp(-av)} \tag{5}$$

or

$$f_h = \tanh(\frac{v}{2}) = \frac{1-\exp(-v)}{1+\exp(-v)} \tag{6}$$

The sigmoid function is the most commonly used function, and can have various slopes (*a*). It is also asymptotic and can thus limit the output of the neuron. Also, the sigmoid function is differentiable, which is important when it comes to the application of minimization of squared error criteria as the basis for the multi-layer learning algorithms, as discussed below (Haykin, 1994:12).

A sigmoid function (g) is depicted in Figure 4.6.

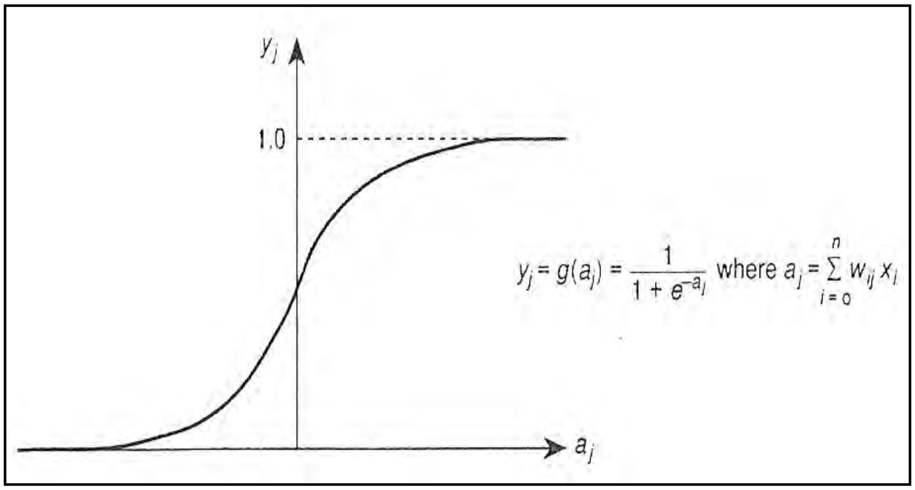

Figure 4.6: The sigmoid function. (Tarassenko, 1998:14)

With reference to figure 4.5, the output of a neuron can be compared to a target value, and an error function can be defined as some difference between the output and actual (target) value. In practice, the square of the error is more convenient, to eliminate negative values. Thus, a sum-of-squares error function can be defined as follows:

$$E = 1/2 \sum_{p=1}^{P} (y^{p} - t^{p})^2 \qquad (3)$$

where y^{p} is the output of a multi-layer network for an input pattern p and t^{p} is the corresponding target value (Tarassenko, 1998:13)

The error function E is minimized by gradient descent by differentiating it with respect to every weight w_i in the network (Tarassenko 1998: Chapter 2). For an individual weight w_i, the weight update (or change in weight) is thus given by:

$$\Delta w_i = -\eta \frac{\partial E}{\partial w_i} \qquad (4)$$

In order to achieve this differentiation, a continuous differentiable function such as a sigmoid function as shown in Figure 4.6 must be used.

Specifically:

$$y_i = g(a_j) = \frac{1}{1+e^{a_j}} \tag{5}$$

where $a_j = \sum_{i=1}^{n} w_{ij} x_i$

Let us now consider the case of a two-layer perceptron, structure as depicted in Figure 4.7.

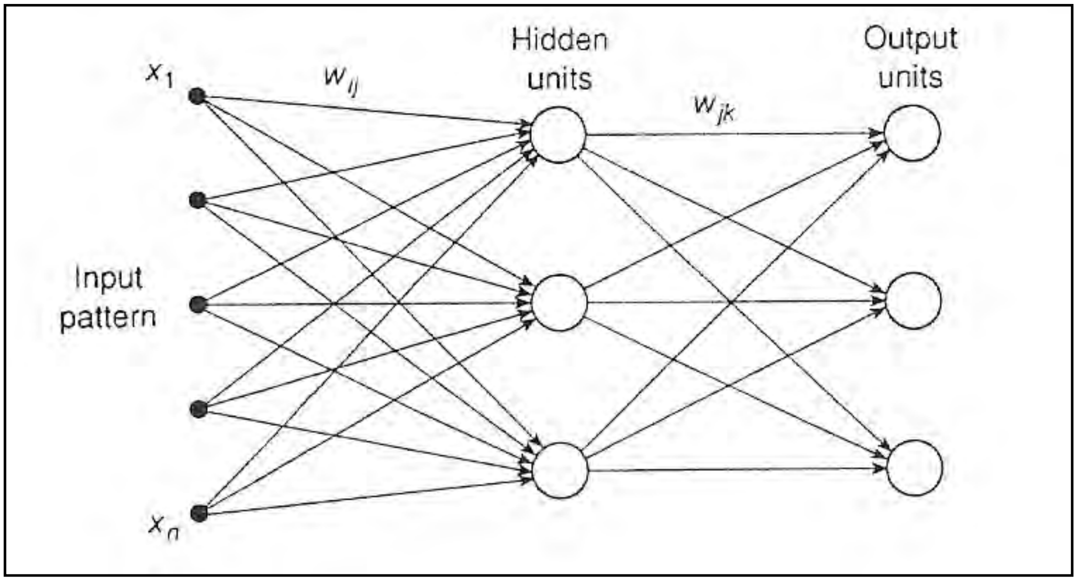

Figure 4.7: A two-layer perceptron structure. (Tarassenko, 1998:15)

The "two" refers to the number of layers of weights, not the number of layers of units. In addition, the terminology of I = number of input parameters (five in this example), J = number of hidden units (three) and K = number of output units (three). For this K class problem, the error function now becomes:

$$E = \frac{1}{2}\sum_{p=1}^{P}\sum_{k=1}^{K}\left(y_k^p - t_k^p\right)^2 = \frac{1}{2}\sum_{p=1}^{P}\sum_{k=1}^{K}\left(g\sum_j w_{jk} y_j^p - t_k^p\right)^2 \tag{6}$$

Which expands to:

$$E = \frac{1}{2}\sum_p \sum_k \left(g \sum_j w_{jk}\, g\left(\sum_i w_{ij} x_i^p\right) - t_k^p\right)^2 \tag{7}$$

In this form E can now be differentiated with respect to each weight to calculate the gradient of the error function. The *error back propagation algorithm* thus arises and is used to update the weights in a multi-layer network. The update equations have been derived (Tarassenko, 1998:15) thus:

For the input - to - hidden layer:

$$\varDelta\, w_{ij} \;=\; -\eta \frac{\partial E}{\partial w_{ij}} \;=\; -\eta \delta_j y_i$$

where $$\delta_j = \frac{\partial E}{\partial a_j} = \textstyle\sum_k \delta_k\, w_{jk}\, y_j(1 - y_j), \tag{8}$$

And for the hidden-to-output layer:

$$\varDelta\, w_{jk} \;=\; -\eta \frac{\partial E}{\partial w_{jk}} \;=\; -\eta \delta_k y_j$$

where $$\delta_k = \frac{\partial E}{\partial a_k} = (y_k - t_k) y_k (1 - y_k) \tag{9}$$

The error back propagation algorithm derives its name from the fact the errors (δ_k's *)* of the output layer need to be calculated first, as they are required in the calculation on the input layer updates.

It has been shown (Tarassenko 1998:16, quoting Cybenko, G. 1989. Approximation by superpositions of a sigmoidal function. Math. Control, Signals & Systems. **2**: 304-314., and Hornik, K., Stinchcombe, M. and White, H. 1989. Multilayer feedforward networks are universal approximators. Neural Networks. **2**: 359-366) that a two-layer multilayer perceptron with sigmoid transfer functions is able to approximate any function, given the correct selection of the network architecture, in particular the number of hidden units. It is even possible to *over-fit a* function to available data, as discussed in Section 4.6.4.5.

4.4.3 Network training

The training process consists of finding the optimum number of hidden units, *j,* with the associated first-layer weights w_{ij} and second-layer weights w_{jk}. Network training normally occurs in three distinct steps, each requiring its own data. (Tarassenko, 1998:17)

Step 1: Training: present the network with input-output data, which is used to determine w_{ij} and w_{jk}.

Step 2 – Validation: the validation set is presented to the network not to further adjust w_{ij} or w_{jk} but to determine the error of the output. Training is stopped when the error is at a minimum, and the weights are fixed.

Step 3 – Testing: the generalisation of the network is assessed by applying a test set.

The three steps mentioned above refer to a process of *supervised learning.* In supervised learning, a target/output value or *answer* is available for each input vector. In many real world problems, output values are not readily available. Nevertheless it is still possible to train a neural network using clustering algorithms, discussed below.

Training methodology is discussed more fully in Section 4.6.

4.4.4 Other techniques

A number of other mathematical techniques have found application in neural networks (Tarassenko, 1998: Chapter 2):

- Cluster analysis and the use of clustering algorithms as a means of grouping input patterns with similar characteristics.
- A clustering technique called a "Kohonen's feature map" is a technique to represent complex multi-dimensional data in a 2-dimensional representation.
- Radial Basis Function (RBF) networks make use of clustered input vectors and non-normalised Gaussian functions as activation functions. RBF networks offer some simplifications in the training process.
- Auto-associative neural networks have the same dimensionality in inputs and outputs. *viz.* the target data is the same as the input data. These are typically used in data compression algorithms. A two-layer neural network trained in this manner essentially performs linear principal component analysis.
- Recurrent networks: All of the abovementioned networks are exclusively feedforward networks. In Recurrent Networks, feedforward as well as feedback connections are used. Such networks are very complex and dynamic in nature, and often do not settle down to a stable state. Such networks are used mainly in time series prediction applications.

The abovementioned structures were not required in this work, and are thus not discussed further.

4.5 Application and feasibility of neural networks

4.5.1 Introduction

Neural Networks have several key attributes, which make them effective candidates to model a complex system such as a deinking flotation process (Tarassenko, 1998; Haykin, 1994:4):

- ANN's can learn from "experience" and interpolate responses from data not previously encountered. This is also known as the ability to *generalize* data. They have the capability to adapt to changing conditions by simply retraining.
- If enough data is available ANN's can produce solutions in a comparatively short space of time, when compared to traditional methods. However, some experience of the area of application is necessary in order to select the optimal network design.
- Although a considerable amount of computational power is required to train a ANN, once it has been trained, it can act on input data rapidly to produce an output.
- ANN's are particularly suitable for dealing with complex, non-linear systems, as typically found in real-world problems.
- ANN's are robust, and can tolerate noise, distortions and partially incorrect input data (Rudd, 1991).

Tarassenko (1998: 50) lists three criteria which determine if data is suitable for representation by neural networks:

<u>Criterion 1: "The solution to the problem cannot be explicitly described by an algorithm or set of equations or a set of rules".</u>

Attempts have been made to develop first-principle hydrodynamic models, reviewed in Chapter 2 in this work. However, these models are complex and are usually limited to only the physical processes in the flotation stage of the deinking process. The complexity of these models is such that they will find limited application in the everyday operational environment of a deinking plant.

Thus from a practical point of view, the development of a neural network model is more feasible.

Criterion 2: "There is evidence that input-output mapping exists such that $y = f(x)$, where the form of f is unknown".

Many studies have been reported in the literature (Chapters 2 & 3) on the effects of the parameters of the deinking process on the outputs (ink removal and yield). The relationships between inputs and output appear in the majority of cases to be curvilinear in nature. The limitation of these studies is that, as for most laboratory type investigations, one variable is changed while all other are kept constant. This approach unfortunately does not provide an overall response surface to all the variables. As a result, many studies have shown conflicting results, as discussed in Chapter 3. It is expected that by identifying viable control parameters and modeling them with a neural network, a complete picture can be obtained of the behavior of a deinking system.

Criterion 3: There is a large amount of data available to train the network.

In this study, the data required to develop a practical neural network was generated in the laboratory. In this way it was possible to gather many data points over a wide range of conditions. On the other hand, data gathered directly from plant processes would have been limited in range, and hence the predictability of the ANN models would be limited.

In recent years, a large number of successful neural network applications in fields as diverse as fault diagnosis and condition monitoring, financial forecasting, signal and image analysis, pattern detection and process control have been reported (Tarassenko, 1998:52). In addition, a number of more specific applications in the pulp and paper industry are discussed in Section 4.7.

4.5.2 Hardware and software requirement

Many of the earlier challenges with neural network processing have now been overcome with the development of modern computing power. A commercial package MATLAB with a neural network toolbox was used in this work.

4.5.3 Data collection and preparation (Tarassenko, 1998: Chapter 6)

Neural networks are very much driven by the data that is inputted into them. Good quality data in sufficient quantity is essential. One of the advantages of neural networks is that they allow the fusion of data, *viz.* different types of data (quantitative and qualitative or descriptive) can be inputted or outputted together.

It is not necessary to know the nature of the relationship between input and output data, but as discussed in Section 4.5.1, such a relationship must exist.

4.5.4 Quality of data required

As a first approximation, the training of a neural network can be considered similar to that of fitting a polynomial curve to a set of points. Neural networks can only generalize reliably by interpolation. Any extrapolation required will be guesswork, and consequently unreliable. Thus, the network must be trained with the full range of process conditions likely to be encountered to avoid having to extrapolate. Also, the data sets used for training should contain examples of both normal and abnormal operating conditions.

4.5.5 Quantity of data required

By further analogy with polynomials, the number of input vectors (*viz. a* set of input values) should be of the same magnitude as the number of unknowns in the network, which corresponds to the number of weights w_{ij} and w_{jk}. If I = number of inputs, J = the number of hidden units and K = the number of outputs or output classes, then the number of weights W for a two-layer perceptron is given by:

$$P = W = (I + 1)J + (J + 1)K \tag{10}$$

W thus corresponds to the minimum number of input vectors P required.

A term called *network capacity*, defined as

$$\frac{W}{K} \tag{11}$$

has been suggested, with the recommendation that the number of input vectors P be considerably more than the network capacity (Tarassenko, 1998:70). *viz*:

$$P \gg \frac{W}{K} \tag{12}$$

An alternative suggestion has been the use of an “accuracy parameter”, ε, defined as the proportion of input vectors that are incorrectly classified, be taken into account (Tarassenko, 1998:70). Thus $\varepsilon = 0.1$ for a 90% data accuracy and

$$P = \frac{W}{\varepsilon} \tag{13}$$

Taking the above arguments into account, the ideal number of input vectors would lie between W and 10W.

It is obvious that the network architecture (*viz.* J in equation above) plays a large role in determining P. As a rough guide (Tarassenko, 1998:70):

$$J = \sqrt{IK} \tag{14}$$

I and K are determined by the physical system to be modeled, J can be calculated (equation (14)), and hence the number of data vectors required can be estimated from equation (10).

4.6 Design, training and testing (Tarassenko, 1998: Chapter 7)

4.6.1 Introduction

The process of designing a neural network is an iterative one. Trial and error and experimentation will be required to obtain a network with good generalization properties (Hajek, 2010). It might be necessary to apply a blend of different techniques to achieve an overall model that is practical (Tarassenko, 1998: 77).

When designing a neural network, a thorough knowledge of the subject domain is necessary in order to achieve a workable model.

4.6.2 Pre-processing of data

Depending on the nature of the input data, a certain amount of pre-processing of the data might be required. In particular, reducing the dimensionality of the data is usually essential, to limit the size of the network and consequently the required amount of training data. Typical techniques that could be applied here are Principle Component Analysis, signal processing by Fast Fourier Transforms or encoding of non-numerical data into numerical form. In this work, a process of screening experimental design was used to eliminate control variables (*viz.* adjustable operating conditions) that have little influence on the final outputs. It emerged that only about seven to ten control variables would be needed to produce a good model.

Continuous input variables normally can be inputted as they stand, except perhaps for the normalization of data which have vastly differing dynamic ranges (Tarassenko 1998:Chapter 7). The linear normalization commonly applied is the zero-mean unit-variance transformation, equation (15):

$$x_i^* = \frac{x_i - \mu_i}{\sigma_i} \tag{15}$$

where μ_i is the mean and σ_i is the standard deviation.

In this work, all of the input variables are continuous, with magnitude ranging from 0 up to 1000.

4.6.3 Selecting the type of neural network

In this work a supervised training methodology was used. This is because experimental outputs are available for each set of inputs. Furthermore, a multi-layer perceptron (MLP) architecture has been applied, as it has been demonstrated that a two-layer MLP can approximate any function (Tarassenko, 1998:89). Radial basis function (RBF) networks have similar, to slightly inferior generalisation properties and lower training times (Tarassenko, 1998:88). Training times were not a limitation in this work.

4.6.4 Training process

The generalized procedure for the training of a MLP involves the following steps:

4.6.4.1 Partitioning

As discussed in Section 4.4.3 above, before training the available data is randomly partitioned (equally if possible) into training, validation and test data sets.

4.6.4.2 Training

Initialising

In this process, the weights must be initialized by random setting to values, typically between -0.01 and +0.01. If the initialization values are too large, the sigmoid activation functions will be in the *saturated* zone, and incremental changes will be small, resulting in very low learning rates. In extreme cases, neurons could get *stuck* at values close to 0 or 1.0

Training

Thereafter the network is repeatedly presented with training vectors, in random order. The output is calculated, compared to the target and the error, E, is computed. The back-propagation algorithm is then employed to calculate the weight updates (Section 4.4.2). Additional parameters, known as the *learning rate* (η) and the *momentum* (α) have been introduced to speed up the learning processes. Equations (8) and (9) now become

$$\Delta w_{jk} = w_{jk}(t+1) - w_{jk}(t) = -\eta \delta_k y_i + \alpha \left(w_{jk}(t) - w_{jk}(t-1) \right) \quad (16)$$

and

$$\Delta w_{ik} = w_{ik}(t+1) - w_{ik}(t) = -\eta\delta_j y_i + \alpha\left(w_{ij}(t) - w_{ij}(t-1)\right) \quad (17)$$

where δ, y and w are as defined in Section 4.4.2.

η is typically between 0.01 and 0.1, and α lies between 0.5 and 0.99. Learning with momentum prevents the learning process from terminating in small local minima.

The data vectors can be applied to the network in *batch* or *sequential* fashion. In batch learning the weight updates are averaged across all the training patterns, whereas in sequential learning the weights are updated after each pattern has been presented. Sequential learning is preferred in practice (Tarassenko, 1998: 91).

Stopping

The network is trained subject to a stopping criterion. The network is repeatedly presented with training vectors until the classification error (mean square error (MSE) of the validation set, e_{val}) has reached a minimum and starts to increase again (Figure 4.8). At this minimum point, the $(e_{val})_{min}$ and the corresponding set of weights are saved and taken to be the best solution. It is typical for the training error (e_{tr}) to continue decreasing beyond this optimum point. Figure 4.9 demonstrates how the training error (e_{tr}) continues to decrease as the network more closely approximates the data points (Figure 4.9b), whilst the validation error (e_{val}) increases again as generalisation is compromised (Figure 4.9a).

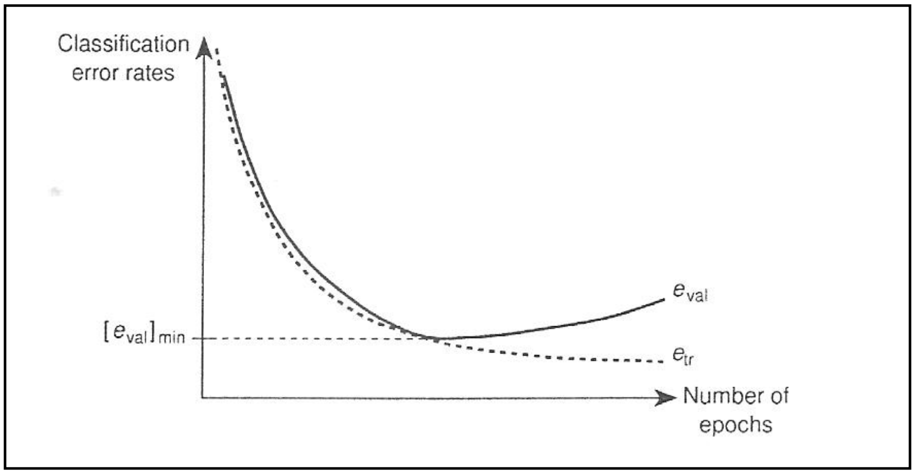

Figure 4.8: Comparison of training error and validation error during training.

(Tarassenko, 1998:93)

4.6.4.3 Selecting the optimum network

During the training process, a number of different network structures (different I-J-K configurations) are presented with the training data, and $(e_{val})_{min}$ is calculated for each structure. On the basis of the lowest MSE's, the *m* best network structures are selected. These *m* structures are then presented with the *test* data sets, and the best network is selected (*viz.* the network that produces the lowest $(e_{val})_{min}$) on the basis of the test set. The test data set must not be part of the training data, and should be separate from the training and validation sets. The test set is nevertheless still part of the original data set, and might still not represent the real world situation.

4.6.4.4 Testing the network

Previously unseen data from the real world are presented to the network, to test the generalization performance of the network.

4.6.4.5 Over training

Common problems that can arise in the process include stuck units (refer to Section 4.6.3.2), poor generalization, insufficient or unbalanced data, over-fitting, over-training and extrapolation. The problem of *over fitting* or *poor generalisation* is illustrated in Figure 4.9. Figure 4.9a represents a curve that generalizes the data well, *viz.* the underlying trends are well captured. Figure 4.9b represents a network that is over fitted. The network has memorized the data, but not the underlying behaviour. This is usually caused by having too many hidden neurons.

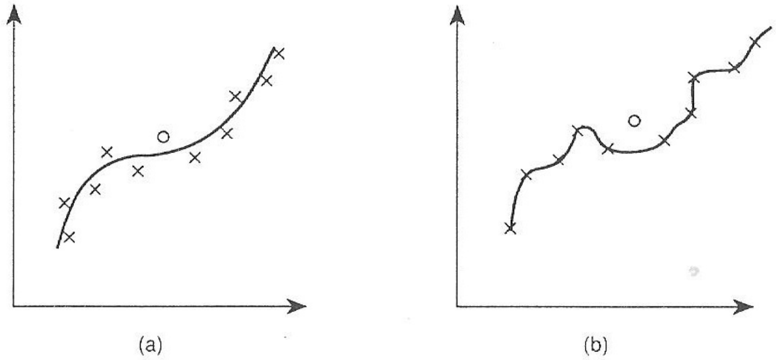

Figure 4.9: (a) Good generalisation. (b) Over fitted data – poor generalisation (x = training data, o = test point) (Tarassenko, 1998:17)

4.7 Review of applications of neural networks in flotation and in the paper industry

4.7.1 Introduction

The effects of various separation unit operations, process chemicals and waste types have been extensively studied by many researchers and reviewed in Chapters 2 and 3. These findings have generally been well applied in the industry. Our understanding of the fundamental physical and chemical processes underlying the deinking processes is growing. But, due to the great variability of the raw material as well as the complexity of the physical processes which occur at the micro level, processing problems and process instability remain as challenges.

The large number of flotation models that have been developed highlights the uncertainty around what exactly happens in a flotation cell (Labidi *et al.,* 2007). Attempts have been made (Beneventi *et al*., 2006; Bloom, 2006; Heindel, 1999; Julian Saint Amand, 1999; Bloom & Heindel, 1997) to model these processes from first principles, in terms of the collision probabilities of ink particles and bubbles. These models are however highly complex and somewhat removed from the daily experience of those who operate deinking plants. Such challenges have also been expressed by Hodouin *et al*. (2001) in the related field of mineral ore processing.

As a result of the abovementioned difficulties, attempts have been made to use Artificial Intelligence based systems to model and control modern flotation plants, in both the fields of mineral flotation, and to a much lesser extent in deinking flotation. The following techniques have been successfully used singly or in combination in trying to address the problems of process control in highly complex and ill-defined systems.

4.7.2 The use of neural networks in flotation processes

In a review article, Hodouin *et al.* (2002) outlines the state of the art and challenges in the control of mineral flotation plants. There are many similarities to the problems faced in flotation deinking plants, *viz.* complexity of raw material, measurement difficulties, complex physical processes and a small number of outputs measuring the process, but a large number of inputs, many of which interact. These conditions make it difficult to develop mathematical models.

Singh *et al.* (2003) in their description of the control difficulties experienced in mineral flotation plants, describe a very similar picture to that experienced in deinking flotation plants: difficult control, interactive circuits, unstable plants, and changing feed conditions. They say that an ideal is to have an algorithm or strategy to find new optimum conditions, rather than an “unguided hunt” for the new conditions. This is essentially the objective of the current work: to develop an algorithm which will guide operations management in the appropriate strategies to adapt to changing raw material conditions.

An ANN model of a copper/lead flotation plant was developed by Forouzi & Meech (1999), and used to predict the assays of the concentrate streams. The model was incorporated into the process control system, and was adaptive in nature, *viz.* it was retrained whenever the prediction efficiency decreased to a pre-determined level.

Cubillos & Lima (1997 & 1998) used a combination of a physical model (mass, energy, momentum) and an ANN model. The ANN was used to predict certain process parameters, which then become inputs into the physical model.

In another hybrid approach, Gupta *et al.* (1999) developed an ANN to predict flotation rate constants from operating variables, and thereafter used these constants in a first principles model to predict the performance of a phosphate flotation column.

Amongst the earliest fields of application of neural networks was in the field of pattern recognition and image processing. This was also applied into the flotation industry. Rughooputh & Rughooputh (2002) describe the application of ANN’s to the complex task of analyzing the visual attributes of the froth in a flotation cell to make deductions about the state of flotation process. The system that was developed was reported to be highly reliable.

4.7.3 The use of neural networks in the pulp and paper industry

Labidi *et. al.* (2007) studied the effects of flotation consistency, airflow rate and agitation speed, at various flotation times, on the rate of ink removal. Ink removal was measured by the increase in brightness and the change in ERIC. Kinetically, ink removal was considered as a first order kinetic process defined by

$$\log_e\left(\frac{B_{BF}-B_D}{B_{BF}-B_F}\right) = k_{brightness}\, t \qquad (18)$$

where B_{BF} = brightness of unprinted paper, B_D = disintegration brightness, and B_F = floated brightness of printed paper. Similar expressions were developed for ERIC. An ANN was developed which effectively modelled the brightness and ERIC out of the flotation cell. The outputs of the ANN correlated closely with the experimental results. They found that ink removal was enhanced by higher consistency and airflow rates.

In a review of the applications of neural networks in the pulp and paper industry, Laperriere & Wasik (2001) found that ANN's have compared well with deterministic models, in particular the modelling of a Kraft digester. In another study, Rughooputh & Rughooputh (2002) compared a deterministic model and a ANN model to simulate the pulping process in a Kraft digester. They were found to produce similar results.

Rudd (1991) relates the use of an ANN to model and control a brownstock washer system. It was found that the percentage errors achieved by the ANN were superior to those achieved by traditional regression techniques.

Figueiredo *et al.* (2008) reported that the output of a causticising process was successfully predicted by an ANN.

In addition, ANN models have also been successful in the more complex field of predicting functional pulp or paper properties and diagnosing web breaks. Edwards *et al.* (1999) described the use of an ANN to classify and predict paper curl. Curl is an important quality characteristic, which can only be measured off-line, after the paper has been manufactured. It was found that the ANN was successful in the classification tasks to a level of confidence of 68%.

In a practical plant study, Smith & Broeren (1996) reported on the use of an ANN to analyse and optimise a newsprint deinking facility, which recycled a mixture of old newsprint and magazines. Time-stamped plant operating data was acquired and fed into an ANN. An input vector of 66 variables was inputted, and the influence of a large number of process variables was analysed and ranked in order of influence. As a result, large cost saving were achieved in terms of reduced pulper chemical additions.

ANN's have found extensive application in the field of image analysis. Verikas *et al.* (2000) used an ANN, together with Fuzzy Logic to analyse the colour of dirt specs in a sheet of recycled paper.

As examples from completely different fields, Zhang & Stanley (1999) reported on the use of an ANN to model a water treatment process. On-line parameters were used to train and test the model, which was incorporated into a real-time process control scheme. Schlang *et al.* (2001) reviewed the extensive use of hybrid ANN models for the control of rolling strip mills in the steel industry.

4.7.4 Neural networks in combination with other techniques

Neural networks can be used in combination with other Artificial Intelligence techniques. In a review article, Huang & Zhang (1995) reviewed the synthesis of ANN and expert systems and their applications in manufacturing. They maintain that the strengths of the two techniques have been found to complement each other in the solving of complex manufacturing problems.

ANN's have also been used together with Fuzzy Logic systems in a number of applications. Verikas *et al.* (2000) used an ANN, together with Fuzzy Logic to analyse the colour of dirt specs in a sheet of recycled paper. Bergh & Yianatos (2002), in their review article state that Fuzzy Logic and ANN's have proven to be powerful components in expert supervisory systems.

Multivariate data processing has been used by various workers to analyse the complexities of flotation processes. Eriksson *et al.* (2001) and Wold *et al.* (2001) report on the use of multivariate regression in the prediction of inter alia the COD load of an effluent resulting from the deinking of recycled paper. These applications could well have been tackled with neural networks, with similar results.

4.8 Conclusions

The successful use of artificial neural networks in the field of flotation monitoring and control has been demonstrated. It is the intention of this work to model the effect of variable raw material conditions on the outcome of a laboratory-based deinking process, with a view to developing a predictive model, which could help plant management to cope with unexpected raw material changes.

CHAPTER 5: METHODOLOGY

5.1 Introduction – overview of methodology

The objective of this research was to model the combined processes of pulping, deinking and washing with respect to raw material changes and process parameters. The output parameters that were modelled are ISO brightness, ERIC, and yield. The proposed methodology was as follows:

1) Firstly, establish general deinking conditions in the South African tissue and newsprint deinking industry. This was done through field surveys of the local industry and assessment of the current and future requirements for deinking of different quality materials.

2) Secondly, to model the industrial processes in the laboratory. Experimental work was done in the laboratory to establish the best process control parameters. A distinction was made between *control* parameters and *optimisation* parameters. Optimisation parameters are parameters which, whilst important for the overall efficiency of the process, are not suitable to control short term variations. On the other hand, control parameters are those which are suitable to change and thus to control the short term variations in the process. Once the control parameters were established, experimental work was performed with a wide blend of different recycled paper raw materials and control parameters to generate data to train a neural network.

3) Model the laboratory processes mathematically, using neural networks. The pulping, flotation and washing processes as well as the effects of a range of variables on the efficiency of deinking were modeled. Neural networks were selected as the potential best method due to the number of potential variables and non-linearities which could be encountered.

4) Test the model on an industrial scale. This would involve inputting plant data into the mathematical model to determine how well the model generalizes and predicts outputs on a plant scale.

5) The model's purpose would be to enable process operators to adapt to changing recycled paper raw material conditions using predictive model-based control methods.

5.2 Review of deinking conditions in newsprint and tissue manufacture

The three main companies involved in deinking operations in South Africa are Mondi Shanduka Newsprint - Merebank mill, Nampak Tissue, which has deinking mills in Belville - Cape Town and Klipriver - Johannesburg, and Kimberly Clark - Enstra mill. Two mills, namely Mondi Shanduka Merebank mill and Nampak Klipriver mill were the initial participants in this study. It is from these two mills that the ranges for the modelling parameters were determined. As the study progressed, the Nampak Belville mill was included in the model testing exercise. Executives and process personnel from both companies were interviewed, and readily provided information. Table 5.1 below summarizes the range of process conditions of paper recycling in SA.

Table 5.1: Paper Recycling in South Africa.

PROCESS	**PAPER GRADE USED** (refer to Section 7.2.1 for definitions)	**PROCESS CONDITIONS**
Newsprint deinking	ONP, SBM	Alkaline slushing in presence of H_2O_2, deinking flotation with displector system, washing, dispersion, bleaching
Tissue manufacture	HL1, HL2, mixed office paper	Neutral slushing, deinking without chemicals, dispersion, bleaching
Linerboard and carton board manufacture	K3, K4	Slushing, no deinking, cleaning (hydrocyclones), screening, dispersion

As can be seen in Table 5.1, deinking is only carried out by the newsprint and tissue manufacturers. The largest volume of recycled paper is processed by the manufacturers of packaging papers and boards (Table 7.2), but no deinking is carried out in these processes. It can also be seen from Table 5.1 that quite different process regimes apply to the different recycled paper grades.

5.2.1 Grades of recycled paper

Table 5.2 depicts the quantities of the various grades of paper recovered in South Africa.

Table 5.2: Recovery of recycled paper in South Africa. (Pamsa, 2007).

DESCRIPTION	**RECYCLED PAPER GRADE DESIGNATION** (refer to Table 7.3 for definitions)	**2007 CONSUMPTION (tpa)**
Newspapers	FN, SN	105 922
Magazines	SBM or OMG	40 617
Corrugated & kraft papers	K1, K2, K3, K4	512 705
Office, graphic papers	HL1, HL2, Supermix	168 132
Other, mixed papers	CMW	119 001

Recycled paper is broadly classified in pre-consumer and post-consumer waste. Pre-consumer waste is paper that has been processed but has not fulfilled its function, for example, an over-run of issues of a daily newspaper. The paper has been printed but the newspapers have not been sold. They are returned to the recycler as pre-consumer waste. On the other hand, if the newspaper had been purchased, read and discarded, it would have to be recovered from the domestic waste stream. This is termed post-consumer waste.

Pre-consumer waste is relatively clean and uniform in its composition. Post-consumer waste has a very much more varied composition, and extensive sorting is invariably required. It is thus more costly to collect and commands a lower price in the market.

The designations and the respective specifications for recycled paper collected in South Africa, as detailed in Table 5.3, are relevant to this work:

Table 5.3: Overview of recovered paper specifications. (Harper, 2009, Steyn, 2009, South African Standard Grade Definitions for Recovered Paper, 2009)

DESIGNATION	SPECIFICATION	COMMENTS
SBM or OMG “sorted books & magazines”	Books and magazines, all types including ledgers, invoice books etc., free of covers and other contaminants.	Pre-consumer waste, includes light weight coated (LWC), supercalendered (SC), wood-free coated paper, advertising inserts. Contains 5-10% mechanical grades.
FN “Flat News”	Newspaper – over issues and once-read newspapers.	Pre-consumer newsprint and over-issues. Newspapers, including advertisement inserts. No flexographic prints.
SN “Special News”	Post-consumer, kerbside collection of newsprint	Newspaper includes ca. 10% magazines, 5% letter, no packaging or brown paper.
HL1 “Heavy Letter 1”	White heavy letters such as woodfree letter papers, office records, with a maximum[1] of mechanical papers and written-on papers, free of covers, bindings etc.	White base papers – includes office papers, carbonless copy paper, ledger, white boards, some colour printing.
HL2 “Heavy Letter 2”	Pastel coloured heavy letters such as white or coloured writing papers, office records, containing a maximum of mechanical or written-on papers, free of covers, etc.	As for HL1 but contains coloured and pastel base papers. No heavily printed or coloured stock.
SUPERMIX	A 50/50 blend of HL1 And HL2	
CMW “common mixed waste”	Any mixture of acceptable paper for pulping, free of extraneous matter.	Various grades of paper and board.

Note 1: Specified by individual customers, usually ca. 10%.

Old newsprint (ONP) is a collective designation for Flat News and Special News.

There are many more grades of paper collected in South Africa, but they are not relevant to this study, so will not be discussed further.

5.2.2 Newsprint deinking conditions

5.2.2.1 Process configuration

Figure 5.1 gives a self explanatory overview of the process flow of the newsprint deinking facility. The plant is a common single-loop flotation process with Voith EcoCell's ®

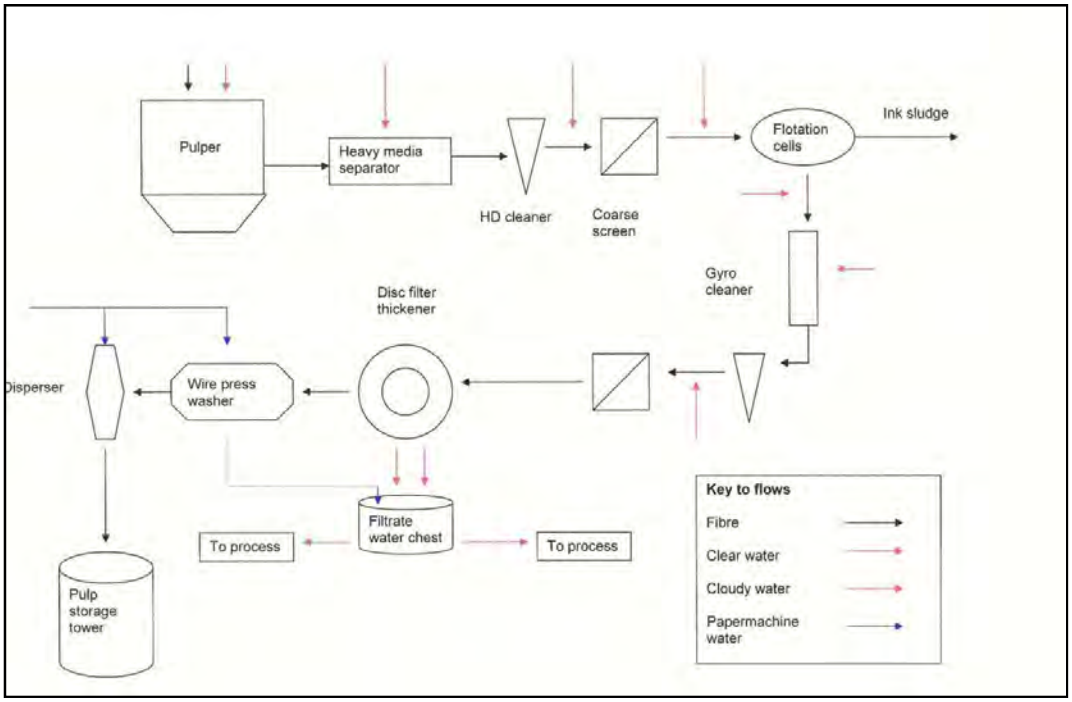

Figure 5.1: Process flow diagram – single-loop newsprint deinking plant. (Refer to Figure 9.4 for greater clarity)

5.2.2.2 Raw materials

The mill uses a mixture of ONP and SBM in the approximate bale ratio of 75:25. Depending on availability, the ratio of Flat News and Special News varies to make up the 75%. The SBM is essential to achieve the brightness targets, so its use is optimized depending on availability and cost constraints. The paper is stored under cover and is less than six months old.

5.2.2.3 Process conditions

The process conditions pertaining to pulping, flotation and washing are presented in Table 5.4. The parameters that are used to monitor and control the process are also detailed:

Table 5.4: Process conditions and control of a newsprint deinking plant.

PROCESS	STANDARD CONDITIONS	MONITORING & CONTROL
Pulping	Consistency 14-20%	Monitored
	pH 9-10	Controlled to 9.5-9.7
	Pulping time 13.3 mins.	Kept constant
	Temperature 50°C	Monitored
	H_2O_2 , 0.48-0.52 %[1]	A small residual is maintained
	NaOH 0.55-0.6 %	Pulper brightness monitored >40, Pulper ERIC 300-800
	Chelant – nil	
	Sodium silicate 0.38-0.4 %	
	Surfactant 0.085-0.1%	
Flotation	Temperature 42˚C	Control weir level in flotation cell
	Consistency 1.2-1.4%	Monitor- brightness out >50
	pH 7.5-8.0	Monitor- ERIC out 200-400
	Calcium hardness ca. 240ppm $CaCO_3$	Monitored – Calcium collector not used. An average of ca. 210 ppm.
Washing-disc filter	Consistency in: 0.9%, out:4.7%	Monitored
Washing – wash press	Consistency in: 4.7%, out:28%	Consistency monitored. Brightness out >50 ERIC out <250
Dispersion		Brightness out 57-58 ERIC out <250
Final after bleaching	Brightness >58 ERIC 150-300 pH 5.5-6.5	Exit specification

Note 1: Addition rates are quoted as % active material per dry mass of paper.

5.2.2.4 Process control philosophy

If a process upset or out-of-specification event occurs, the control strategy is to restore standard conditions and increase the level of SBM relative to ONP to increase the brightness. Water is purged from the filtrate water chests to reduce the fines and colloidal load of the system. The yield of the process is an issue as it has economic consequences.

5.2.3 Recycled office paper deinking conditions – double loop process

5.2.3.1 Process configuration

Figure 5.2 below gives an overview of the process flow of a office paper deinking facility, which produces a variety of toweling tissue grades. The flotation cells are Escher Wyss CS cells.

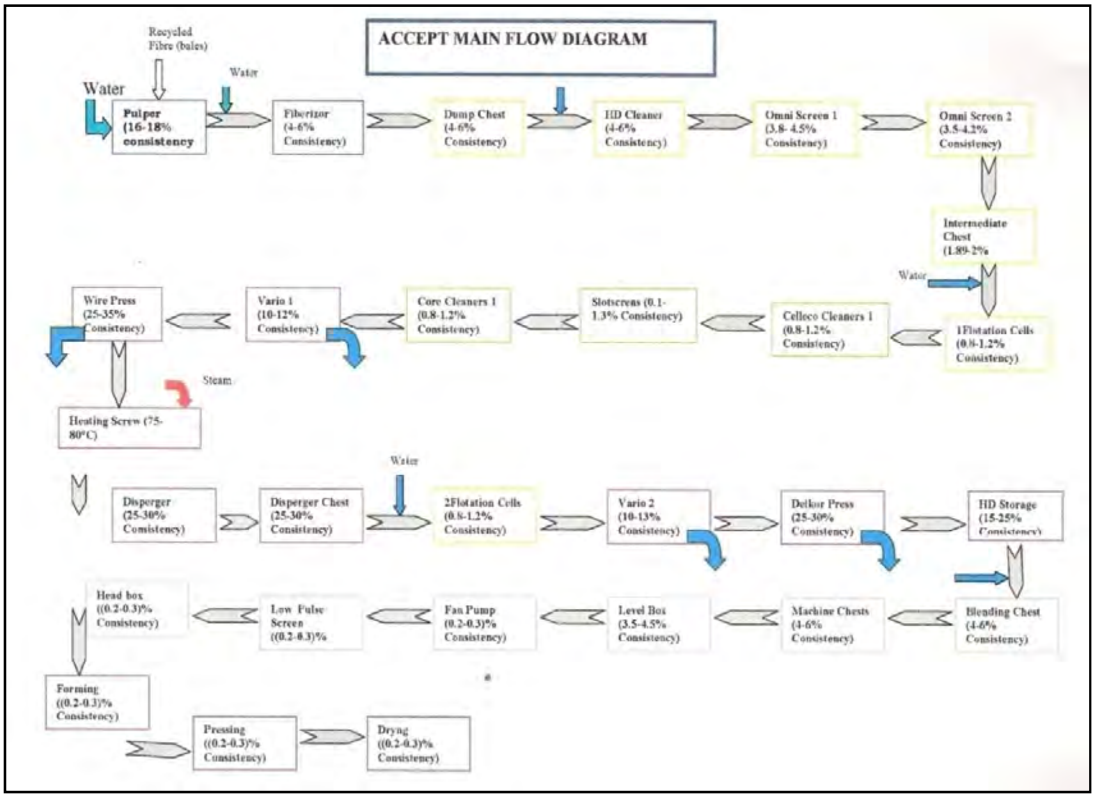

Figure 5.2: Process flow diagram – double loop office waste deinking plant. (Refer to Figure 9.11 for greater clarity)

5.2.3.2 Raw materials

The mill uses a mixture of HL1, HL2, SUPERMIX, ONP and SBM in various ratios, depending on the quality of tissue made. The percentage mixing ratios are given in the Table 5.5. In practice, the use of HL2 has been dwindling over the last few years, due to availability. It has been replaced by SUPERMIX, with the deep colours going into the Common Mixed Waste (Steyn, 2009).

Table 5.5: Percentage additions of recycled paper in various towelling tissue grades.

WASTE PAPER GRADE	Low grade	High grade	Medium grade
SUPERMIX	11	67	56
HL1	11	33	11
HL2	11	-	11
FLAT NEWS	33	-	
SBM	33	-	22

The low grade towelling tissue is no longer produced as this mill.

5.2.3.3 Process conditions

The process conditions and monitoring and control parameters are presented in Table 5.6. The deinking of office paper for tissue is carried out under neutral conditions, with no addition of hydrogen peroxide (Table 5.6 and Figure 5.2). In contrast to the deinking of newsprint, two flotation stages, interspersed with a washing and dispersion stage are required for effective deinking.

Table 5.6: Process conditions and control of a double loop office paper deinking plant.

PROCESS	**STANDARD CONDITIONS**	**MONITORING & CONTROL**
Pulping	Consistency 16-18%	Monitored
	pH 7-8	monitored
	Pulping time 16 mins.	Kept constant
	Temperature 35-40^{o}C	Monitored
	H_2O_2 0 %	
	NaOH 0 %	Pulper brightness monitored 61-68%
	Chelant – nil	
	Sodium silicate 0 %	
	Surfactant 0.1%[1]	
Flotation I	pH	Monitored
	Consistency 0.8-1%	Monitor- brightness out >50
		Monitor ash content
		Monitor air flow to float cell
Washing-Vario I	Consistency out 10-12%	Monitor consistency and pH Brightness out boosted by bleach addition [2]
Washing – wash press I	Consistency out 25-35%	
Dispersion	Temperature 75-80^{o}C Consistency 25-30%	Monitor
Flotation II	Consistency 0.8-1.2%	Monitor consistency, pH, brightness
Washing – Vario II	Consistency out 10-12%	Monitor
Washing – wash press II	Consistency out 25-35%	Monitor
HD storage		
Final after bleaching	Brightness >80 high grade, 74-78 medium grade	Exit specification

Note: 1. Addition rates are quoted as % active material per dry mass of paper.
2. Bleaching with formamidine sulfinic acid (FAS)

5.2.3.4 Process control philosophy

The most important quality requirement for tissue manufacture is the softness. This parameter is however not affected by the recycling process. Secondly, visual properties, *viz.* cleanliness (no dirt specs) and brightness are important. Brightness is adjusted by varying the amount of HL1.

5.2.4 Recycled office paper deinking conditions – single loop process

5.2.4.1 Process configuration

Figure 5.3 gives an overview of the process flow of the single loop deinking facility, which produces a variety of toweling tissue grades. The flotation cells were supplied by Voith, and comprise a mixing cell, five flotation cells in series and a secondary cell for the flotation of the rejects from the first five stages. The cells are circular in cross-section with an estimated volume by calculation of 42.4 m^3 for the 5 primary cells. The overall process flow is shown in Figure 5.3.

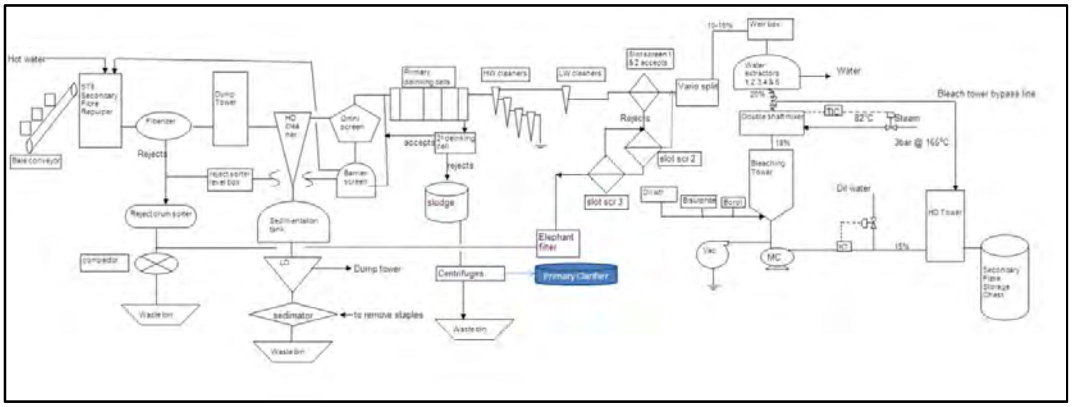

Figure 5.3: Process flow diagram – single loop office waste deinking plant
(See Figure 9.15 for greater clarity)

5.2.4.2 Raw materials

The mill uses a mixture of HL1, HL2, SUPERMIX, ONP and SBM in various ratios, depending on the quality of tissue made. The percentage mixing ratios are given in the Table 5.7.

Table 5.7: Percentage additions of recycled paper in various towelling tissue grades.

WASTE PAPER GRADE	Low grade (D)	High grade (Industrial wipes)	Medium grade (A)	Very High grade
SUPERMIX	40	100	85	0
HL1	0	0	0	100
HL2	0	0	0	0
FLAT NEWS	30	0	0	0
SBM	30	0	15	0

.

5.2.4.3 Process conditions

The process conditions and monitoring and control parameters are presented in Table 5.8. In this case, the deinking of office paper for tissue is also carried out under neutral conditions, with no addition of hydrogen peroxide, alkaline chemicals or even surfactant.

Table 5.8: Process conditions and control of the single loop office paper deinking plant.

PROCESS	STANDARD CONDITIONS	MONITORING & CONTROL
Pulping	Consistency 16-18%	Monitored
	pH 7-7.5	Monitored
	Pulping time 16-20 mins.	Kept constant
	Temperature setpoint 85°C, actual 60 °C.	Monitored
	H_2O_2 - 0 %	
	NaOH - 0 %	Pulper brightness monitored 60-70%
	Chelant – nil	
	Sodium silicate - 0 %	
	Surfactant 0%[1]	
Flotation	pH ca. 7-7.5	Monitored
	Consistency 0.6-0.8%	Monitored
	Temperature setpoint 50 - 55°C, actual 48-50 °C.	Brightness into float cell, brightness after float cell
Washing-Vario split	Consistency out 10-(12)-16%	Monitor consistency and pH
Thickening	Consistency out 18%	
Bleaching	Temperature setpoint 80°C Consistency 15%	Brightness after bleaching.[2]
Final after bleaching	Brightness >80 high grade, >75 low grade	Exit specification

Note: 1. Addition rates are quoted as % active material per dry mass of paper.
2. Bleaching with Direct Borol Injection.

In contrast to the double loop plant, there is only one flotation stage, followed by cleaning and screening, washing, thickening and bleaching.

5.2.4.4 Process control philosophy

The most important quality requirement for tissue manufacture is the softness. This parameter is however not affected by the recycling process. Secondly, visual properties, *viz.* cleanliness (no dirt specs) and brightness are important. Brightness is adjusted by varying the amount of bleaching solution. The brightness's are generally within specification, but *ad.hoc.* additions of bleach solution are used to bring the brightness into specification.

5.3 Process control of deinking plants

The deinking processes are such that there are few opportunities to make adjustments to the process if the quality of the output changed. In particular the setup of the flotation cells offers no flexibility. The aeration air is aspirated into the cell through a fixed aperture, so the air flow can't be adjusted. The level in the float cell can be controlled, so in theory one could adjust the froth height. In practice however the float cell level or froth height is maintained at a set point and not varied in response to changing conditions. Even so it is very difficult to consistently control the height at this set point. The construction of the cells does not offer a great height difference to adjust this parameter. It is of course possible to adjust the level of addition of process chemicals, but with the exception of the final bleaching chemicals, this is not done. The general strategy is to check the quality of the incoming recycled paper as a first step. Thereafter, adjustment in process chemicals might be attempted. Such adjustments are in the main ad-hoc and experience based (Crosby, 2008). Thus, the main driver of quality in a paper recycling plant is the variability of the incoming recycled paper, with little possibility to remedy poor paper quality in the process. Certain grades of recycled paper, depending on the process, are known as "brightness boosters", and are employed as such to control the final brightness. For example, OMG is used to boost brightness in newsprint deinking and HL1 boosts the brightness in tissue deinking. However, this approach is becoming less viable due to constrained availability of such high quality feedstocks. The deinking mills are having to make use of lower grade and mixed paper.

5.4 Determination of potential control parameters

With reference to Tables 5.4, 5.6 and 5.8, the list of possible control variables in the combined pulping, flotation and washing processes totals about 15 variables. Processes such as dispersion and final bleaching were not modelled, as they differ for the newsprint and tissue deinking processes and would not be accommodated in a global model. In addition, dispersion can at this point in time not be replicated in the laboratory.

It was desirable that the list of 15 possible control variables be reduced, to avoid having to build a large and complex neural network model requiring vast amounts of training data. In order to screen the large number of possible variables in a reasonable amount of time, it was necessary to use experimental design techniques. For example, to investigate all possible combinations of 15 factors at only two levels would require 2^{15} or 32768 experiments. Plackett-Burman fractional factorial designs have been found to be effective in investigating large numbers of experimental variables with a minimum number of experimental runs (Barrentine, 1999: 39).

The list of possible control variables can also be reduced by eliminating variables that from a process plant point of view are not practical control variables. A good *control variable* is one that can be easily changed or adjusted without throwing the process out of balance, reducing the capacity of the plant or requiring considerable operating or capital expenditure. On the other hand a variable which has a significant effect on the process but is not a practical control variable would still need to be optimized. Such a variable would be considered to be an *optimisation variable*. The conditions listed in Tables 5.4, 5.6 and 5.8 were considered in the light of these requirements as possible practical control variables.

5.4.1 Pulper consistency

The effect of the consistency in the pulper on the deinking process has been studied (Section 2.2.2). Bennington *et al.* (1998) found that pulping time and pulping consistency were not major influencing factors, as the ink was released very rapidly from the fibres, and that continued pulping tended to redeposit ink on the fibres. On the other hand, Ackerman *et al.* (1999) reported that pulping consistencies and alkalinities interacted to influence the final deinked brightness.

A pulper designed to operate at for example 14-20% consistency would not slush pulp effectively at 5% consistency. Similarly, a low consistency pulper would not be able to pulp at high consistency. In addition, a reduction of pulping consistency from 14% to

5% at the same hydraulic throughput would constitute a 280% reduction in plant throughput, in terms of dry fibre processed. Thus the consistency in the pulper is not a practical control variable, although the exact level of pulping consistency could be optimized. In the laboratory, the pulper could not effectively deflake the recycled paper at a consistency of 5%, but deflaked effectively in the 8 to 10% consistency range. At consistencies above 10%, poor movement (and thus mixing) of the stock occurred. Thus 8-10% consistency was chosen as the practical range for the laboratory experiments.

5.4.2 Pulper pH

The pH is the result of the addition of chemicals such as sodium hydroxide and sodium silicate, whose addition in turn is determined by the level of hydrogen peroxide required (Ferguson, 1992). The pH was thus not considered to be a control variable, but rather a variable to be monitored as an indication of the level of addition of other chemicals.

5.4.3 Pulping time

The pulping time has also been studied by a variety of researchers. Bennington *et al.* (1998) found that pulping time was not a major influencing factor, but Ali *et al.* (1988) found that pulping time interacted with pulping temperature and the level of addition of bleaching chemicals to influence the final bleaching, and hence brightness. The pulping time is easy to manipulate on a plant, although it could have throughput implications. Pulping time was thus considered as a possible control variable.

5.4.4 Pulping temperature

In addition to the pulping time discussed above, the temperature could be considered as a possible control variable. Borchardt (1997) says that typical pulping temperatures are 40 ^{o}C to 60^{o}C, with 50-90 ^{o}C more usual for office paper. High pulping temperatures can soften adhesive components in the pulper and lead to stickies problems. Increasing temperature can have energy use implications but it is a relatively easy parameter to increase with the direct injection of steam. Temperature was considered as a possible control variable.

5.4.5 Addition of hydrogen peroxide

Hydrogen peroxide is a bleaching agent added into the pulper to overcome the yellowing associated with the alkaline environment. Hydrogen peroxide thus has a direct effect on the final brightness and can be added to overcome the effects of lower grade raw materials. The level of addition of hydrogen peroxide is easy to manipulate, and was thus considered an important control variable.

5.4.6 Addition of sodium hydroxide

The addition of sodium hydroxide is necessary to provide the alkaline environment necessary for the effective functioning of hydrogen peroxide and the fragmentation of ink particles (Section 2.2). The amount of sodium hydroxide necessary relative to hydrogen peroxide has been the subject of a number of studies (Azevedo, 1999; Dionne, 1994; Renders, 1993; Section 3.2.4). These studies have suggested various ratios as being optimum. However, the effect of the independent addition of sodium hydroxide was studied to determine the potential of sodium hydroxide as a control variable.

5.4.7 Addition of chelating agent

Chelating agents are added in order to complex heavy metal ions which might decompose the hydrogen peroxide. Studies by Renders (1993), Mathur (1991) and Ferguson (1991) on the effects of chelating agents on the deinking process have shown that levels of about 0.2% to 0.5% assist in achieving the brightness targets. Chelant is thus a necessary additive to be optimized, but does not influence the process to such an extent to show any control effect on the process.

5.4.8 Addition of sodium silicate

The role of sodium silicate is multi-faceted and has been shown to play a role in both pulping and flotation (Section 3.2.5). Its efficacy as an agent of process control independent of sodium hydroxide needed to be established. Optimum addition levels are said to be ca. 2.5% (Borchardt, 1997; Dionne, 1993), although it can be added at levels of up to 5%.

5.4.9 Addition of surfactant

The surfactant is responsible for the dispersion and stabilization of ink particles in the pulper and the generation of the froth in the flotation cell. It has been shown to influence both flotation efficiency and yield (Sections 3.2.6 & 3.3.2). The addition rate of surfactant is easy to change and it was thus an obvious choice as a control variable. On the other hand, the type of surfactant system chosen for a process is more a question of optimisation.

5.4.10 Flotation temperature

Very little has been reported in the literature on the effect of temperature on the flotation process. However, the temperature will affect the cloud point, and thus the efficacy of non-ionic surfactants. Also the effect of temperature on the viscosity of the water, and hence on the hydrodynamics of the flotation processes suggests the temperature could influence the deinking process (Section 3.3.3). Although increasing the temperature of the flotation slurry will require large amounts of energy, due to the low consistencies involved, it was worth consideration as a potential control variable.

5.4.11 Flotation conditions

Flotation consistency, together with agitation speed and air flow rates have been shown to greatly affect the flotation process.

Hunold *et al.* (1997) studied the effects of air flow rates and air bubble size distribution on flotation efficiency (as measured by brightness gain) and yield, by using different injector configurations. They found that different injector designs did not seem to produce different air bubble size distributions in a deinking flotation device, but that air flow rates were decisive in determining the brightness gain. Brightness gains however, came at the expense of lower yields.

On the other hand, in a laboratory study, Carrasco *et al.* (1999) found an empirical relationship between deinkability E and pulp consistency c (%), agitation speed N (rpm) and air flow rate q (l/hr) to be as follows:

$$E = 0.21c^{0.70}N^{0.74}q^{0.07} \tag{1}$$

where $E = \frac{Brightness\ after\ flotation - brightness\ after\ pulping}{Brightness\ of\ unprinted\ paper\ after\ flotation - brightness\ after\ pulping}$

Equation (1) suggests that the air flow rate q has little influence on the process. The flotation time was not included in this model, but Carrasco *et al.* (1999) found that E increased rapidly in the first four minutes, and levelled off asymptotically after about ten minutes of flotation time.

Flotation consistency is a variable which is easy to manipulate, although it does have implications for the throughput of a plant, *viz.* a lower consistency at the same hydraulic throughput would imply a lower mass throughput of fibre. On the other hand, agitation conditions and air flow rates cannot be controlled on the flotation plants under study. These parameters are determined by the equipment design. Two of the plants use flotation cells supplied by Voith, which aspirate air through a venturi effect, and the third plant uses Escher Wyss cells in which the air flow is regulated by pressure. In this case it would be possible to adjust the air flow, but in practice this is not done. In addition, these conditions are difficult to duplicate in the laboratory equipment available.

Peters *et al.* (2007) treated the subject of the interaction of flotation cell variables in a similar way. They stated that the Specific Air Volume (SAV, Litres air/kg solids), defined as the volume of air applied to a flotation line per kilogram of solids in the feed determines the flotation efficiency. Thus for a laboratory batch cell:

$$SAV_{lab} = \frac{qt_f}{Vc} \tag{2}$$

where V = cell volume, c = consistency, q = air flow rate, t_f = flotation time.

In the laboratory cell, the agitation speed was maintained constant between 1500 and 1600 rpm. Thus the q would be constant and the equation reduces to one of the form

$$SAV_{lab} = L \quad c^{-1} t_f \tag{3}$$

where L is a constant.

Similarly, for a continuous flotation cell, where Q_s is the flow rate of the stock

$$SAV_{plant} = \frac{q}{cQ_s} \tag{4}$$

But, aspirated air flow per cell (*q*) depends on the stock flow Q_s

$$q = dnQ_s = d' t_f Q_s \tag{5}$$

where d and d' are constants, n = number of float cells in series, and because t_f is proportional to *n*

Substituting into equation (4) and rearranging reduces to an equation of the general form of equation (3), with a different constant P:

$$SAV_{plant} = P \quad c^{-1} t_f \tag{6}$$

The two different empirical approaches discussed above confirm that flotation residence time and consistency are important control parameters.

Flotation time and consistency, through their influence on the SAV (Peters *et al.,* 2007), will affect the yield of the process, and changes in flotation time will obviously have an effect on plant throughput rates. Thus, flotation time and consistency are two variables central to the performance of a deinking plant.

5.4.12 Flotation pH

As discussed in Section 3.2.7, pulping pH and flotation pH play a significant role in flotation deinking. In particular lower pH's favoured the deinking of office papers. In addition, the pH of flotation will affect the function of surfactants, particularly the fatty acid soaps, and could potentially be an important control parameter.

5.4.13 Calcium concentration

The calcium concentration, or calcium hardness, has been shown to affect the performance of deinking systems, both in terms of deinking and yield (Section 3.3.4). This is particularly true for soap-based deinking systems, where the calcium acts as a collector. However, in the processes under study, fatty acid soaps are not used and the calcium hardness is monitored but not controlled. Also large amounts of calcium enter the deinking system in the form of calcium carbonate fillers. The calcium concentration in solution will thus be determined by the ambient pH and solubility equilibria and any attempt to control this will be futile. Thus the calcium concentration of the process water was maintained at an ambient level of ca. 200 ppm, but was not considered as a control variable.

5.4.14 Washing efficiency

Washing as a process consists of dilution followed by filtration and is commonly carried out in deinking plants. It serves to remove fine particles and fillers. The washing process generally occurs within certain dilution ranges. The fibrous slurry after flotation (typically at ca. 1% consistency) is dewatered in stages up to ca. 30% consistency. The efficiency of washing is determined by the consistency increase across the dewatering equipment (Section 2.6) and the particle size distribution of the fine materials, which turn have been determined by conditions in the pulper and flotation cells. Washing can thus not be independently controlled. In this work, washing was simulated by the process of making hand sheets. In this process, the fibrous sample is diluted to a consistency of about 0.3% and dewatered on a 150 micron mesh to form a hand sheet of approximately 20% consistency.

5.4.15 Dispersion

The equipment required to simulate this process was not available in the laboratory. This was not modelled in this work.

5.4.16 Final bleaching

Final adjustment of the brightness is carried out by bleaching, sometimes in a specialised bleach plant, but most often in the storage chests prior to utilization by the paper making process. This is achieved either oxidatively using hydrogen peroxide or reductively using strong reducing agents such as sodium dithionite. Combinations of the two processes are also possible (Sections 3.4). This is a separate process, carried out after deinking, and was excluded from the modelling exercise.

5.4.17 Grade of recycled paper

Lastly, the grade of paper being recycled is one of the major determinants of the output of a recycling plant. The process plants under consideration in this work use four basic grades of recycled paper as raw material: newsprint (ONP), magazines (OMG), white office papers (HL1) and pastel coloured office papers (HL2). Some of the recycled grades of paper being used are blends of the four basic grades. For example, SUPERMIX is a 50/50 blend of HL1 and HL2, and Special News (SN) consists of newsprint with some magazine and office papers (Table 5.3). Nevertheless, it is possible to describe the raw material mix of any of the plants in terms of ratios of the four basic grades.

5.4.18 In summary

The parameters that were considered as possible control variables are summarized in Table 5.9. The levels that were chosen for the screening process, designated as LOW and HIGH in Table 5.9, encompassed the range in practical use by the participating mills.

Table 5.9: Summary of screening of control variables.

PARAMETER	LEVELS IN NEWSPRINT DEINKING	LEVELS IN TISSUE DEINKING	LEVELS IN LABORATORY MODELING [Low-High]	COMMENTS
PULPING				
% Pulping consistency	14-16	16-18	8-10	Not a control variable
pH	9.5-9.8	7.0-8.0	Monitored	Not a control variable
%NaOH	0.55 -0.6	0	0 - 0.67	Control variable
% Sodium silicate	0.38-0.4	0	0 - 2	Control variable
%H_2O_2	0.48-0.52	0	0 – 1	Control variable
% Dispersant %Surf-p	0.085-0.1	0.1	0.25 - 0.75	Higher levels needed in laboratory to achieve frothing
Pulping time, t_p mins	13.3	16	5 – 15	Control variable
Temperature, T_p °C	50	35 – 40	35 – 50	Control variable
Chelant	0	0	0.2	EDTA, keep constant
FLOTATION				
Temperature, T_f °C	42		30 – 45	Control variable
% Consistency	1.2 – 1.4	0.8 – 1.2	0.8 – 1.3	Control variable
pH	7.5 – 8.0		8 - 10	Control variable
Hardness, ppm $CaCO_3$	240	200	200	Add $CaCl_2$ to a level of 200 ppm $CaCO_3$
Flotation time, t_f mins	See Chapter 9	See Chapter 9	5 – 20	Control variable
% Dispersant %Surf-f	0 added	0 added	0 – 0.5	Higher levels needed in laboratory to achieve frothing

5.5 Measurement of effects of control variables

The effects of the selected control variables in Table 5.6 were measured by determining the final brightness (R_{457}) and the final residual ink concentration (ERIC) after the washing process.

The yield, calculated on a dry basis and defined as follows:

$$\%Yield = \frac{mass\ of\ solids\ after\ flotation}{mass\ of\ solids\ before\ flotation} \times 100 \tag{7}$$

was used as a measure of losses to the process. This corresponds to the total solids yield, as the pulp pad would include any filler present.

5.6 Screening of potential control variables

5.6.1 Pulping and flotation methods

After a process of trial and error, based on previous experience (Pauck, 2003), the following laboratory pulping and flotation procedures were used:

5.6.1.1 Recycled paper sample preparation

In order to standardise on the recycled paper raw materials used in the laboratory work, the follow compositions were used to represent the basic grades. These blends were obtained by visual estimation of the composition of recycled paper in the warehouses of the participating mills.

Newsprint (ONP)

Local newspapers less than 6 months old were used. The inserts were removed.

Magazines (OMG)

A blend of 33% (by weight) of heavy-weight glossy coated magazines with 67% supercalendered and light-weight coated grades (magazines and inserts) was made to represent this grade of recycled paper.

Heavy letter 1 (HL1)

A blend of 80% Xerographic printed paper (laser printer and photocopier) and 20% inkjet printed paper was used to represent this grade.

Heavy letter 2 (HL2)

This comprised 44% white or grey papers and the balance a blend of yellow, green, blue and red pastel shades of paper.

In each case, enough paper for about 30 runs was torn into short strips, mixed well and stored in cardboard box under standard paper laboratory conditions.

5.6.1.2 Laboratory pulping procedure

1. Add the following chemicals in order into the pulper, in the quantities specified in the experimental design:
    - Water at 5 °C above the pulping temperature.
    - Caustic soda 35% solution
    - Sodium silicate 38% solution
    - Chelating agent (EDTA powder)
    - Calcium chloride ($CaCl_2.2H_2O$) powder
    - Surfactant

2. Agitate briefly in the pulper to dissolve.
3. Add the paper, torn into strips, into the pulper. Allow the paper to wet out and leave to soak for 10 mins.
4. Start the pulper motor and allow to mix until the paper has started to disintegrate (about 30 seconds).
5. Then add hydrogen peroxide 30% solution (if required) and start the pulping timer.
6. Allow to pulp for the specified time and temperature. Make sure that the pulp is mixing well by “rolling over” in the pulper.
7. Take a sample and test the temperature, consistency, pH, hardness and residual peroxide according to standard methods, as required in the recipe.
8. Make two pulper pads on the Rapid-Koethen sheet former as follows:
    a) take a sample of pulp. [Mass of sample = 6.3/consistency x 100], about 80 grams of sample at ca. 8-10% consistency.
    b) dilute the sample to 500ml and stir to disperse;
    c) fill the former to 2 litres, introduce air agitation and pour in the sample, allow to agitate for 15 seconds and then commence draining,
    d) form a pad. The pad will have a mass of approximately 200 g/m^2
    e) couch off the pad in the standard manner;
    f) dry the pad in the sheet dryer in the standard manner.

5.6.1.3 Flotation method

One hour after the paper had been pulped; the flotation is commenced, according to the method below. The laboratory flotation cell has a working volume of 15 litres.

1. Add into a bucket, in the following order:
   - 12 litres of water, at 5 °C above the specified flotation temperature;
   - The required quantity of pulp, from the pulper at ca. 8-10%;
   - Calcium chloride ($CaCl_2.2H_2O$) powder;
   - Surfactant (if required).
2. Adjust the pH drop-wise to the required level while stirring, using 10% NaOH or 10% H_2SO_4 solution.
3. Transfer the pulp to the flotation cell, make up with water to achieve the required starting temperature.
4. Switch on the agitator, and float at 1550 to 1600 rpm for the specified time. Maintain the level in the float cell by making up with water at the correct temperature from time to time.
5. Scrape off the froth in a steady and repeatable manner.
6. When the float is complete, stop the motor and drain the entire contents of the cell quantitatively into a tared bucket.
7. Weigh the contents of the bucket and determine the consistency of the floated pulp. Be sure to stir the bucket very well before drawing the samples. Calculate the %Yield as per equation (7).
8. Prepare the following samples:
   - 600 grams of sample for consistency test, in duplicate;
   - Two floated pulp pads, as per Section 5.6.1.2(8) above, but using the following mass of sample: Mass of sample = 6.3/consistency x 100;
   - Six 60g/m^2 handsheets, as per the standard method (Formation of handsheets for physical tests of pulp. CSIR Methods Manual no. FFP_15, based on Tappi T 205 sp-95 and ISO 5269-1:1998(E)), formed on a Rapid-Koethen sheet former.
9. Perform the following measurements on the pads and handsheets:
   a. Brightness, L*, a*, b*, measured on the top-side and wire-side, 4 measurements per pad or sheet (1 in each quadrant).
   b. ERIC, 4 measurements (one in each quadrant) on the pulper and flotation pads, and one on each of the handsheets. Top-side and wire-side to be measured.

5.6.1.4 Equipment and test methods

Equipment used

The pulper used was a Laboratory Hydra Pulper model UEC 2020 (Universal Engineering Corporation, India) shown in Figure 5.4:

Figure 5.4: External (above left) and internal (above right) view of laboratory pulper.

Figure 5.5 depicts the "rolling" action in the pulper, demonstrating good pulping. A Flotation Cell model UEC 2026 (Universal Engineering Corporation, India) was used for the flotation work (Figure 5.6). The flotation action and generation of froth is shown in Figure 5.7.

Consistency

The consistency (mass percent of dry fibre in a fibre slurry) was determined according to Tappi T 240 om-93.

Figure 5.5: View of pulping action, demonstrating good mixing action.

Figure 5.6: Laboratory flotation cell.

Figure 5.7: Laboratory flotation cell froth generation.

Pulp pads

Pulp pads were formed to determine the brightness of the pulped paper before flotation (referred to as *pulper pads*) and after flotation (referred to as *floated pads*). The pads were formed on the Rapid-Koethen sheet former, with the modification that less dilution water was added (2 litres instead of 7 litres). This was based on the method: Forming handsheets for reflectance testing of pulp, Tappi 218 om-91. This procedure produces a pad of weight 200 g/m^2.

Handsheets

Sixty g/m^2 handsheets were formed on the Rapid-Koethen handsheet preparation machine, according the procedure FFP_015: Formation of handsheets for physical testing of pulp, based on Tappi T 205 sp-95 and ISO 5269-1:1998(E). The process of handsheet formation involves the dilution of the sample to 0.3%, followed by dewatering on a 150 micron mesh screen. The process of dilution and filtering allows for considerable quantities of fine material, including ink particles, to be washed through the screen. This results in different reflectance measurements to the pulp pad method of forming sheets and also between the top and wire sides of the handsheet. These differences have been investigated by a number of researchers (Pala *et al.,* 2007; Dorris, 1999; Levesque *et al.,* 1998a & 1998b). Levesque *et al.* (1998) concluded that the pad methods showed better ink retention than the handsheet method. The addition of coagulants like alum or polyacrylamide together with pH adjustment to 5.5 showed less two-sidedness, although no particular pad preparation chemistry was consistently better with respect to ink retention. In the interests of simplicity, for this work it was decided not to use any particular pad or handsheet preparation chemistry but to use tap water as dilution water with no pH adjustment. To accommodate the two-sidedness, the brightness and ERIC of both sides of the pads or sheets were measured and the average was taken.

Thus, for the first two stages of the process, where it is important to measure all the ink in the pulp, the pad process was used. The washing out effect that has been observed in the preparation of the handsheets was used in this study to simulate the washing process that occurs in a deinking plant. The ink particles present on the fibres after washing represent those particles that have either re-deposited or have not been detached from the fibres. This ink will thus never be removed (Carré, Galland & Julien Saint Amand, 1994). These samples were referred to as *washed* pulp.

Optical properties

The optical properties were measured according to CSIR Methods Manual FFP_03: Determination of Brightness, on a Technidyne ColorTouch PC spectrophotometer, set up to measure GE brightness (D65 source, 10° observer), and Effective Residual Ink Concentration (ERIC) under the following conditions: illuminant C, 2° observer, scattering coefficients usual for newsprint are s_{950} = 47.00 and s_{557} = 52.00, absorption coefficients 10000 at 950 nm and 15000 at 557 nm.

The full range of optical properties were recorded on the pulped, floated and washed pulps *viz.* brightness (UVex), UV brightness (UVin), lightness (L*), b* (blue-yellow) and a* (red-green) and ERIC. However, only the brightness and ERIC on the final washed pulp were used to generate the models, as this is the final output of the process.

There is a distinction between brightness and UV brightness. In the measurement of UV brightness, the illuminant in the spectrophotometer has an ultraviolet light component which fluoresces as blue light, thereby boosting the perceived brightness. The UV brightness is thus always higher than the non-UV brightness if the paper contains fluorescent whitening agents. However, the UV brightness is what the user of a paper product will actually see and perceive, and was thus the brightness which was modelled in this study.

5.6.2 Experimental design

When confronted with a large number of factors which could potentially influence a process, it is essential to perform screening runs, in order to sift through the many factors and eliminate those that have little or no influence on the process. In particular, Plackett-Burman experimental designs have proven themselves to be efficient ways of screening large numbers of variables in relatively few experimental runs. An 11-factor, 12-run Plackett-Burman design is depicted in Table 5.10. This design was adapted from Barrentine (1999: 56). In this table, a “1” represents the high value of a variable, and a “-1” represents the low value.

Table 5.10: A 12 run Plackett-Burman design, with reflection.

	FACTORS											OUTPUT	
RUN NO.	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Y**	**S^2**
1	1	-1	1	-1	-1	-1	1	1	1	-1	1		
2	1	1	-1	1	-1	-1	-1	1	1	1	-1		
3	-1	1	1	-1	1	-1	-1	-1	1	1	1		
4	1	-1	1	1	-1	1	-1	-1	-1	1	1		
5	1	1	-1	1	1	-1	1	-1	-1	-1	1		
6	1	1	1	-1	1	1	-1	1	-1	-1	-1		
7	-1	1	1	1	-1	1	1	-1	1	-1	-1		
8	-1	-1	1	1	1	-1	1	1	-1	1	-1		
9	-1	-1	-1	1	1	1	-1	1	1	-1	1		
10	1	-1	-1	-1	1	1	1	-1	1	1	-1		
11	-1	1	-1	-1	-1	1	1	-1	-1	1	1		
12	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1		
13	-1	1	-1	1	1	1	-1	-1	-1	1	-1		
14	-1	-1	1	-1	1	1	1	-1	-1	-1	1		
15	1	-1	-1	1	-1	1	1	1	-1	-1	-1		
16	-1	1	-1	-1	1	-1	1	1	1	-1	-1		
17	-1	-1	1	-1	-1	1	-1	1	1	1	-1		
18	-1	-1	-1	1	-1	-1	1	-1	1	1	1		
19	1	-1	-1	-1	1	-1	-1	1	-1	1	1		
20	1	1	-1	-1	-1	1	-1	-1	1	-1	1		
21	1	1	1	-1	-1	-1	1	-1	-1	1	-1		
22	-1	1	1	1	-1	-1	-1	1	-1	-1	1		
23	1	-1	1	1	1	-1	-1	1	1	-1	-1		
24	1	1	1	1	1	1	1	-1	1	1	1		
ΣY_+													
ΣY_-													
Y_{avg+}													
Y_{avg-}													
NET EFFECT													
S_+^2 AVG													
S_-^2 AVG													
F													

The runs 13 to 24, shaded in Table 5.10 are the “reflection” or inverse of the first 12 runs. Reflection makes it possible to determine the effect of the main variables free from two-factor interactions (Barrentine, 1999:46). The control variables and associated high and low values identified in Table 5.9 now become the experimental design depicted in Table 5.11:

Table 5.11: Screening experimental design for control variables.

	PULPING						FLOTATION					OUTPUT
	A	B	C	D	E	F	G	H	I	J	K	Y
RUN NO.	%NaOH	% Sod Silicate	%H_2O_2	% Surf-p	t_p, min	T_p, deg C	T_f, deg C	% cons	pH	% Surf-f	t_f, min	
1	0.67	0	1	0.25	5	35	45	1.3	10	0	20	
2	0.67	2	0	0.75	5	35	30	1.3	10	0.5	5	
3	0	2	1	0.25	15	35	30	0.8	10	0.5	20	
4	0.67	0	1	0.75	5	50	30	0.8	8	0.5	20	
5	0.67	2	0	0.75	15	35	45	0.8	8	0	20	
6	0.67	2	1	0.25	15	50	30	1.3	8	0	5	
7	0	2	1	0.75	5	50	45	0.8	10	0	5	
8	0	0	1	0.75	15	35	45	1.3	8	0.5	5	
9	0	0	0	0.75	15	50	30	1.3	10	0	20	
10	0.67	0	0	0.25	15	50	45	0.8	10	0.5	5	
11	0	2	0	0.25	5	50	45	1.3	8	0.5	20	
12	0	0	0	0.25	5	35	30	0.8	8	0	5	
13	0	2	0	0.75	15	50	30	0.8	8	0.5	5	
14	0	0	1	0.25	15	50	45	0.8	8	0	20	
15	0.67	0	0	0.75	5	50	45	1.3	8	0	5	
16	0	2	0	0.25	15	35	45	1.3	10	0	5	
17	0	0	1	0.25	5	50	30	1.3	10	0.5	5	
18	0	0	0	0.75	5	35	45	0.8	10	0.5	20	
19	0.67	0	0	0.25	15	35	30	1.3	8	0.5	20	
20	0.67	2	0	0.25	5	50	30	0.8	10	0	20	
21	0.67	2	1	0.25	5	35	45	0.8	8	0.5	5	
22	0	2	1	0.75	5	35	30	1.3	8	0	20	
23	0.67	0	1	0.75	15	35	30	0.8	10	0	5	
24	0.67	2	1	0.75	15	50	45	1.3	10	0.5	20	
ΣY_+												
ΣY_-												
Y_{avg+}												
Y_{avg-}												
NET EFFECT												

For each run under the specified conditions, the outputs "Y" are the washed brightness, washed ERIC and Yield. Ideally, a number of replicates of a design should be carried out to determine the S^2 for each run and each variable. This makes it possible to calculate the statistical significance of the differences observed. However, because of the large number of runs required for this project, replicates of the screening designs were not performed. Instead, a number of *midpoints* were run, using the average of the low and high values of the variables. The variance for the midpoint runs gives an indication of the variability of the runs. The midpoints were also run at intervals through each screening run, to detect any significant drift in the processes.

CHAPTER 6: RESULTS OF SCREENING RUNS

6.1 Introduction

In the previous section, the possible control variables were summarised in Table 5.9. As discussed in Section 5.6.2, a statistical experimental design procedure was used to drastically reduce the number of experimental runs required to obtain meaningful information on the independent effect of many different process parameters.

6.2 Results of screening runs – general trends

The general results of the screening runs are presented. Flotation time (t_f) emerged from the Plackett-Burman screening trials as one of the major determinants of overall performance. Accordingly, the brightnesses, ERIC and yield as a function of flotation time for the different grades are shown in Figures 6.1, 6.2 and 6.3 respectively. A flotation time of zero was assigned to the brightnesses of the pulper sample. The average brightness, ERIC and yield for all 24 runs of the Plackett-Burman design is reported, at 5 minutes and 20 minutes flotation time. There was obviously a large variability in the results, due to the high-low pattern in the experimental design. Therefore, the averages only are reported for simplicity and the variability is depicted by error bars showing plus and minus one standard deviation.

6.2.1 Dependence of brightness on flotation time

The large variability is a result of the high-low nature of the experimental design, but serves to demonstrate the magnitude of the variability induced by the process conditions as compared to that induced by paper grade, flotation time or processing stage. The variability can be further appreciated in the cluster plots, Figures 6.6 to 6.9.

The brightness increased rapidly with flotation time (Figure 6.1), with the major proportion of the ink was removed after 5 minutes. In the case of the heavy letter grades, the increase in brightness was very small. The heavy letter grades nowadays contain large proportions of lightly printed electrographic material (photocopy and laser printed). It is well known that toner inks form large ink particles, which do not float very well, unless they are reduced in size by further processing (usually dispersion) and removed in a second flotation stage (Goettsching & Pakarinen, 2000:276). This was observed on the laboratory hand sheets; the toner inks had agglomerated into large dirt specks.

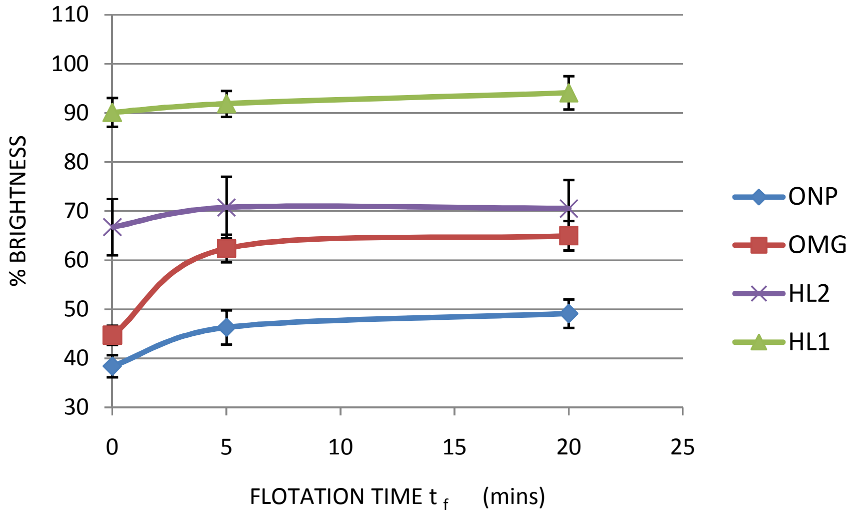

Figure 6.1: Variation of brightness as a function of flotation time (Average of 24 Plackett-Burman runs reported).

6.2.2 Dependence of ERIC on flotation time

The dependence of the 24 run average ERIC values on flotation time is shown in Figure 6.2. The ERIC values for ONP and OMG undergo large changes and show greater variability than those for HL1 and HL2, probably due to the fact that ONP and OMG are more heavily printed than the office grades.

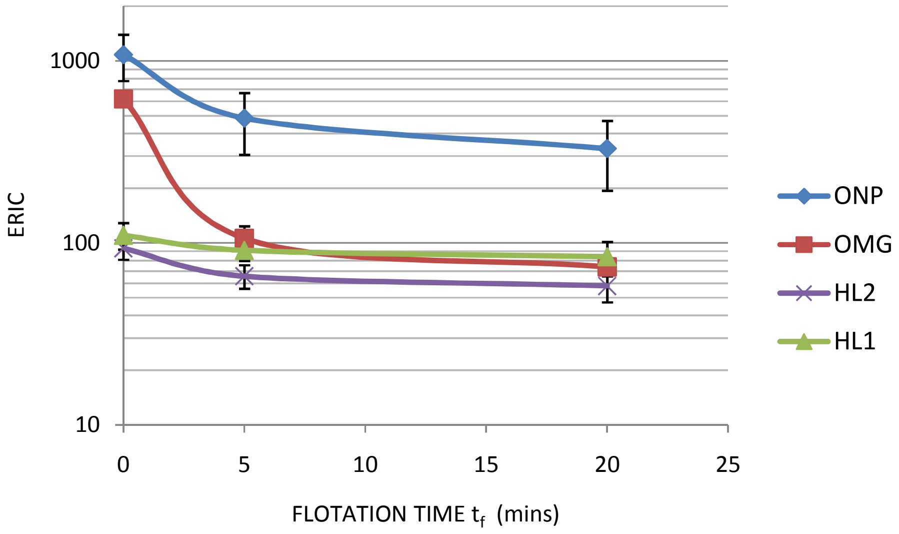

Figure 6.2: Variation of ERIC as a function of flotation time (Average of 24 Plackett-Burman runs reported).

6.2.3 Dependence of yield on flotation time

The 24 run average yield decreased rapidly with flotation time (Figure 6.3), and continued to decrease after about 5 minutes flotation time with no great improvement in brightness.

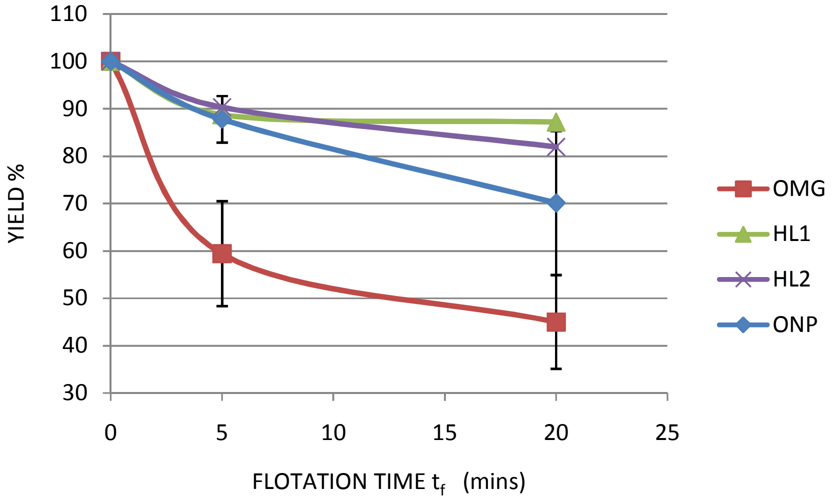

Figure 6.3: Variation of yield as a function of flotation time (Average of 24 Plackett-Burman runs reported) .

Yield and optical properties represent the trade-off between economy and quality that has to take place in every deinking operation. The yield losses were highest for OMG, due to the high level of filler both in the paper and as a component of the coatings (Borchardt, 2003).

6.2.4 Variation of brightness and ERIC with processing stage.

As outlined in the experimental procedure, the waste was first pulped, then floated and washed, in sequence. The brightness of all grades increased from pulping through flotation to washing as shown in Figure 6.4. A 19 point overall increase in brightness was observed with the OMG waste grades, almost double the 10 point increase for ONP. The heavy letter grades again showed minimal brightness increases. A less than 5 point overall increase in brightness was observed, with the HL2 waste grades showing marginally greater increases than HL1.

Also, the variability induced by the process variables (as indicated by the error bars) is considerable compared to the changes caused by processing (flotation time in Figure 6.1, and processing stage in Figure 6.4). In other words, the error bars depict the influence of the process variables whereas the y-axis differences between the grades represent the influence that the different grades would have on the final brightness of a mixture of grades. These differences can often be more significant than the effect of the deinking process and this points to the significant potential of furnish composition as a strong control variable.

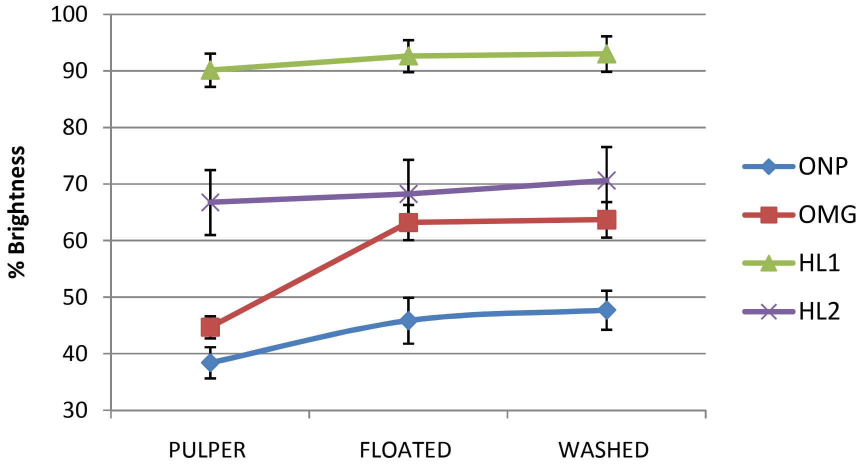

Figure 6.4: Effect of processing stage on brightness.

It was apparent from Figure 6.4 that washing had a minimal but nevertheless positive effect on the final brightness of all the grades.

The variation of ERIC with processing stage was the inverse of that found with the brightness, as ERIC decreases as brightness increases (Figure 6.5). Similar comments as made for brightness apply in the case of ERIC.

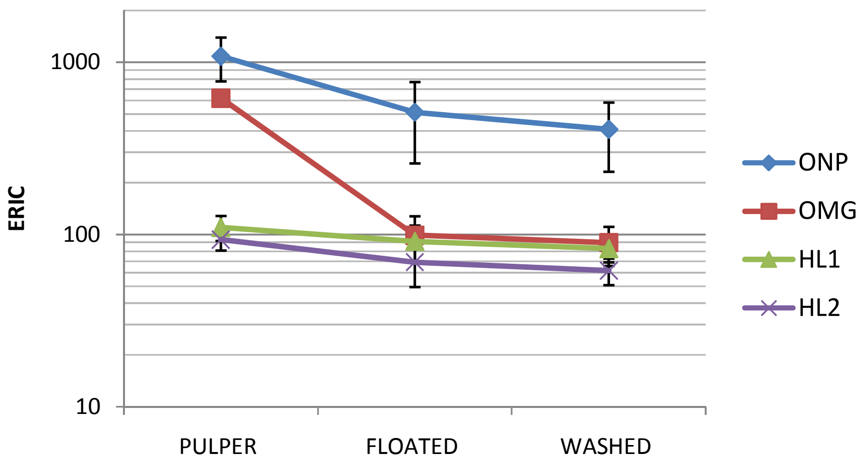

Figure 6.5: Effect of processing stage on ERIC.

6.2.5 The relationship between ERIC and brightness

Figures 6.6 to 6.7 depict the relationship, in the form of cluster-plots, between ERIC (logarithmic scale) and brightness from pulping through to washing.

Haynes (2000) reported a linear relationship between the log of ERIC and brightness above an ERIC value of 500, and another linear relationship below an ERIC value of 500, with a discontinuity of slope at 500. A roughly linear relationship is apparent from Figures 6.6 to 6.8, with the exception of HL2 (Figure 6.9).

The strongest relationship between brightness and ERIC was demonstrated by the newsprint grade (Figure 6.6) and HL1 (Figure 6.8). In general the scatter was highest at the high brightness/low ERIC range, due to the cumulative effect of the variable processing conditions.

The range of ERIC values at the pulping stage was always higher than the range of brightness, presumably due to various types of ink, which fragmented differently in the pulper. The fragmentation of ink in the magazine grade was more clustered (Figure 6.7) than the newsprint grade. This is presumably due to the coated component of the magazines, which could be expected to fragment in a more reproducible fashion.

The HL 2 grade showed the least correlation between ERIC and brightness, presumably because this grade was the most variable in terms of type of printing and coloured constituents. A stronger relationship between brightness and ERIC was shown by the HL1. The scatter was similar for all of the processing stages.

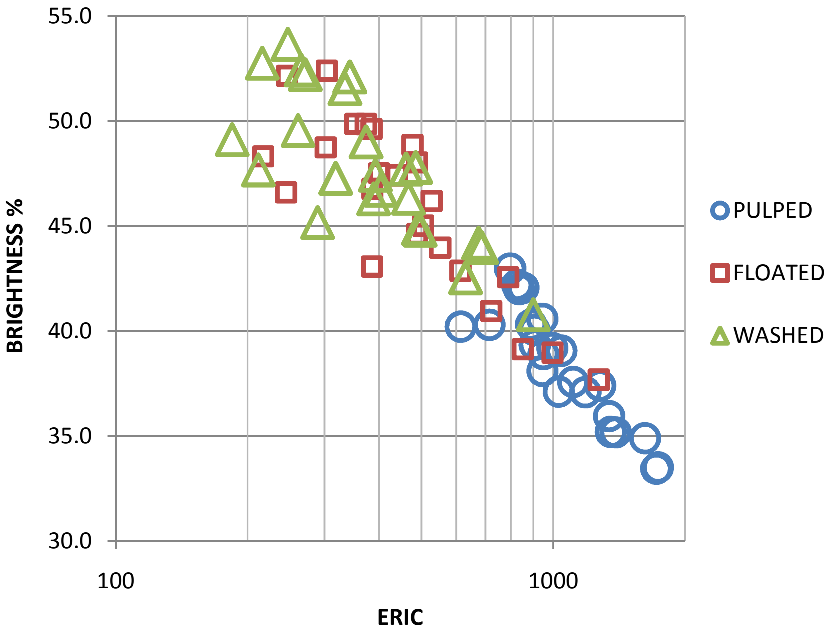

Figure 6.6: Cluster plot of brightness vs. ERIC for newsprint.

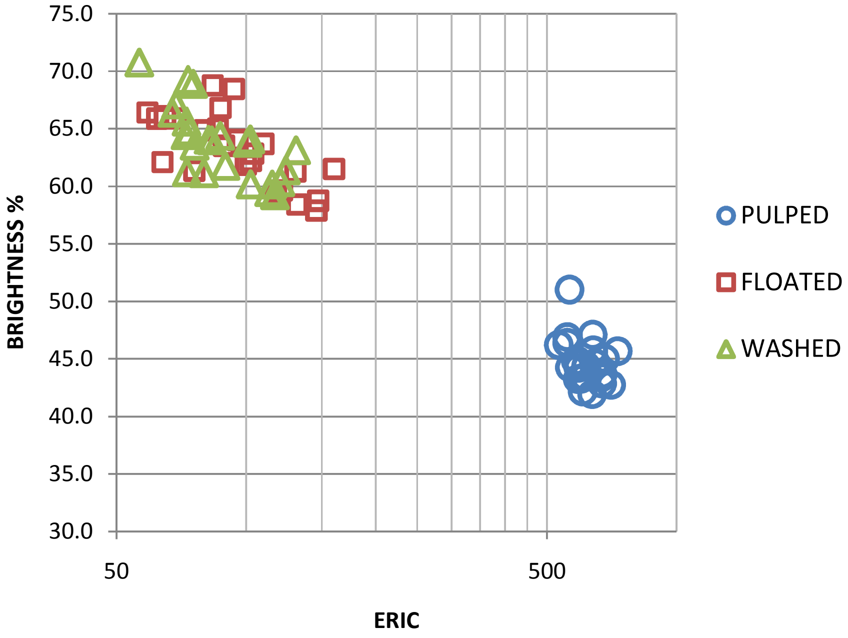

Figure 6.7: Cluster plot of brightness vs. ERIC for magazines.

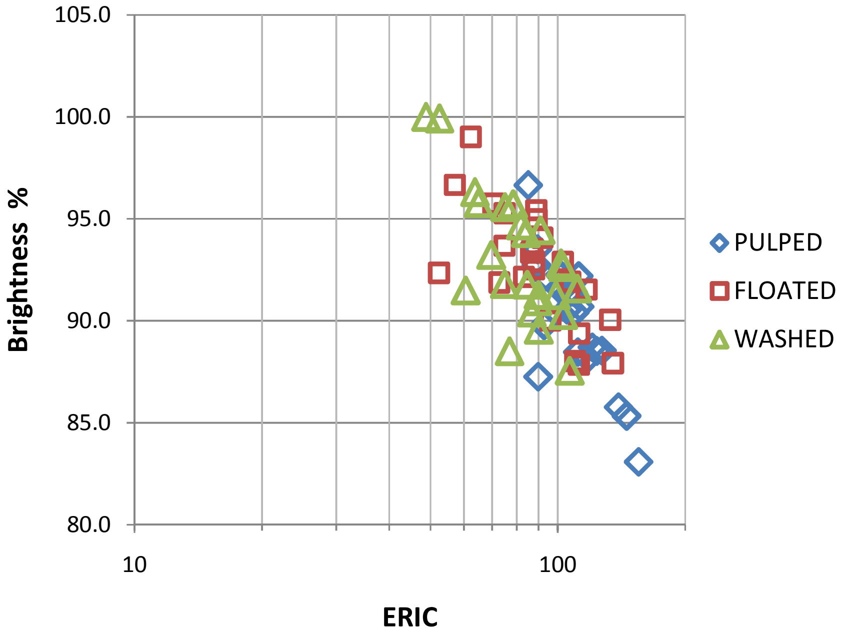

Figure 6.8: Cluster plot of brightness vs. ERIC for heavy letter 1.

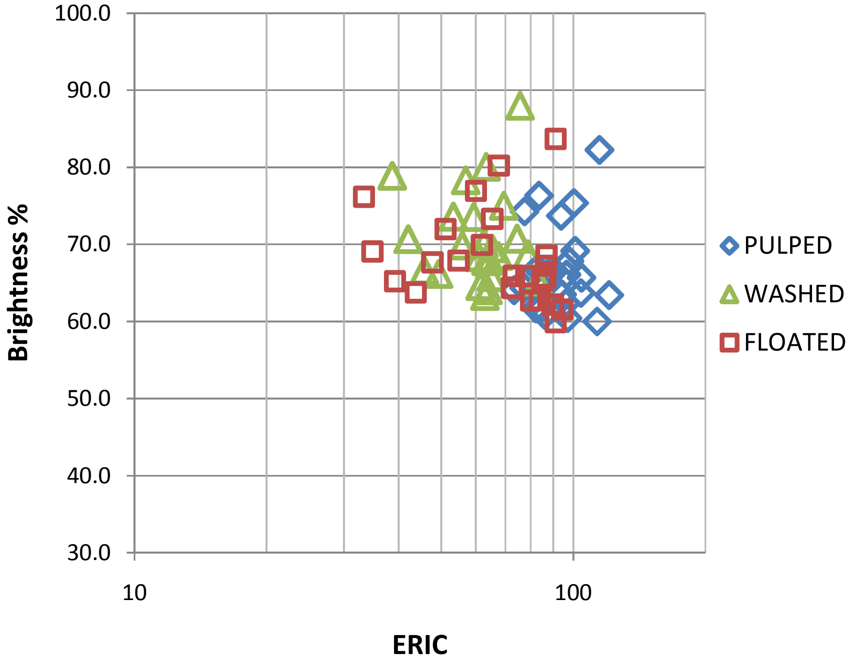

Figure 6.9: Cluster plot of brightness vs. ERIC for heavy letter 2.

6.3 Variability and drift

Throughout a screening design of 24 runs, replicates of midpoint runs (*viz.* all inputs are at their central values) were performed at random intervals, to determine the stability of the pulping and flotation procedures. The results for the trends in the midpoints of the four screening runs are shown in Figure 6.10. The coefficients of variation (CV = standard deviation/mean x100) were the highest in the HL2 runs at 4.3%, and trended upwards slightly in the HL1 run. This is most likely due to the raw material changing slightly through the run.

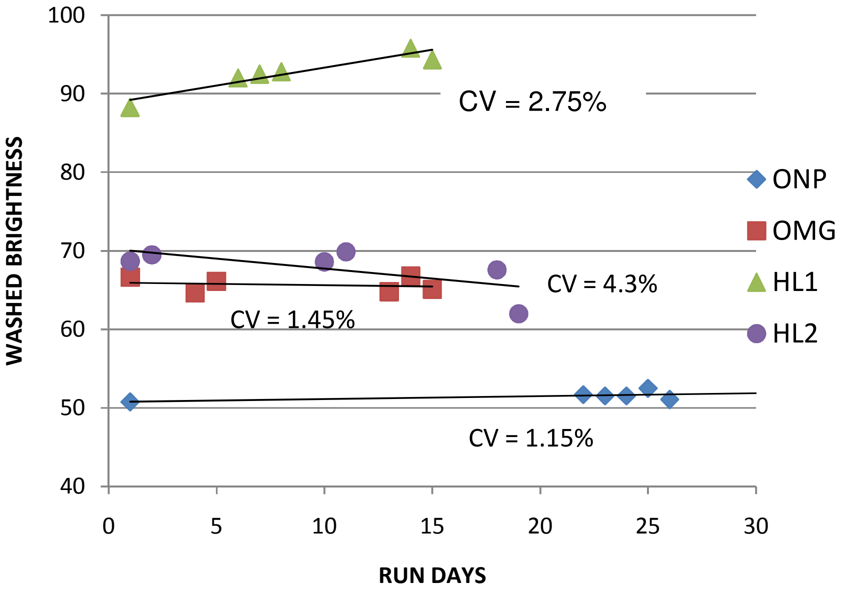

Figure 6.10: Variability and drift of final brightness.

The relatively flat trends in figure 6.10 indicate fairly constant conditions within the different runs.

6.4 Correlation between UV included (UV_{in}) and UV excluded (UV_{ex}) brightness

Paper grades contain varying quantities of fluorescent whitening or optical brightening chemicals. Newsprint contains no optical brighteners and high brightness office papers (HL1) contain large quantities. These chemicals absorb UV radiation and re-emit it in the blue region of the spectrum, thereby artificially boosting the perceived brightness of a sheet of paper. These chemicals are typically stilbenes, which can be substituted with 3 to 6 sulphonate groups, and are generally substantive (adhere chemically to the cellulose fibres). Fluorescent whitening agents are not significantly broken down by hydrogen peroxide (Section 2.9), and thus remain in the recycled fibre. In the screening trials, very close correlations were observed between the UV_{in} and UV_{ex} brightness for all the grades which contained optical brighteners (Figure 6.11).

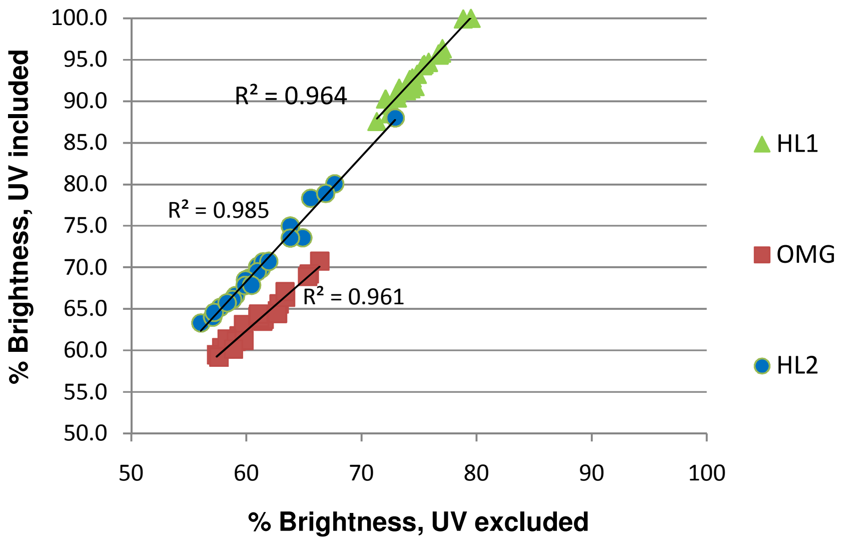

Figure 6.11: Correlation between final washed UV_{in} and UV_{ex} for HL1, HL2 and OMG.

There was a substantial difference in the UV_{in} and UV_{ex} brightness of HL1, but they were closely correlated (Figure 6.11). This confirmed that the optical brighteners were not acted upon by the bleaching or deinking processes. In this work, the UV_{in} brightness was used as the final measure, as it represents more closely what the end user of recycled paper will observe.

6.5 Results of screening runs – net effect of variables

6.5.1 Newsprint

The results of the screening runs with the associated calculation of the net effect of the various variables and waste paper grades are shown in Appendix 1A-D. A Pareto analysis of the net effects of the variables on the final washed brightness, washed ERIC and yield is depicted in Figures 6.12 to 6.14 below. Square brackets ([….]) indicate variables that have an adverse effect on the final property, *viz.* a drop in brightness or yield or an increase in ERIC.

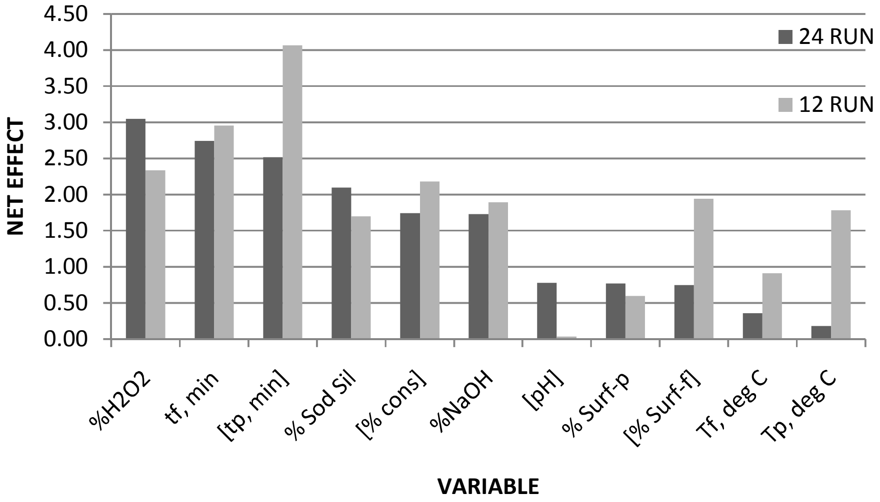

Figure 6.12: Net effect of variables on the washed brightness of newsprint.

It was observed that the net effect of the 12-run and 24-run (*viz.* reflected design) are different for some or all of the variables. The reflected design eliminates the influence of the confounded second-order or two-factor interactions from the net effect. However, where there is a significant difference between the base design (*viz.* the 12-run design) and the reflected (24-run) design, this indicates the presence of interactions. The so-called *hereditary rule* in experimental design states that the significant main effects often have significant interactions. (Barrentine, 1999:46). With reference to Figure 6.12, the large differences in t_p and T_p are probably as a result of interactions with hydrogen peroxide in the bleaching reaction, *viz.* the longer the time (t_p) and the higher the temperature in the pulper (T_p) the higher the brightening effect.

With reference to Figure 6.13, the five most significant main effects on the washed ERIC all appear to interact slightly. Since the ERIC does not depend on the bleaching chemistry so much as the ink removal efficiency, variables such as time (t_p and t_f), alkalinity ([NaOH] and [sodium silicate] concentrations) and flotation consistency all play a small role, but hydrogen peroxide plays no role.

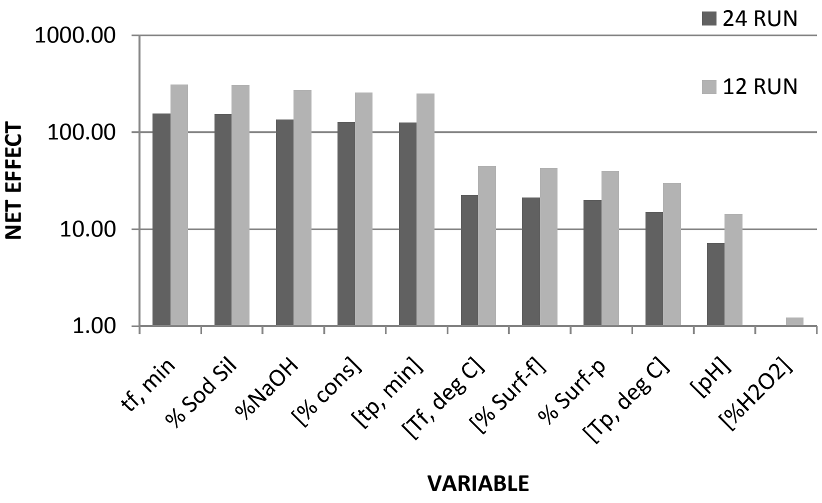

Figure 6.13: Net effect of variables on washed ERIC of newsprint.

Factors which affect the flotation of fibres rather than ink seem to play a role in determining the yield. Figure 6.14 indicates that the main variables influencing fibre yield were flotation conditions (t_f and consistency) and to a lesser extent sodium hydroxide concentration and surfactant concentrations (Surf-f and Surf-p).

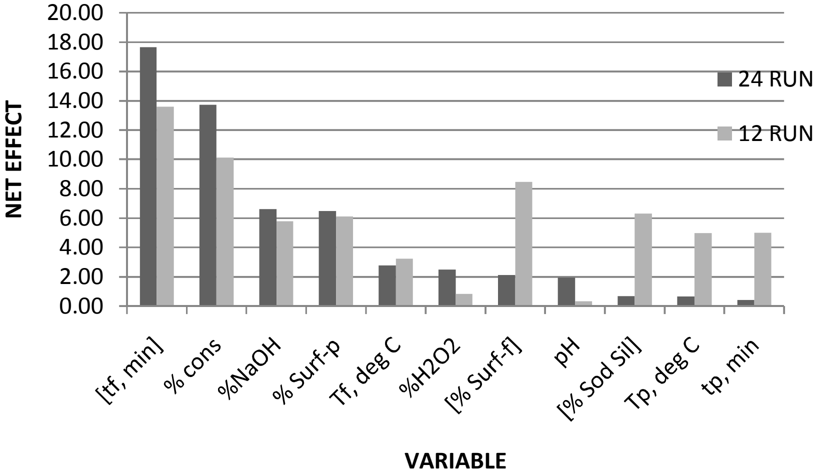

Figure 6.14: Net effect of variables on the yield of newsprint.

6.5.2 Magazines

Similarly, the Pareto analysis of the main variables affecting the deinking of magazine waste are shown in Figures 6.15 to 6.17. In general terms, the variables had similar effects for both newsprint and magazine waste. The ERIC was not influenced by the concentration of hydrogen peroxide or bleaching chemistry, because ERIC is a direct measure of ink, irrespective of the underlying brightness of the paper substrate.

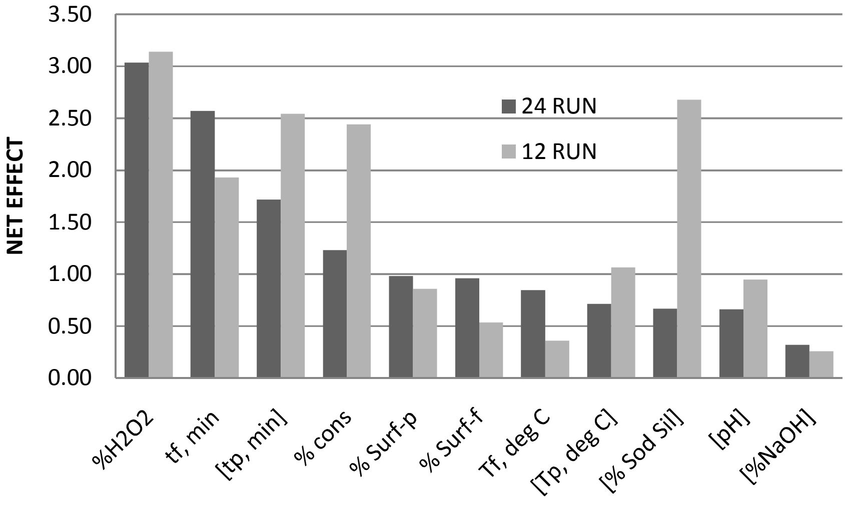

Figure 6.15: Net effect of variables on the washed brightness of magazine papers.

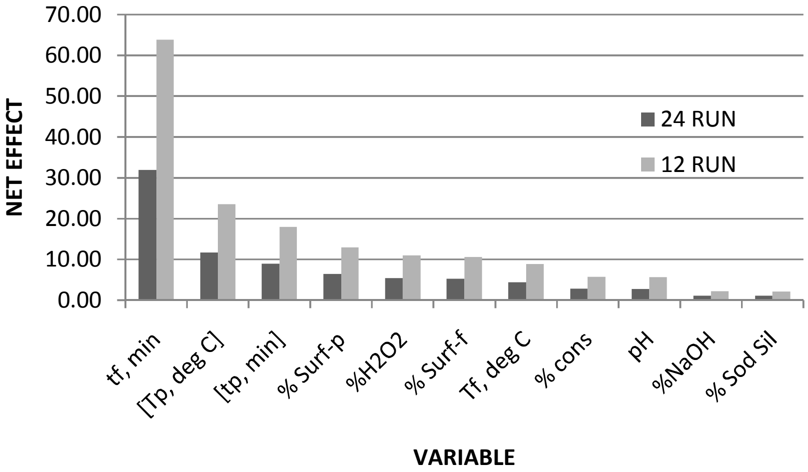

Figure 6.16: Net effect of variables on the washed ERIC of magazine papers.

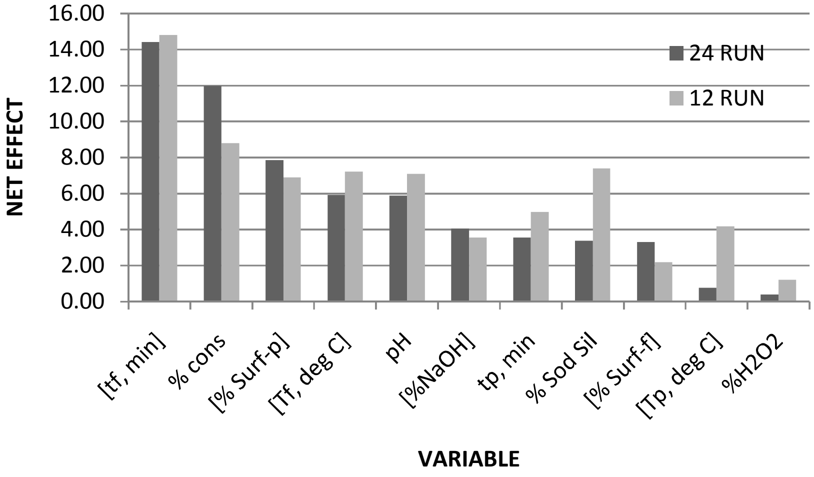

Figure 6.17: Net effect of variables on the yield of magazine papers.

6.5.3 Heavy Letter 1 (HL1)

The Pareto analysis for heavy letter 1 is shown in Figures 6.18 to 6.20.

With reference to Figure 6.18, the process residence time (as given by pulping time t_p and flotation time t_f) plays a large role in determining the final brightness, as does the alkalinity (combination of sodium silicate and sodium hydroxide). Hydrogen peroxide seems to play a lesser role, probable due to the already very high base brightness of Xerographic papers.

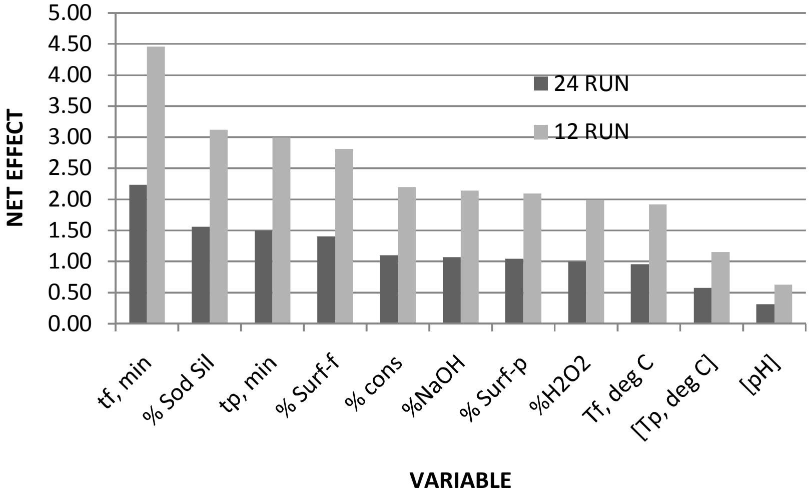

Figure 6.18: Net effect of variables on the washed brightness of HL1.

The influence of pulping temperature (T_p) in deinking of office paper grades agrees with Berg *et al.* (1997), who found that higher temperatures close to or above the softening points of the toner particles facilitated the detachment of toner from fibres. The prominent role of sodium hydroxide and its effect on ink fragmentation was also evident.

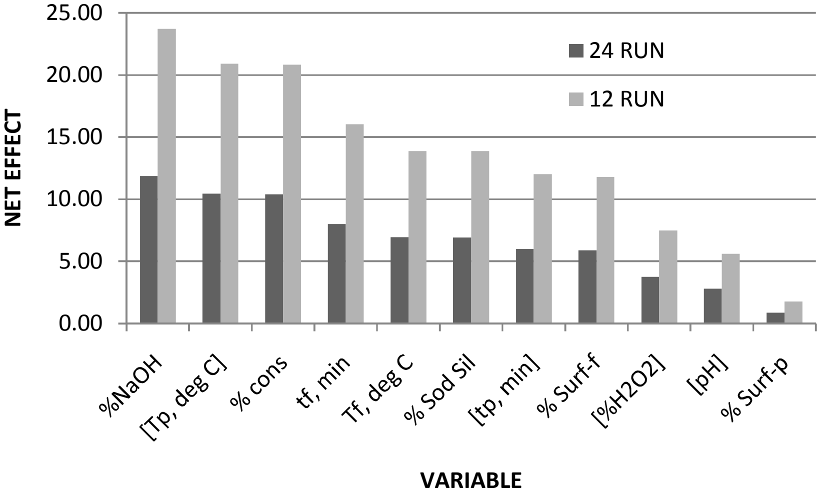

Figure 6.19: Net effect of variables on the washed ERIC of HL1.

Not surprisingly, the hydrogen peroxide concentration is not a significant factor. In fact the data suggests that it plays a slightly negative role on the ERIC, which is not easy to explain.

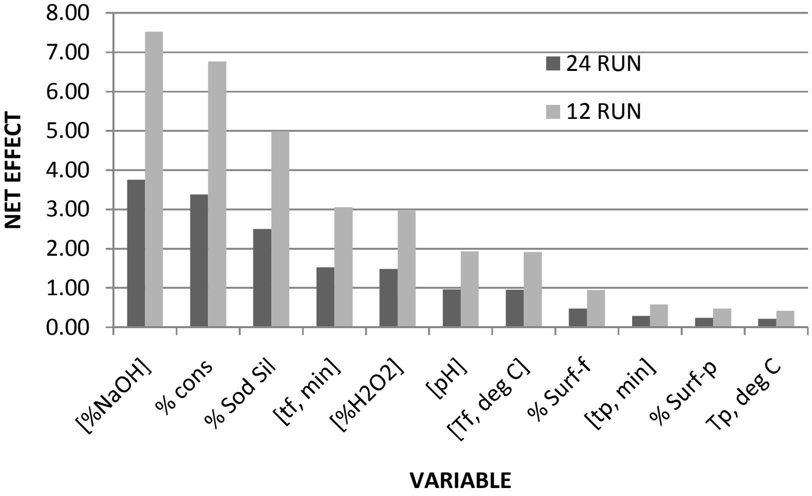

Figure 6.20: Net effect of variables on the yield of HL1.

Factors which affect the flotation of fibres rather than ink seem to play a role in determining the yield. Figure 6.20 indicates that the main variables influencing fibre yield were alkalinity (NaOH and sodium silicate) and flotation conditions (t_f and consistency). As expected, hydrogen peroxide played a minimal role.

6.5.4 Heavy Letter 2 (HL2)

The Pareto analyses of the main variables affecting the deinking of HL2 are shown in Figures 6.21 to 6.23. The effect of pulping temperature (T_p) on brightness was prominent for this grade, again due to its role in the fragmentation of the electrographic inks found on this type of paper. A higher pulping temperature also benefited the bleaching reaction. HL2 has a lower base brightness than HL1, and thus hydrogen peroxide was seen to have a greater effect on the brightness.

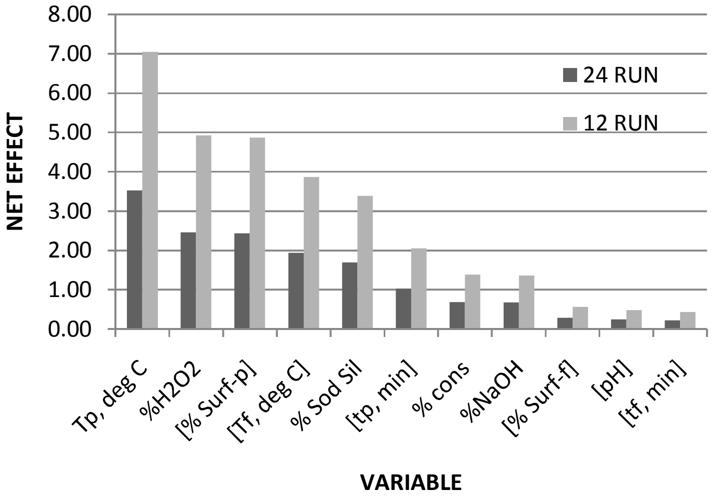

Figure 6.21: Net effect of variables on the washed brightness of HL2.

With respect to the ERIC of HL2 (Figure 6.22), hydrogen peroxide continued to play a negligible role, with flotation conditions (consistency and time t_f) dominating.

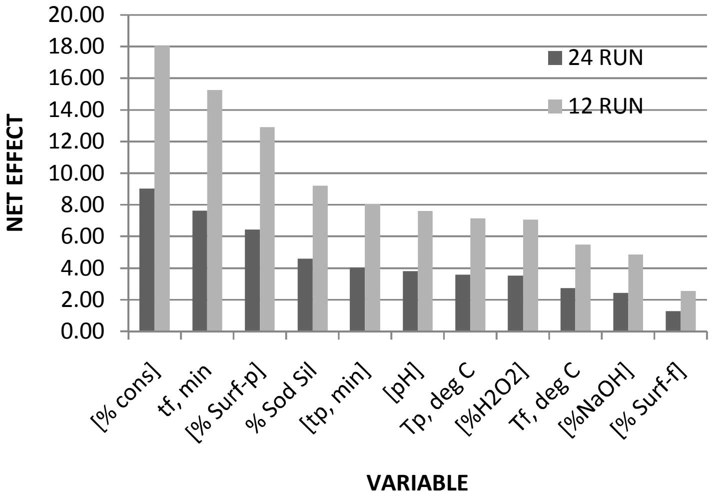

Figure 6.22: Net effect of variables on the washed ERIC of HL2.

A different set of variables affected the yield of HL2 (Figure 6.23). Flotation conditions (consistency and time) now dominated and alkalinity has become less influential.

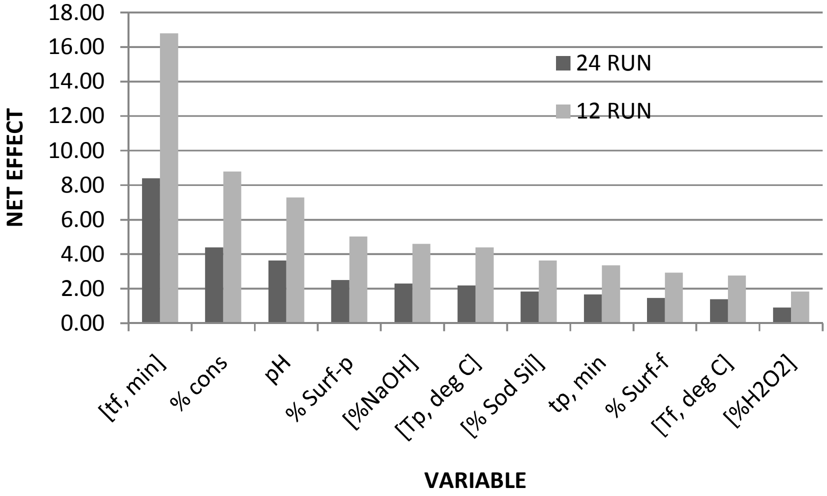

Figure 6.23: Net effect of variables on the yield of HL2.

6.6 Selection of control variables

The objective of this work was not so much to identify and explain all the interactions that take place in a deinking system, but rather to identify the global variables most influential in producing the main effects and then model the output. In order to select the best combination of potential control variables, a *factor ranking analysis* was carried out. The variable or factor responsible for the greatest net effect in each case was assigned the rank of 1, intermediate factors were assigned ranks of 2 to 10 and the factor with the least effect was assigned a rank of 11. The outputs for which factors were ranked were washed brightness, washed ERIC and the yield. For each factor the mean, greatest (1) and least (11) rank across all of the waste paper grades and all outputs was calculated and arranged in ascending order. The order of priority for the ranking was taken as greatest rank first followed by mean rank. These calculations are shown in Appendix 2, and summarized in Figure 6.24.

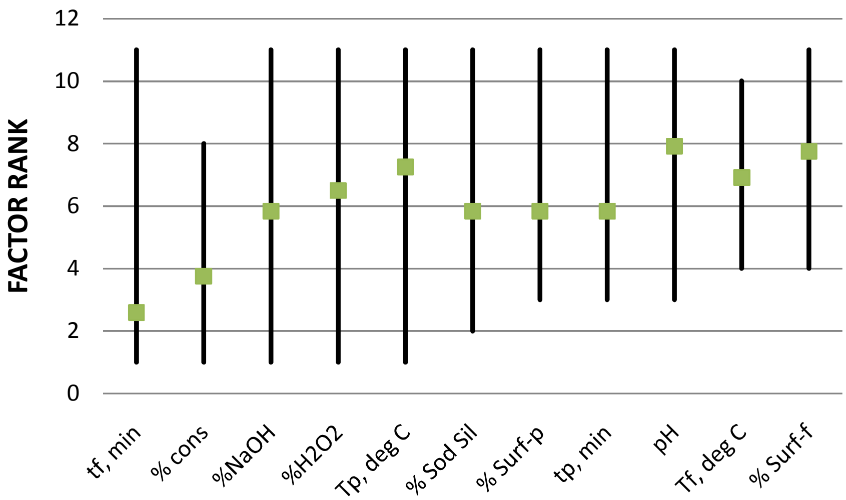

Figure 6.24: Ranking of control variables – greatest influence-MEAN-least influence.

It can be seen from Figure 6.24 that the flotation pH, surfactant concentration in the float cell (%Surf-f), the flotation temperature (T_f) and pulping time (t_p) are the least ranked variables on average. Their greatest ranking was only 3-4.

Energy constraints and the requirement for heat transfer equipment make the temperature an uneconomical control variable. In addition, the effect of temperature in flotation was small. Thus temperature was eliminated as a practical control variable. However, in some instances T_p (in the case of HL2 brightness, HL1 ERIC and OMG ERIC) was a factor which showed significant influence. In these cases the T_p can be considered an important *optimisation* variable, whilst not being suitable for process control purposes.

The pulping time (t_p) appeared to have a small influence on the outcome of deinking. This is in agreement with the discussion in Section 2.2.4.

Flotation pH and surfactant concentrations, particularly in the flotation cell in the float cell were deemphasized in terms of data collection, especially as no surfactant is added into the float cells in the three deinking mills under study.

In addition to the grade of recycled paper, the remaining variables *viz.* flotation conditions (time and consistency), alkalinity (sodium hydroxide and sodium silicate) and bleaching are the most practical and influential variables to control the de inking process.

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CHAPTER 7: GENERATION OF LABORATORY DATA

7.1 Introduction

A combination of a statistically designed screening process, a ranking analysis and practical considerations resulted in the elimination of pulping temperature, flotation temperature and surfactant addition in the flotation cell as influential parameters in the deinking process. This resulted in a shortened list of modelling parameters, listed in descending order of ranking of effect:

- Flotation time
- Flotation consistency
- NaOH addition level
- H_2O_2 addition level
- Sodium silicate addition level
- Surfactant addition to the pulper
- Pulping time
- Flotation pH

These parameters were varied, in conjunction with the four grades of recycled paper in varying proportions to generate data for the training of a neural network model. Excluding the four grades of waste paper, eight possible control variables remained under consideration.

7.2 Methodology

The four grades of recycled paper formed a "mixture", which means that the sum total of all the components must total 100%. A four-component mixture can be represented in a tetrahedral mixture space, which will correspond to all possible proportions of waste that add up to 100%. With reference to Figure 7.1, the single components are represented by the corners of the tetrahedron. Two-component mixtures are represented along the edges of the tetrahedron, three-component mixtures fall on the surfaces and four component mixtures will fall within the body of the tetrahedron. (Brereton, 2006: 86)

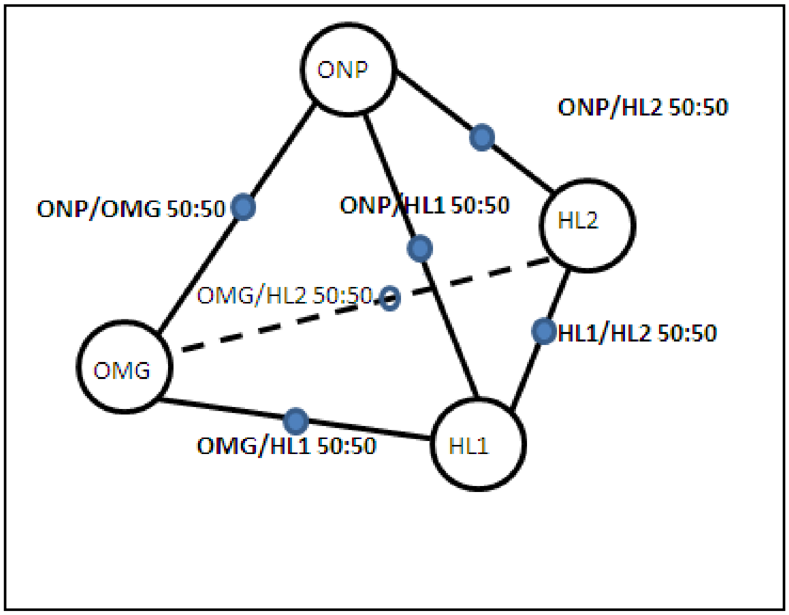


Figure 7.1: Mixture space for four recycled paper grades.

Accordingly, the percentage waste mixes depicted in Table 7.1 were run.

For each of these mixtures, about 15 runs were performed in which the eight variables listed in Section 7.1 were varied randomly (using the random number function RAND() in Excel), and the remainder were held constant. The ranges of variation were modified due to practical reasons. The new ranges are summarized in Table 7.2.

In addition to these mixtures, a number of ONP/OMG 25:75, ONP/OMG 75:25, HL1/HL2 25:75 and HL1/HL2 75:25 blends were run, to provide more data for the specific industrial processes of newsprint deinking and office waste deinking.

Thereafter, numerous runs (denoted as Test1 to Test60) were carried out in which all variables (waste grades and process parameters) were varied randomly within the limits given in Table 7.2. In addition, a Plackett-Burman design on a ONP/OMG/HL1/HL2 25:25:25:25 waste mix was run, denoted as ALL1 to ALL24. Finally Mix1 to Mix40 were run at a higher flotation consistency, as the plants were running higher consistencies than the original consultations had indicated. The brightness, ERIC and yields were determined as described in Chapter 5.

Table 7.1: Waste mixture experimental design.

WASTE GRADE MIX	ONP	OMG	HL1	HL2
Plackett-Burman ONP	100	0	0	0
Plackett – Burman OMG	0	100	0	0
Plackett – Burman HL1	0	0	100	0
Plackett – Burman HL2	0	0	0	100
ONP/OMG 50:50	50	50	0	0
ONP/HL1 50:50	50	0	50	0
ONP/HL2 50:50	50	0	0	50
OMG/HL1 50:50	0	50	50	0
OMG/HL2 50:50	0	50	0	50
HL1/HL2 50:50	0	0	50	50
ONP/OMG/HL1 33:33:33	33.3	33.3	33.3	0
ONP/OMG/HL2 33:33:33	33.3	33.3	0	33.3
ONP/HL1/HL2 33:33:33	33.3	0	33.3	33.3
ONP/OMG/HL2 33:33:33	33.3	33.3	0	33.3
OMG/HL1/HL2 33:33:33	0	33.3	33.3	33.3
ONP/OMG/HL1/HL2 25:25:25:25	25	25	25	25

Table 7.2: Modified ranges of deinking parameters with reasons for changes.

Variable	Plackett-Burman range	Modified range	Reason for change
ONP	100	0; 25; 33; 50; 75; 0-100	Mixing design and randomly varied
OMG	100	0; 25; 33; 50; 75; 0-100	Mixing design and randomly varied
HL1	100	0; 25; 33; 50; 75; 0-100	Mixing design and randomly varied
HL2	100	0; 25; 33; 50; 75; 0-100	Mixing design and randomly varied
%NaOH	0 7 & 0.67	0 – 1.5	Extended to include greater variability
% Sodium silicate	0 & 2	0 - 3	Extended to include greater variability
% H_2O_2	0 & 1	0 - 2	Extended to include greater variability
%Surfactant in pulper	0.25 & 0.75	0.25 – 1.0	Extended to include greater variability
Pulping time, mins	5 & 15	5 - 15	
Pulping temperature, ºC	35 & 50	43	Eliminated as control variable, maintained constant
Flotation temperature, ºC	30 & 45	38	Eliminated as control variable, maintained constant
Flotation consistency, %	0.8 & 1.3	0.8 – 1.3	
Flotation pH	8 & 10	7 -10	Extended to include greater variability
% Surfactant in flotation cell	0 & 0.5	0 – 0.25	De-emphasized as a control variable, only a few variations run
Flotation time, mins	5 & 20	2 - 12	Reduced, very little change in 12-15 min. range.

7.3 Results

A total of 490 deinking runs were carried out, as per the methodology described in Section 7.2. The raw material inputs, process variables and outputs are detailed in Appendix 3.

Interspersed with the deinking runs were midpoint runs for the four base recycled paper grades. Figures 7.2 to 7.5 depict the midpoint results for the four base grades across all the main properties measured. Statistics for the midpoint runs are summarized in Table 7.3. The statistics are presented for the Plackett-Burman runs in Chapter 6 and the total data base of Chapter 7.

A logarithmic scale was used for the y-axis, to accommodate the large range in the data and to enhance visibility.

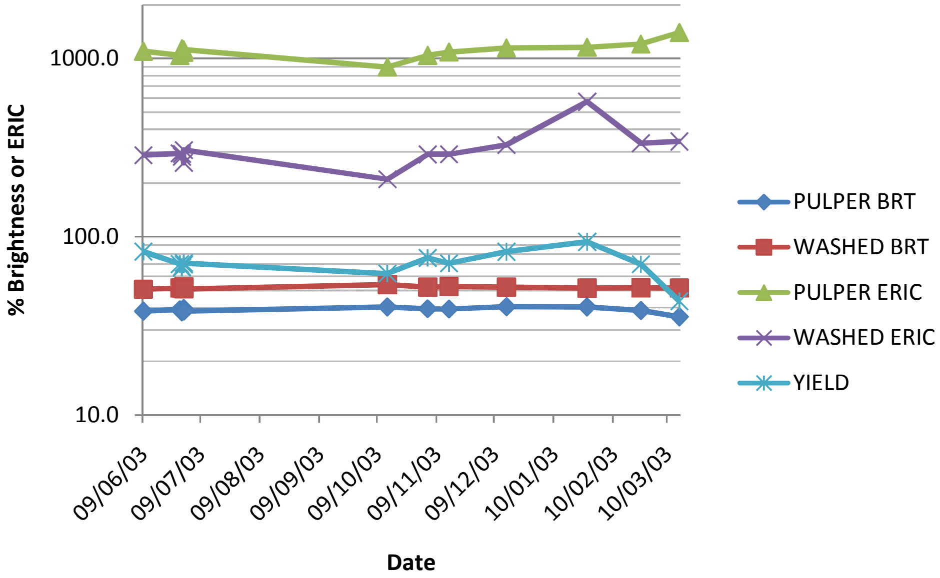


Figure 7.2: Variability and drift in ONP results (Brightness & Yield in %, Eric in ppm).

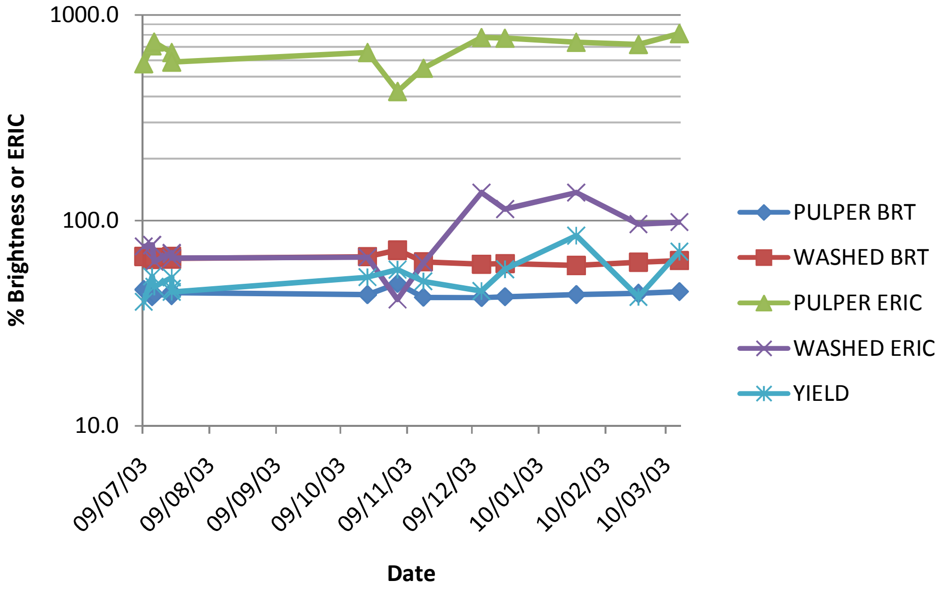


Figure 7.3: Variability and drift in OMG results (Brightness & Yield in %, Eric in ppm).

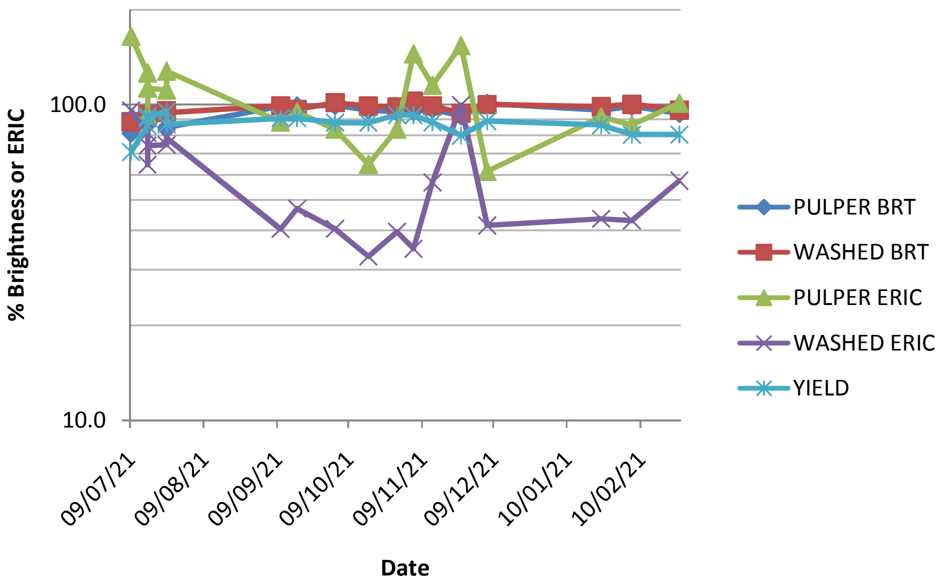


Figure 7.4: Variability and drift in HL1results (Brightness & Yield in %, Eric in ppm).

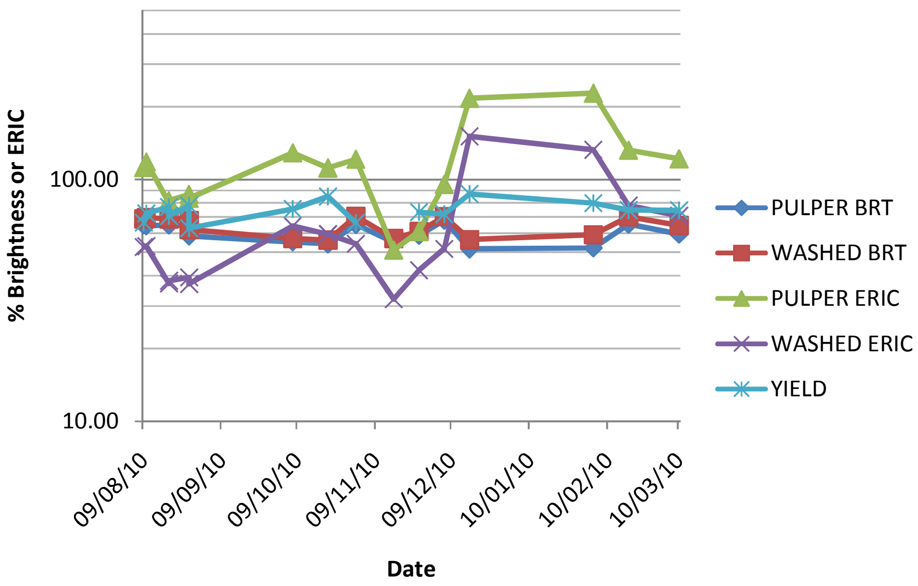


Figure 7.5: Variability and drift in HL2 results (Brightness & Yield in %, Eric in ppm).

7.4 Conclusions

It is apparent from Figures 7.2 to 7.5 that approximately level trends were maintained throughout the experimental period, with some variability. As the laboratory runs progressed, the variability of the midpoints increased to higher levels than seen in the initial Plackett-Burman runs (Table 7.3). The coefficient of variation of the brightness generally remained below *ca*. 6%, with HL2 varying at 9%. On the other hand, the variability of the ERIC was much higher, reaching 42% for HL2. Also, the office waste grades showed greater variability than the newsprint or magazine grades. The variability of the yield data was between that of the brightness and ERIC, peaking at 22% for OMG, but generally in the region of 8-10%.

This variability is the result of varying recycled paper composition through the experimental period. It was difficult to obtain exactly the same blend of raw materials for each series of runs, particularly for the HL2. The HL2 contained difficult to reproduce blends of pastel colours. On the other hand, the newsprint composition remained stable. This variability was not considered a negative, as great variability is a feature of real world deinking plants, and it was expected to contribute to greater robustness of the neural network model.

These results formed the data base for the training of the neural networks.

Table 7.3: Statistics for the midpoints of the base grades.

Grade	Experimental design	Statistics	Pulper bright %	Washed bright. %	Pulper ERIC, ppm	Washed ERIC, ppm	Yield %
ONP	**Plackett-Burman**	Mean	38.5	51.5	1098	287	71.5
		Standard deviation	0.6	0.6	33	16	5.6
		Coefficient of variation %	1.5	1.1	3	5	7.9
	Overall	Mean	38.9	51.9	1117	314	71.4
		Standard deviation	1.3	0.8	113	84	11.8
		Coefficient of variation %	3.4	1.5	10	27	16.5
OMG	**Plackett-Burman**	Mean	44.1	65.7	643	69	47.5
		Standard deviation	1.3	1.0	68	5	5.0
		Coefficient of variation %	2.9	1.5	11	7	10.5
	Overall	Mean	44.0	64.6	664	83	53.3
		Standard deviation	1.9	2.9	107	29	11.8
		Coefficient of variation %	4.3	4.5	16	34	22.1
HL1	**Plackett-Burman**	Mean	88.0	92.6	123	78	86.8
		Standard deviation	4.5	2.5	24	10	8.6
		Coefficient of variation %	5.1	2.7	20	13	9.9
	Overall	Mean	93.9	96.7	106	58	87.0
		Standard deviation	5.3	3.8	29	21	5.9
		Coefficient of variation %	5.7	3.9	27	37	6.8
HL2	**Plackett-Burman**	Mean	63.6	67.7	94	43	71.1
		Standard deviation	2.6	2.9	17	8	5.9
		Coefficient of variation %	4.1	4.3	18	18	8.3
	Overall	Mean	60.4	64.2	114	62	74.3
		Standard deviation	5.4	5.7	48	34	6.6
		Coefficient of variation %	9.0	8.9	42	54	8.9

CHAPTER 8: NEURAL NETWORK MODELLING OF LABORATORY DATA

8.1 Introduction

Neural network projects are akin to information technology projects in terms of their development. Neural networks are data driven and typically need large quantities of data to effectively model large complex systems (Tarassenko, 1998). The amount of data that had been collected (490 inputs) was limited due to time and resource constraints. The challenge in this particular case was to obtain the best possible network with the data available.

In terms of Equation 10 in Section 4.4.5, the ideal number of input vectors P, should lie between W and 10W:

$$\mathrm{W} = (\mathrm{I} + 1)\mathrm{J} + (\mathrm{J}+1)\mathrm{K} \tag{10}$$

Where I = number of inputs, J = number of hidden neurons and K = number of outputs. In order to make optimum use of the 490 (=P) training vectors available, K was restricted to 1 output, and I was minimized by training the network with only those variables which have the most significant effects on the process. Restricting K to 1 meant that the properties of brightness, ERIC and yield were modelled separately using the same data set. The number of neurons in the NN model (J) was selected so as to produce the highest performance.

8.2 Software

A commercial software package, MATLAB Version R2009a was used to implement the neural network model of the laboratory deinking data. Notwithstanding the general principles of neural networks outlined in Chapter 4, the specific terminology and methodology as implemented in the MATLAB package was used. This is discussed in Section 8.3.

8.3 Training using MATLAB

8.3.1 General methodology

The application in question was that of function fitting, and it has been found that a feed-forward network structure with one hidden layer and an output layer is capable of approximating any function (Demuth *et al.*, 2009). In particular, the hidden layers typically contain the tan-sigmoid transfer (or activation) function and the output layer commonly contains a linear transfer function (Section 4.4.2).

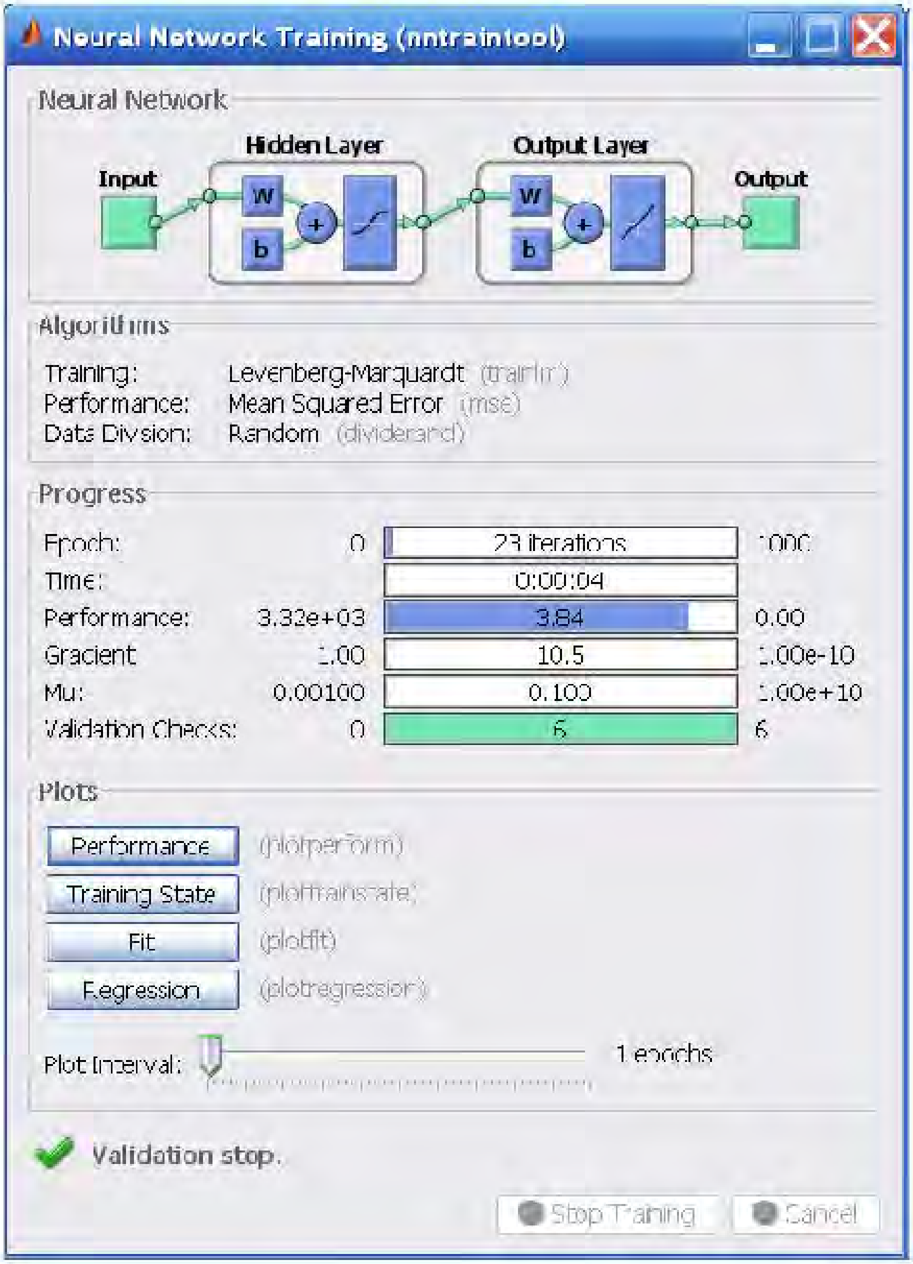
The number of input layers corresponds to the number of variables in the input vector, and the number of output layers corresponds to the number of outputs. In this work, a single output layer was chosen as explained in Section 8.1. The number of neurons required was to be determined by iteration. The greater the number of neurons, the more complex is the function which can be approximated. On the other hand, more neurons require more data which can also lead to over-fitting of a function (Demuth *et al.*, 2009:1-8).

The MATLAB neural network toolbox makes use of the following default settings and procedures for training networks for function fitting:

- The input vectors are divided randomly upon initialisation into three sets as follows: 70% of the data for training; 15% of the data for validation and 15% for independent testing.
- The network is initialized with random values close to zero and the data is presented as a batch *a.k.a.* batch training (Figure 8.1 and Section 4.6.3).
- The performance of the network is determined by computing the mean-square-error (MSE) of all the sets.
- The MSE of the validation and test sets typically decrease to a minimum and then increase again. However, the MSE of the training set continues to decrease as training proceeds. The network is approximating the data more and more closely, and gets to a point where the data is memorized. This is referred to as over-fitting, illustrated in Figure 4.9. Unfortunately the result of over-fitting is that the underlying trends are compromised, and the network will no longer predict well (poor generalisation) with unseen data (Demuth *et al.,* 2009). Thus, once the validation set has increased for six iterations, the training

is stopped (early stopping) and the network weights at the minimum point are retained as the final weights for the trained network (Figure 4.8 and Figure 8.2).

- Once the training is complete, the regressions of the training, validation and test sets are calculated and displayed (Figure 8.3).



Algorithms

Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Data Division: Random (dividerand)

Progress

Epoch: 0 | 23 iterations | 1000
Time: 0:00:04
Performance: 3.32e+03 | 3.84 | 0.00
Gradient 1.00 | 10.5 | 1.00e-10
Mu: 0.00100 | 0.100 | 1.00e+10
Validation Checks: 0 | 6 | 6

Plot Interval: 1 epochs

Validation stop.

Figure 8.1: MATLAB training window, showing training parameters. (Demuth *et al.*, 2009:1-9)

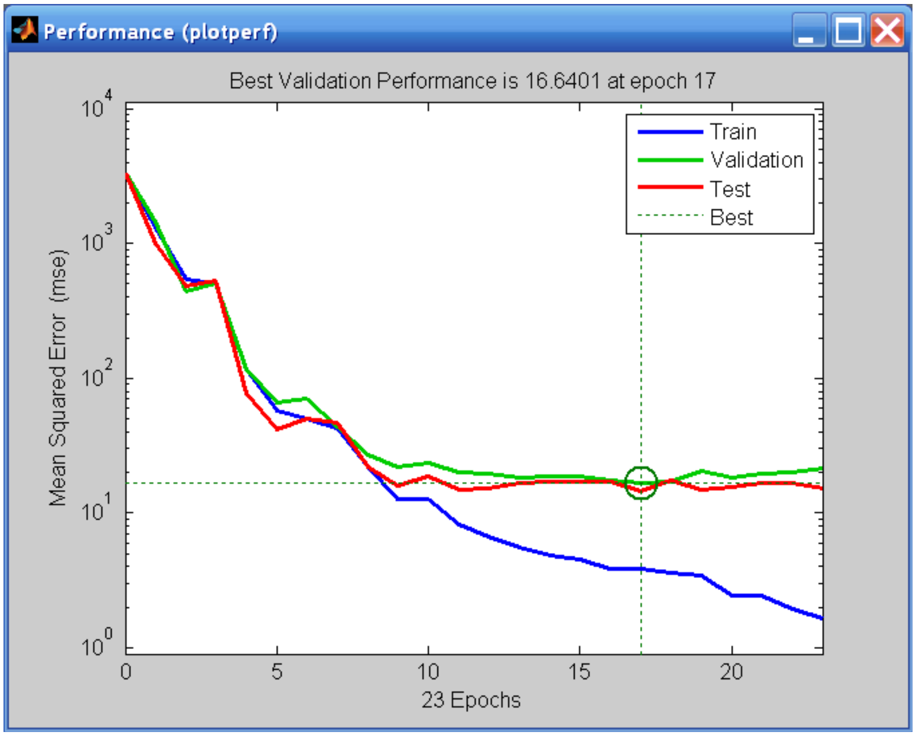


Figure 8.2: Example of plot of performance of training, validation and test sets, demonstrating early stopping. (Demuth *et al.*, 2009: 1-10)

The phenomenon of the error associated with the validation set increasing after the optimum stopping point has been discussed in Section 4.6.4.2.

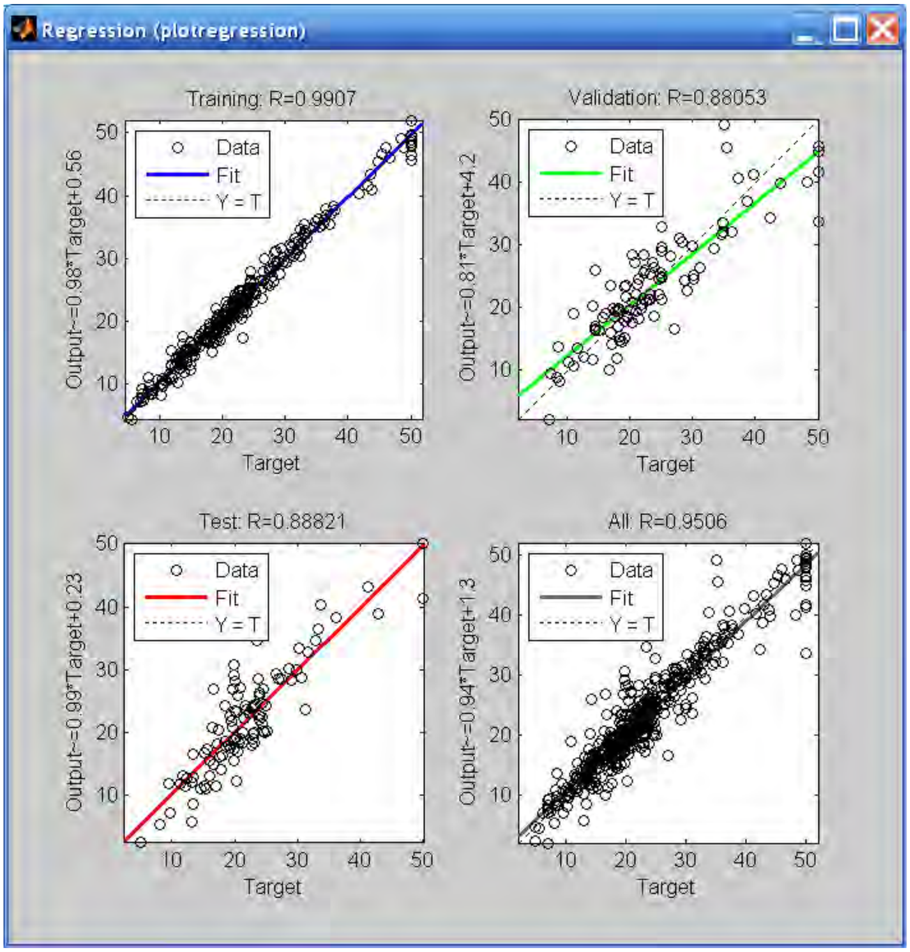


Figure 8.3: Example of plots of regression of a training session. (Demuth *et al*., 2009: 1-10)

At this point the training information and the neural network can be saved and inputted with other real data to produce a predicted output. If the performance of the network is not adequate, a number of possibilities exist (Demuth *et al*., 2009: 1-10):

- The network can be reset or initialized with new initial weights and biases and retrained,
- The number of neurons can be increased or decreased,
- More data can be added to the training set,
- Change the number of input values,
- The ratio of data in training, validation and test sets can be changed,

- Try alternate learning and training algorithms.
- Pre-processing of inputs and outputs

It is obvious from the above that training of a neural network was a highly iterative process, with many parameters that could be manipulated to produce the desired result. There are no hard and fast rules, and experience plays a role. Arriving at the final “best” network has been likened to cooking (Hajek, 2010), where a good recipe has to be found by trial and error.

8.3.2 Specific training options used

8.3.2.1 Network initialisation

Each time the network is initialised, different initial parameters are introduced which might produce a different final solution. Thus with the same network structure and input data a number of different solutions can be obtained purely by re-initializing and retraining. It was found that the first training attempt could generally be improved upon, but after three or four initializations the training performance started to decrease.

8.3.2.2 The number of neurons and layers

An increasing number of neurons will give the network more power to approximate the function. However, too many neurons will lead to over-fitting and poor generalisation (Demuth *et al.,* 2009:5-52). In addition, more neurons will require more data as discussed in Section 8.1, a shortage of which could lead to under-characterization of the function (Demuth *et al.,* 2009:5-6).

It was found in this work that low numbers of neurons (1 to 3) generally lead to linear functions, more neurons (3 to 5) produced curve-linear functions and more neurons (> 5) tended to produce complex, over-fitted functions. However, the use of Bayesian Regularisation (Section 8.3.2.6) tended to reduce the tendency of networks to over-fit.

In addition to the number of neurons, the number of hidden layers could also be increased, to allow the network to respond to complex functions. This will of course require even more data. This was attempted in this work but did not improve generalisation. As in polynomial fitting, the network should have fewer parameters (weights and biases) than data points in the training set. Thus the practice is to use the simplest network that adequately describes the data (Hagan *et al.,* 1996:11-23).

8.3.2.3 Addition of data

As with polynomial fitting, more data will allow more neurons to be used and better generalisation to be achieved. The data in this work was limited to 490 training vectors, due to time and resource constraints.

8.3.2.4 The number of input values

The number of input values could not be arbitrarily reduced, but had to be done with due consideration of the effect of the different parameters on the final outcome. Thus, the process of selecting the initial number of input values was informed by the results of the Plackett-Burman designs, where only those process parameters which have a consistent and significant effect on the final properties were selected. These experimental designs were useful as a first step, but could not be expected to predict the behaviour of the system in complex mixtures of four different waste grades. The process of evaluating the neural networks (see Section 8.6) revealed that certain parameters were not consistently reliable in influencing the process and were thus eliminated. This resulted in a further reduced number of input variables.

8.3.2.5 The ratio of data in training, validation and test sets

Initial work was carried out using the default split of training:validation:test::70:15:15. As more data became available, the split was changed to 80:15:5, and an additional test set of 40 vectors, drawn from the database of 441 vectors and common to all training runs was employed. This facilitated a comparison of networks by using the same test set for all networks.

The training, validation and test data sets were divided randomly in the ratios specified above, for all training runs.

8.3.2.6 Learning and training algorithms

Data structure

There are two types of input data structure: *concurrent* input vectors are presented to the network at the same time in no particular time sequence, and *sequential* input vectors, which are presented one at a time, in a particular order.

Static networks (where there are no feedback loops or delays) are commonly trained with concurrent data, whereas *dynamic* networks are trained with sequential data, where the order of data presentation is important. In a processing environment, neural networks which undergo continual training with live plant data would be dynamic in nature. For the current work, a static network was used. (Demuth *et al.,* 2009:2-14)

Training styles

In *incremental* training the weights and biases of a neural network are updated each time an input vector is presented to the network, whereas in *batch* training all the input vectors are presented and the weights and biases are then updated. Incremental training is commonly used to train dynamic networks, although incremental training can also be applied to static networks (Demuth *et al.,* 2009:2-20). This can assist to alleviate the problem of converging to local minima in back propagation training (Hajek, 2010). In the current work, because a static network was being trained, batch training was used.

Training algorithms

MATLAB presents many different methods of mathematically implementing back-propagation by gradient descent. The Levenberg-Marquardt method of back-propagation by gradient decent has been shown to be fast and accurate for function approximation type problems for networks with less than one hundred weights, and has thus been used in this work. A disadvantage of the Levenberg-Marquardt algorithm is that it requires a large amount of computer memory (Demuth *et al.,* 2009:5-50, Hagan *et al.,* 1996:12-27), which was however not a constraint in this work.

Prevention of over-training

The early stopping procedure described in Section 8.3.1 was used for all training.

Performance functions

The default performance function is the mean square error (mse), which is defined as the difference between the network output and the target output, squared and summed. This function was used in the early training exercises. However, this was modified in later training runs by invoking *regularisation.* In regularisation, a performance term consisting of a combination of the mean squared sum of the network weights and biases (msw) and the mean square error (mse) is used, as follows:

$$msereg = \gamma . mse + (1 - \gamma) . msw \qquad (1)$$

where γ is termed the *performance ratio*.

This function tends to reduce the weights and biases in the network itself, resulting in a smoother response with less likelihood of over-fitting. There is some guesswork involved in the selection of the performance ratio. If γ is too close to 1 then the performance function will essentially be mse, and if it is too low msw will dominate and generalization will be poor. The MATLAB default of γ = 0.5 was used. An advanced technique called *Bayesian Regularisation* has been implemented in MATLAB, which chooses the optimum value for γ (Demuth *et al.,* 2009:5-56). This technique was used in the final phases of training.

8.3.2.7 Pre-processing

By default, MATLAB applies the following processing functions to data and outputs:

- Unknown input values are re-encoded into numerical values. This functionality was not required as all inputs were numerical values, and there were no blanks.
- Input values that do not change for all the input vectors are automatically removed.
- Input values were scaled linearly to values between -1 and 1, to allow faster training and obviate scaling problems with very large or very small numbers. These processes are reversed for the output values.

8.4 Problems with backpropagation

In the backpropagation algorithm, the mean square error is minimized. The error surface of a single layer linear network is a quadratic function, which when differentiated and set to zero has only one minimum. However, the error surface of a more complex multilayer network will not necessarily have only one minimum. One of the problems with back propagation is that it can converge to any one of a number of local minima, instead of the global minimum. Thus networks should be retrained a number of times, and a number of different network structures should be tried in order to find the best (global optimum) solution (Hajek, 2010; Demuth *et al.,* 2009:5-71; Hagan *et al.,* 1996:12-13). It is possible that the network can converge to two different minima, but with the same value of the squared error, resulting in very different values for the weights and biases (Hagan *et al.,* 1996:12-17).

8.5 Evaluating neural network performance

To generate a neural network for the flotation deinking system is a simple process of inputting the data into the MATLAB program and letting the computer generate any number of networks. The problem arises in deciding which network is a good representation of the physical system. As a first step this can be done mathematically by selecting the networks with the lowest mean square errors or the highest regressions.

8.6 Specific methodology and results

As the above discussion indicates, the procedure of producing a valid neural network model is highly iterative and not well defined. The following methodology was adopted after considerable trial and error.

8.6.1 Selection of output variables

To reduce the complexity of the network and the resultant data requirements, it was decided to produce separate networks for the brightness, ERIC and yield, with a view to optimising the inputs and networks for each property. The methodology was worked out using the brightness as a starting point, because the brightness is the most important and least variable of the outputs. The methodology developed for brightness was then applied to ERIC and yield.

8.6.2 Final selection of input variables by sensitivity analysis

The first decision to be made was how many variables to include in the model. Whilst the Plackett-Burman experimental runs gave an indication for single grades of recycled paper, they were limited in their ability to predict behaviour in mixtures of waste grades.

The first possibility was to start with the four waste inputs and by adding additional parameters the network performance could be monitored and the growing of the network could be stopped once a performance peak was passed (Hajek, 2008). This approach was tried, but abandoned because of the large number of possible permutations in selecting the additional parameters.

An alternate approach proved to be more convenient:

- An independent test set of 44 runs was extracted from the data. This set was selected by taking every 10th run. The training set was formed from the balance of the data.
- A series of large networks were produced by using all of the input parameters with an increasing number of neurons (ranging from 1 to 10) and retrained four times each. The number of neurons was limited to a maximum of 10, for reasons discussed in Section 8.3.2.
- The networks were ranked according to performance (regression value of the independent test set). In this way each network was tested with the same independent data set, which facilitated comparison of the networks.
- The individual variables of each network were assessed (as described later in this section) for their effect on the model output.
- Those variables which displayed a consistent behaviour (as described later in this section) were adopted as inputs to the final network.

The results of the neural network training are listed in Appendix 4A to 4C.

Those variables which displayed a consistent behaviour were adopted as inputs to the final network.

By considering hydrogen peroxide as an example, the Plackett-Burman experiments suggest, and this agrees with what is well known in the industry, that hydrogen peroxide has a favourable (mathematically positive) effect on brightness. Thus a network should predict a positive trend for brightness as a function of increasing hydrogen peroxide concentration. In some cases a trained network actually predicted a negative trend, even though the regression and mean square error values for this network were acceptable. In this case the network had obviously converged to a non-optimum local minimum, as discussed in Section 8.4. In the light of this behaviour it was necessary to use an additional means of determining whether a network actually correlated with what is well known behaviour for the deinking system. This was done by visually assessing the slope or shape of the response surface of the network output with respect to changes in input variables. The descriptors used to describe the response surface are listed in Table 8.1.

Table 8.1: Symbols and descriptors of response surfaces.

SYMBOL	DESCRIPTOR OF RESPONSE SURFACE
+	The surface had a general positive slope with respect to the independent variable. There might be maxima or minima, but an overall positive trend was discernible.
-	The surface had a negative positive slope with respect to the independent variable. There might be maxima or minima, but an overall negative trend was discernible.
+-	The surface had both positive and negative slopes with respect to the independent variable, *viz.* the surface had a saddle, ridge, maxima or minima or saw tooth shape, with no overall trend.
O	The surface had no significant slope with respect to the independent variable, *viz.* a flat response, less than 1 brightness point change.
O+, O-	The surface had a general flat response with respect to the independent variable, with a slight positive or negative slope respectively.

With reference to Figure 8.4, and applying the descriptors listed in Table 8.1, an example of such an assessment is shown in Table 8.2.

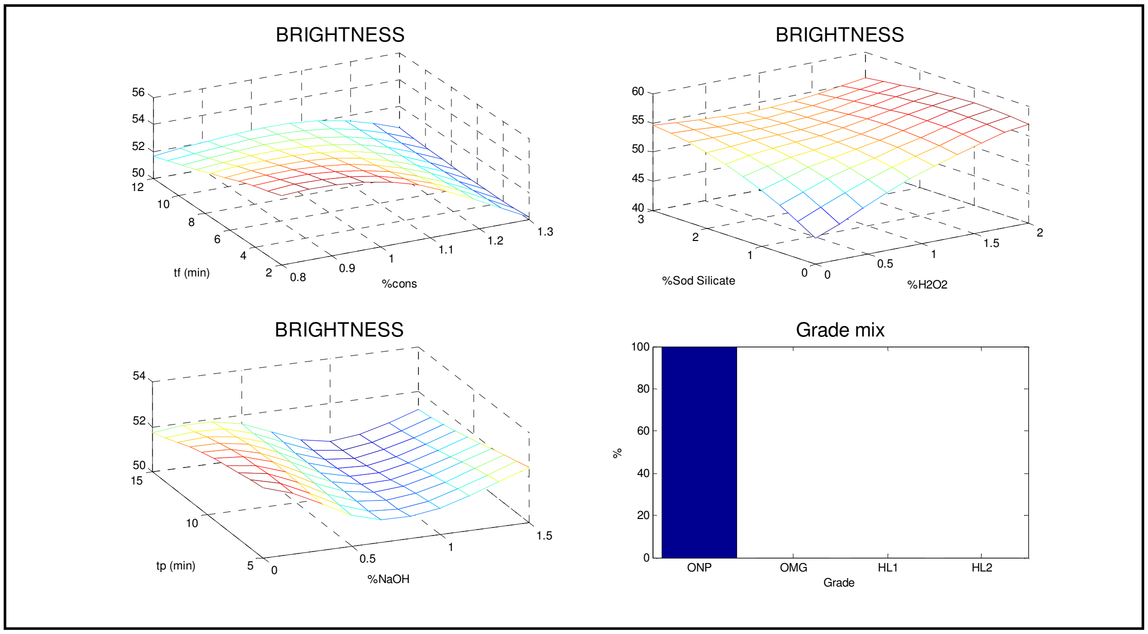


Figure 8.4: Response surface of brightness to selected variables.

Table 8.2: Assessment of response surfaces in Figure 8.4.

Variable	**Characterisation of response surface**
t_f	-
Consistency	-
% sodium silicate	+
H_2O_2	+
t_p	o-
NaOH	+-

A response surface characterized as "+" or "–"suggests that the variable has a strong and consistent influence on the output, and should be included as a potential control variable in the model. On the other hand, responses characterised by **"+-", "o", "o+"**

or “o- “ do not have a consistent or strong enough influence to qualify as good control variables.

The twenty best networks (according to regression of the independent test set, two per network size) were assessed according to Table 8.1. The results of this assessment are tabulated in Appendix 5A to 5C. For each variable, the % of each characteristic response was calculated (Appendix 5A-C), and summarized in Table 8.3.

Table 8.3: Summary of neural network model % responses to process parameters.

		%NaOH	%Sod Silicate	$\%H_2O_2$	$\%Surf_p$	t_p	%cons	pH	$\%Surf_f$	t_f
Brightness	+	[73]	74	[84]	22	47	11	14	50	[82]
	-	14	6	4	38	26	[72]	59	[26]	3
	other	13	21	13	40	27	17	27	24	15
ERIC	+	9	21	79	18	53	[85]	53	21	1
	-	[77]	48	[6]	50	21	4	12	43	[94]
	other	14	31	16	32	26	11	35	36	4
Yield	+	24	[64]	76	22	30	[84]	[68]	20	1
	-	50	6	[7]	[47]	15	1	2	42	[94]
	other	26	30	16	31	55	15	30	38	4

The shaded cells in Table 8.3 indicate those parameters for which more than 67% of the 20 neural network models predicted a definite (“+” or “–“) response. The numbers in square brackets “[ ]” indicate the most significant responses according to the Plackett-Burman screening designs. It can be seen from Table 8.3 that in most cases the results of the Plackett-Burman screening runs agreed with the predictions of a “committee” of neural networks.

The one noticeable exception is the behaviour of hydrogen peroxide. The neural networks predicted with a high percentage that hydrogen peroxide has an adverse effect on ERIC and a positive effect on the yield. In both cases this is counter-intuitive, and difficult to explain. It would be expected that hydrogen peroxide would improve brightness and leave yield and ERIC unaffected.

8.7 Discussion

The results of the training are listed in Appendix 4A to 4C. The best results for each property have been summarized in Table 8.4.

Table 8.4: Summary of best Neural Network performance.

Property	**Highest regression (R)**	**Lowest mean square error (mse)**	**Root mean square error as % of highest and lowest average**
Brightness	0.954	17.6	4.5 to 8.4
ERIC	0.840	3781	19.6 to 106
Yield	0.725	84.3	10.6 to 19.3

It is apparent that the brightness had the highest correlation (0.954) and the lowest percentage errors (4.5 to 8.4%). The correlation for ERIC was reasonable at 0.84, but the error was considerable in the case of low ERIC grades such as HL1. The yield had the lowest regression, although the percentage errors are smaller than those of ERIC.

By considering the parameters listed in Table 8.3, it can be seen that the pulping time (t_p), and surfactant concentrations in pulper and float cell (% Surf $_p$ and %Surf$_f$) do not produce consistent trends more than 50% of the time, and can thus be eliminated as influential modeling parameters. The pH had an influence on the yield. Thus, the final list of parameters reduced to:

- Flotation time (t_f),
- Flotation consistency,
- % Hydrogen peroxide,
- % Sodium hydroxide,
- % Sodium silicate and
- Flotation pH.

8.8 Further work

Subsequent to the sensitivity analysis described above, another 50 deinking runs were performed, to produce the final training data base of 490 vectors. A new set of neural networks were trained with the additional data and the consolidated list of process parameters. The final networks were tested against actual plant data (Chapter 9).

CHAPTER 9: PLANT TESTING OF NEURAL NETWORK MODELS

9.1 Introduction

In the process of training the neural networks, the test data was drawn from the laboratory generated training data set. The final process of testing involved inputting real data from functioning plants and comparing the plant outputs to the outputs predicted by the neural networks.

The laboratory simulation data was collected for the processes of (in order):

- pulping (with hydrogen peroxide bleaching),
- flotation (batch process, single stage), and
- washing (single stage)

The mills who participated in the model testing process had in some cases either more unit operations, or operations in a different order. The exact nature of the processes is discussed below. It was thus expected that the neural networks based on the laboratory model would more or less approximate the real plant processes.

9.2 Alignment of plant and laboratory flotation processes

Laboratory cells can and have been used to successfully simulate plant processes (Beneventi *et al.*, 2007; Dionne, 1994). Laboratory processes do not exactly replicate mill scale plants (Borchardt, 1993b), but are useful for comparisons and trends. Laboratory tests do not produce absolute values, as they do not take into account factors such as recirculation of contaminants in back-water systems (Ferguson, 1993). Thus, a means of “closing the gap” between laboratory and plant scale processes was sought.

Figure 9.1 depicts a typical brightness response of a laboratory cell in relation to the solids losses *viz.* the yield. Solids loss is often used as a basis for comparing laboratory flotation results to plant flotation performance (Goettsching & Pakarinen, 2000:167). The ultimate efficiency of a deinking process can be determined by a process called "infinite flotation" (McCool 1993). This is determined by floating a sample of pulp in a laboratory flotation unit for an extended period of time. This results in complete removal of the ink, but at the cost of a high yield loss.

However in this study this basis was not used, as it was not possible to accurately determine the solids losses across the commercial flotation cells. It was necessary to roughly estimate the actual flotation yields, as discussed in Sections 9.3.1.7, 9.3.2.7 and 9.3.3.7.

Figure 9.1: Brightness development vs solids losses for a ONP/OMG mix. (Goettsching & Pakarinen, 2000:167)

A more convenient basis for comparison was the flotation time. The brightness developed in a laboratory cell depends on flotation time. Figure 9.2 depicts a typical theoretical brightness response to flotation time. The initial sharp increase is due to the removal of ink particles. The dip in the plateau on the response graph represents the removal of bright fillers, which leads to a reduction in brightness. Once the fillers have been removed, the brightness increases again as lower brightness mechanical pulp fibres continue to be removed. This behaviour obviously depends on the nature of the recycled paper being floated (Goettsching & Pakarinen, 2000:167). In practice, a simpler curve with a maximum is more often encountered.

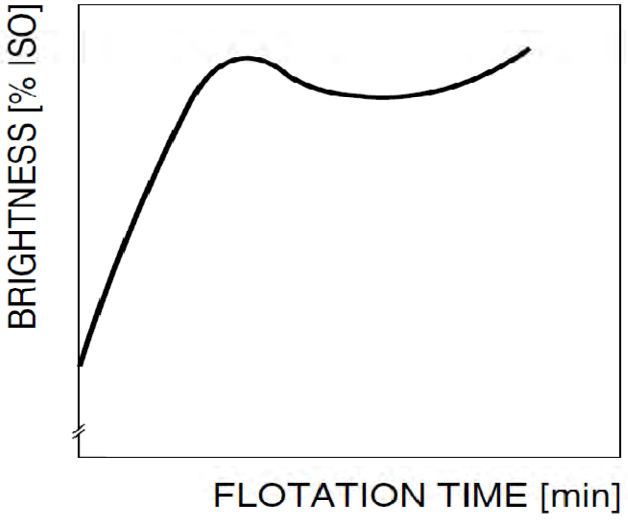


Figure 9.2: Brightness development for a ONP/OMG mixture vs time. (Goettsching & Pakarinen 2000:167)

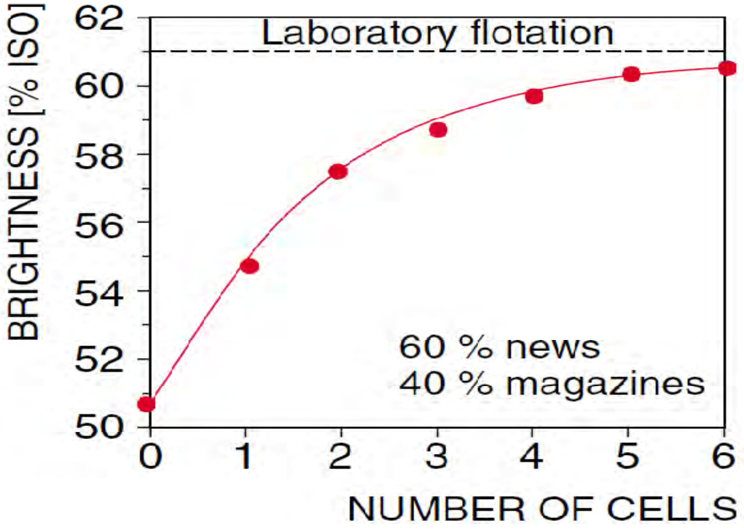


Figure 9.3: Brightness development *vs.* number of cells for a ONP/OMG mix. (Goettsching & Pakarinen 2000:167)

In a flotation plant, the brightness development depends on the relative air volume (ratio of volume of air to volume of suspension) and the number of cells in series (Goettsching & Pakarinen 2000:167), as depicted in Figure 9.3. The plant flotation cells are continuous, and the process variables are consistency and feed flow rate.

The empirical approaches by Peters *et al.* (2007) and Carrasco *et al.* (1999), discussed in Section 5.4.11, suggested a way of aligning the performance of a laboratory batch cell to a continuous plant cell through the common parameters of consistency and flotation residence time. The process of training the neural network would uncover the value of *L* equation (3), and the process of *flotation cell alignment* would determine the relationship between the constants L in equations (3) and P in equation (6) respectively.

9.3 Data collection

The collection of mill data was found to be fraught with complexities. Not all input parameters were monitored or recorded at all times. Typically, considerable variation around set points existed, and the outputs generally contained a strong scatter of data. This has also been the experience of other researchers (Moe & Røring, 2001).

Process data was collected initially from the newsprint deinking mill and the double loop office paper deinking mill. In order to obtain a wider variety of process conditions, the data collection exercise was extended to a single loop office paper deinking mill. The processes have been described in Section 5.2, but are repeated below for ease of reference. The descriptions detailed below provide the basic conditions under which the plants were operating, and formed the basis of the data collected.

Generally, shift averages (8 hours) or daily averages (24 hours) for the process conditions and outputs were collected. This depended on the amount of information normally recorded by the mill in question. Sometimes, a brightness test or other measurement was only performed once per day or once per shift. The process inputs were averaged accordingly to produce one process record per brightness test. The nature of the model being tested allowed this approach. The model was not intended to be a short term dynamic model, but rather a longer term aggregate model, intended for management purposes.

In some cases, process conditions were either not recorded or recorded sporadically. In these cases either average values were inserted for the missing data, or the data was estimated using correlations or interpolations.

Mill data from the immediate past was recorded, up to about one year old. A number of 50 to 100 data points was considered adequate to represent the plant's performance.

In some cases, where grades of paper are not made in huge volumes, much less data was available and hence collected.

9.3.1 Single-loop newsprint deinking mill

The newsprint deinking facility is a typical single loop, alkaline deinking recycling plant, with the following main process steps:

Pulping (peroxide bleaching)-cleaning/screening – flotation –cleaning/screening - washing – dispersing – sodium dithionite bleaching. This plant does not have any backwater clarification process. A schematic of the process is shown in Figure 9.4:

9.3.1.1 Recycled paper inputs

Recycled paper inputs were constant in the ratio of 3 bales of ONP to 1 bale of OMG. This equated to a mass ratio of 64% to 36% respectively, due to the different densities of the baled ONP and OMG. This ratio was increased for a short trial period up to 40% ONP to 60% OMG.

9.3.1.2 Chemical additions

Additions of chemicals were measured in kilograms per ton of dry fibre. These were setpoints on the process control system, and were maintained at the specified levels by online flow measurement and control valves. The unit of Kg/ton was converted to % for use in the models. The addition of surfactant into the pulper was less in practice that the range used in the laboratory. Thus, the addition level of surfactant was assigned the average value of 0.62%.

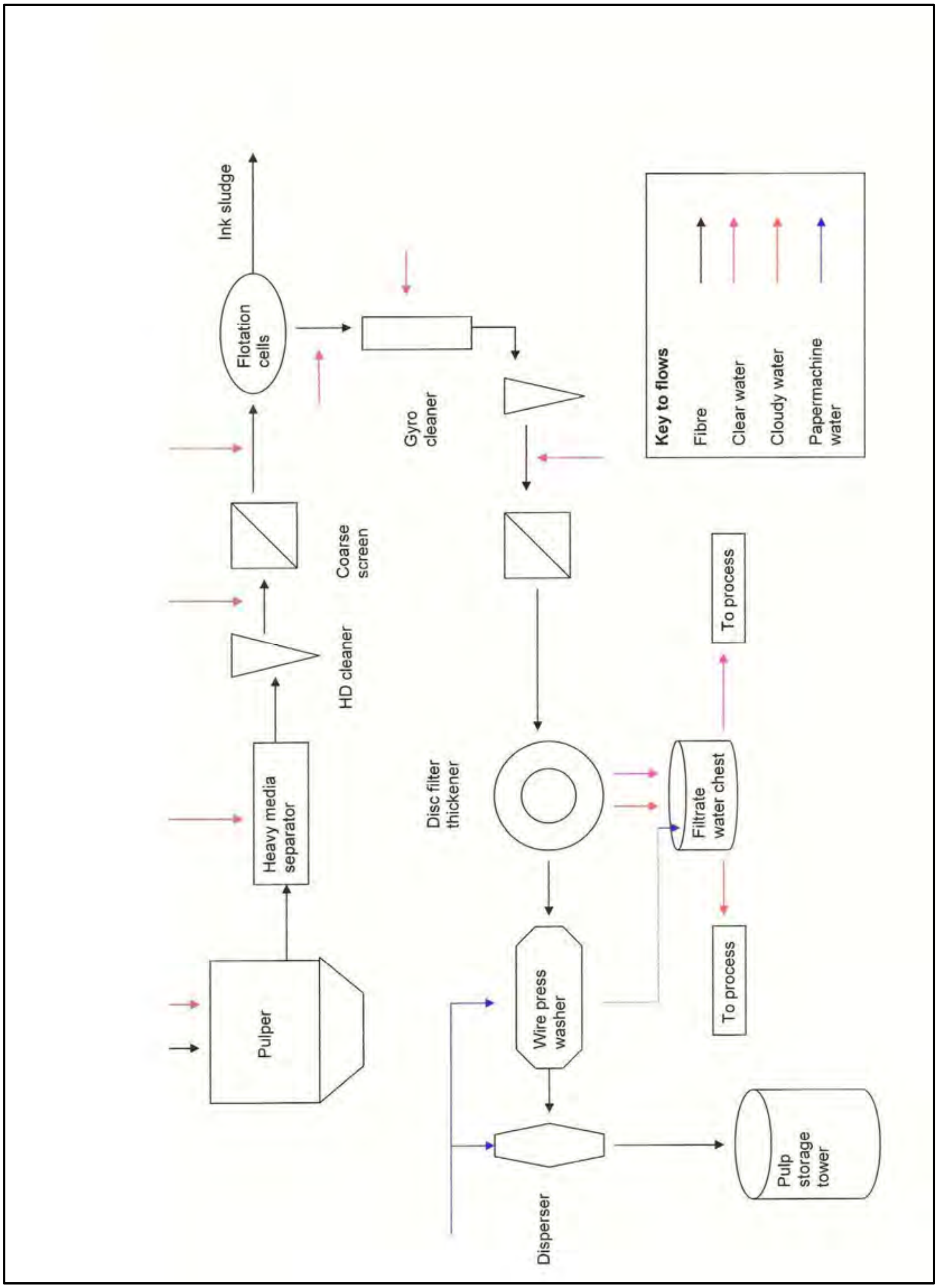


Figure 9.4: Process flow diagram – single-loop alkaline newsprint deinking plant. (Refer to Figure 5.1)

9.3.1.3 Pulping conditions

Pulping time varied between 570 and 700 seconds and averaged 650 seconds (10.83 minutes). This average was inserted for missing data.

The pulper temperature and consistency are measured on a 2-4 hourly basis, and the pulper pH was measured on an 8 hourly basis. Again, the averages were inserted for missing data.

9.3.1.4 Flotation conditions

The flotation temperature is known to be the same as the pulping temperature, and was taken to be constant at 44ºC.

The consistency in the flotation cell was determined on a 2-4 hourly basis. The average was 1.4%, which was inserted for missing data.

The feed flow rate to the flotation cells had a constant set point, but it did show short-term fluctuations. The average flow rate for 8 hours was determined from the trends retained on the process control system.

The flotation cells are eliptical Voith Sulzer EcoCells®, and the flotation sequence consists of a mixing cell, six primary cells in series, and a secondary cell which processes the ink sludge (rejects) from the primary cells. The flotation air is aspirated into the cell through a static air injection device. The percentage of air introduced per cell is about 30% of the stock flow rate (Finch & Hardie, 1999; Kemper, 1999; Martin & Britz, 1995). The working volume of one cell was determined to be 8 m^3, by measurement and calculation from the equipment drawings. The total volume for the six primary cells was thus calculated to be 48 m^3. The residence time was thence calculated from the volume and the flow rate. The average flotation time was 3.1 minutes. This value was inserted for missing data and used in the laboratory/plant flotation alignment exercise (Figures 9.5 & 9.6).

9.3.1.5 Laboratory-plant flotation alignment

The flotation residence time was not immediately equated to the laboratory flotation time. In recognition of the fact that the flotation dynamics and efficiency in a large commercial flotation cell are very different to a laboratory cell, a flotation efficiency comparison was carried out. This involved taking a pulper sample from the plant, floating it in the laboratory under average conditions (*viz.* corresponding to the midpoint conditions in the Plackett-Burman runs) and comparing the result. This exercise determined the relationship of the process constants L and P, as discussed in Sections 9.2 and 5.4.11.This was repeated a number of times, and the results are listed in Appendix 6A.

The changes in brightness, ERIC and yield were expressed as ratios relative to the properties after pulping. The brightness and ERIC after pulping were taken as flotation time zero. The ratios are shown graphically in Figure 9.5 for brightness, ERIC and yield respectively.

Thus, with reference to Figure 9.5, for brightness a plant residence time of 3.1 minutes was equivalent to a laboratory flotation time of *ca*. 3.7 minutes, *viz.* a factor of *ca.* 1.2. For ERIC, a plant residence time of 3.1 minutes was equivalent to a laboratory flotation time of *ca.*6.3 minutes, *viz.* a factor of *ca*. 2.0. For the yield, a plant residence time of 3.1 minutes was equivalent to a laboratory flotation time of *ca.* 3 minutes, hence a factor of *ca*. 1.

The plant residence times for the specific outputs were modified by the time factors determined above.

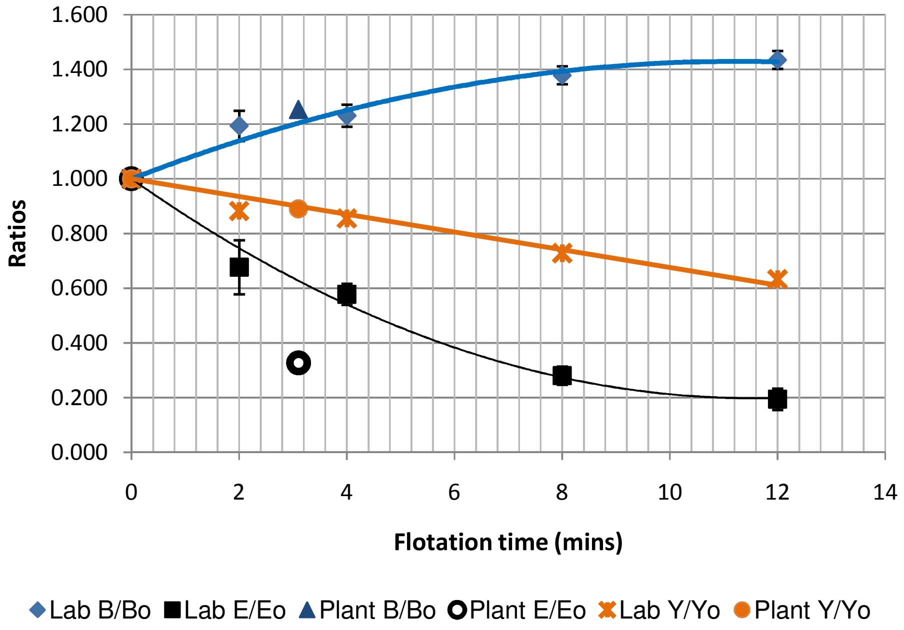


Figure 9.5: Comparison of brightness, ERIC and yield for laboratory to single-loop newsprint deinking plant flotation.

9.3.1.6 Deinked fibre properties

The fibre properties of pulper and floated pulp were measured approximately every 2 hours. The mill measured $UV_{excluded}$ whereas in the laboratory the $UV_{included}$ brightness was used in the training of the neural network. A series of pulp pads were measured in the mill's laboratory and in the experimental laboratory, to determine the correlation between the brightness measurements. This correlation, shown in Figure 9.6, was very high at R^2 = 0.976 and confirmed that the differences incurred in measuring $UV_{included}$ as against $UV_{excluded}$ are small for the ONP/OMG system.

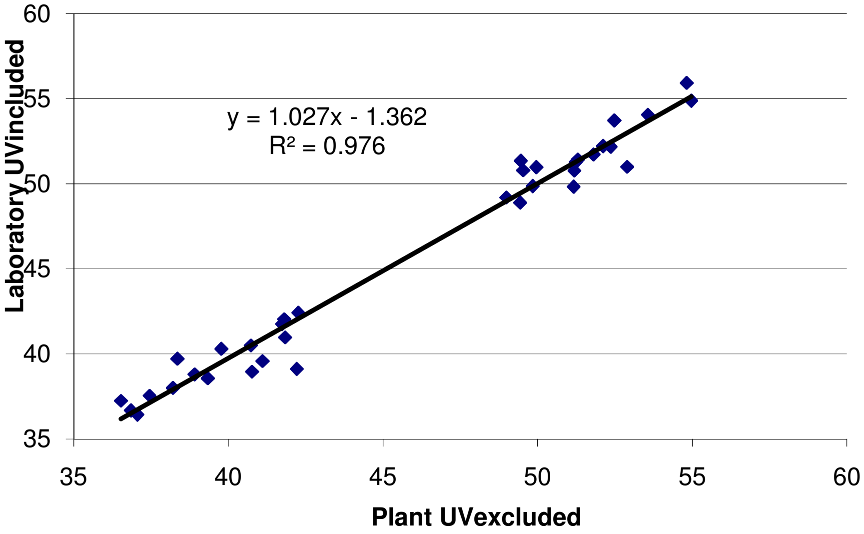


Figure 9.6: Correlation of laboratory and plant brightness measurements.

A further complication was that the washed brightness was not routinely measured in the plant, but only the brightness immediately after the flotation cell. However, the model had been trained on washed brightness, so it was necessary to establish a correlation between plant flotation brightness ($UV_{excluded}$) and the plant washed brightness, measured as $UV_{included}$ in the laboratory. This overall correlation of R^2 = 0.806 as shown in Figure 9.7 is still reasonably high. Hence, the plant flotation brightness values were adjusted according to the following formula (Figure 9.7):

$$\text{Predicted washed brightness} = 1.043 \text{ x plant floated brightness - } 0.972 \qquad (1)$$

in order to align the laboratory and plant measurements. This relationship suggested that there was only a *ca.* 4% improvement in brightness across the washing process.

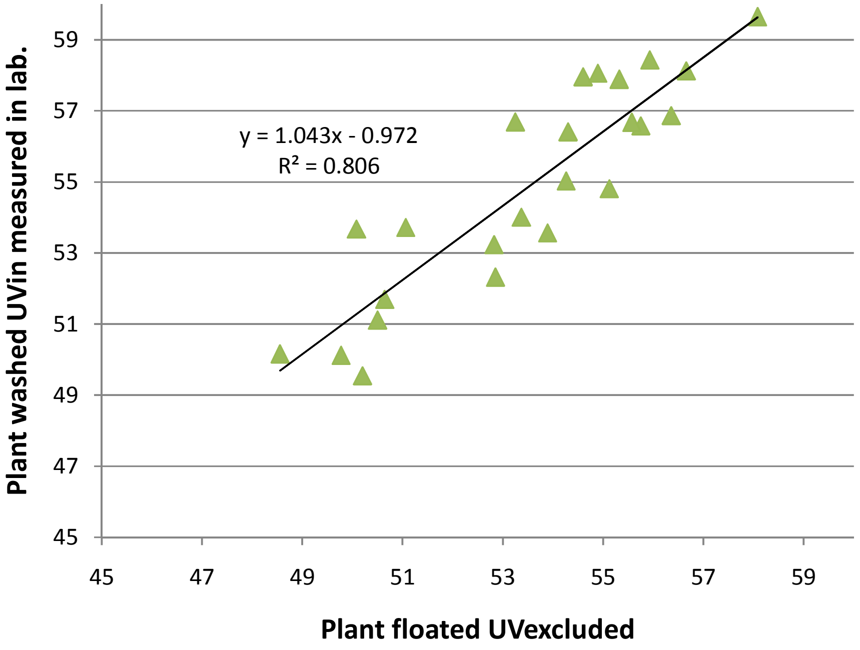


Figure 9.7: Correlation of laboratory washed and plant floated brightness measurements.

A similar exercise was carried out with the ERIC values. The overall correlation between mill measured ERIC values and laboratory measured ERIC values was high (R^2 = 0.989), as shown in Figure 9.8.

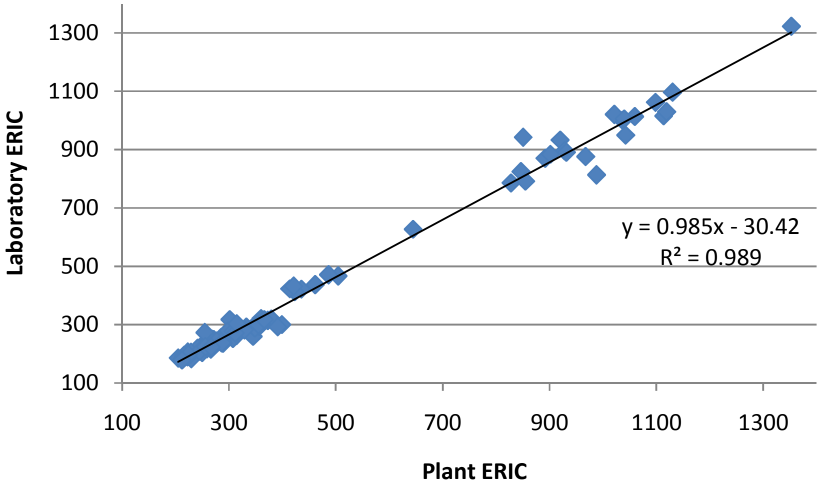


Figure 9.8: Linear correlation between laboratory and plant measured ERIC.

The predicted values of ERIC after washing, measured in the laboratory as a function of the mill ERIC after flotation are shown in Figure 9.9. Thus:

$$\text{Predicted washed ERIC} = 0.805 \text{ x plant floated ERIC} + 22.6 \qquad (2)$$

The washed ERIC is about 80% of the floated ERIC, and represents the effects of washing on the floated ERIC.

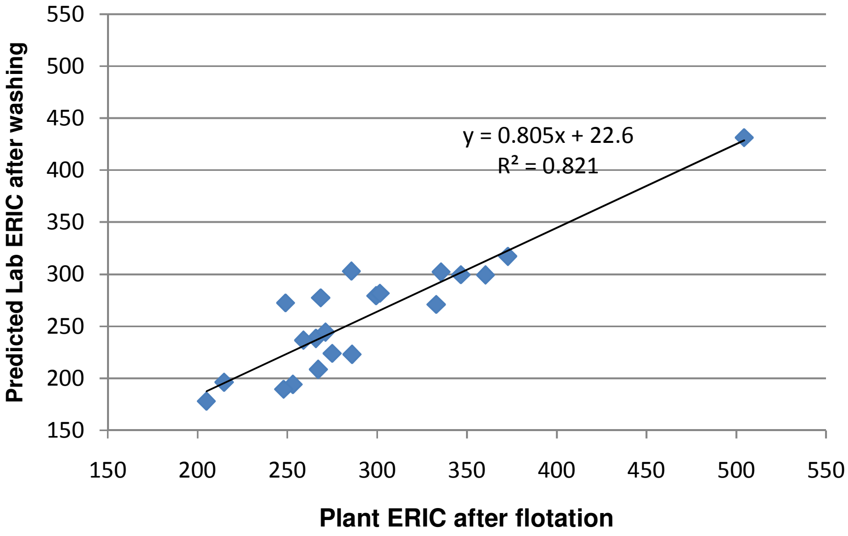


Figure 9.9: Prediction of ERIC after washing from plant ERIC after flotation.

9.3.1.7 Yield

The total yield of the recycling plant is calculated by integrating the final flow to the storage chest and the final on-line consistency measurement, and dividing by the amount of waste added to the pulper for a 24 hour period. This total yield includes the losses due to heavy media separation (staples, metal, grit *etc*.), rejects from cleaners and flotation losses (ink sludge). However the yield measured in the laboratory refers only to the fibres, fines and fillers lost during flotation.

The ink sludge losses by the recycling plant are determined once per day and from these figures a yield loss due to flotation only was calculated. There was a very weak correlation between the total yield (Y_T) and flotation yield (Y_F) (Figure 9.10), as many other factors could influence the yield. However, there was a reasonable inverse correlation (R^2 = 0.707) between the total yield (Y_T) and the difference in yield (ΔY): the higher the total yield the less the difference between flotation yield and total yield.

Thus: $\Delta Y = -0.969Y_T + 87.33$ from Figure 9.10

and $\Delta Y = Y_F - Y_T = -0.969Y_T + 87.33$

gives $Y_F = 0.031Y_T + 87.33$

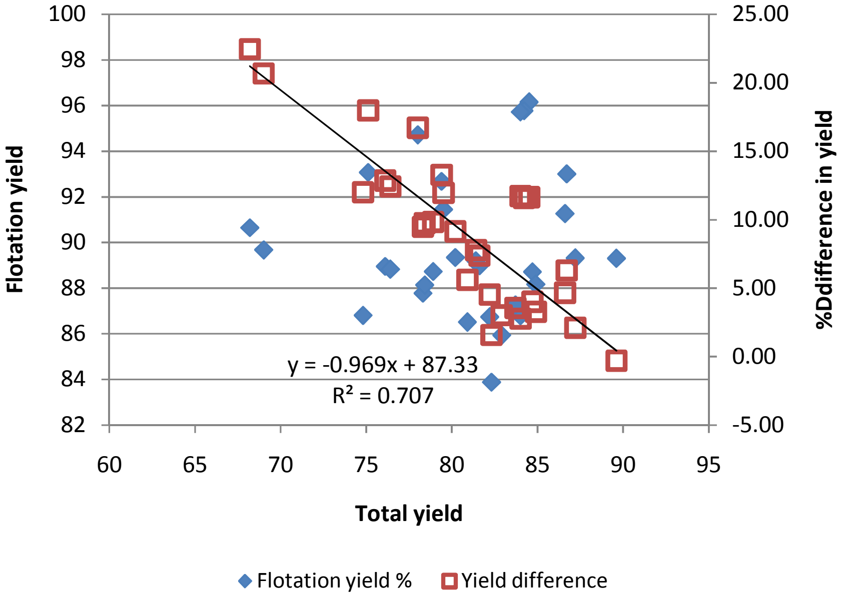


Figure 9.10: Yield relationships in newsprint deinking plant.

Thus, from the total yield, the flotation yield was estimated using the relationship derived above

$$\text{Estimated flotation yield} = 0.031 \text{ x Total yield} + 87.33 \qquad (3)$$

Equation 3 indicates that the flotation yield actually varied vary little from *ca.* 87, and that most of the variation in yield could be ascribed to losses other than flotation. The processed plant data is displayed in Appendix 7.

9.3.2 Double-loop office paper deinking plant

This plant was the most sophisticated of the plants in this study. The process is a multi-stage plant designed for the production of high quality deinked pulp (Carre & Galland 2007). The main steps are:

Pulping – flotation I – washing I – dispersing (FAS bleaching) – flotation II – washing II – storage.

Although not shown in Figure 9.11, this plant has a dissolved air flotation unit to clarify the process water. A schematic of the process is shown in Figure 9.11.

9.3.2.1 Recycled paper inputs

The mill makes two grades of tissue: A medium grade (MG2) and a high grade (HG2) product. The “2” denotes the double-loop process. This process uses a mixture of HL1, HL2, SUPERMIX, ONP and SBM (OMG) in various ratios, depending on the quality of tissue made. The current waste mixes used as raw materials are given in Table 9.1, in terms of furnish mix to the tissue machine. Supermix is a 50:50 blend of HL1 and HL2, thus the breakdown of raw materials fed to the recycling plant in terms of the raw materials used in the modelling exercise (*viz.* ONP, OMG, HL1 and HL2) has been calculated in Table 9.1.

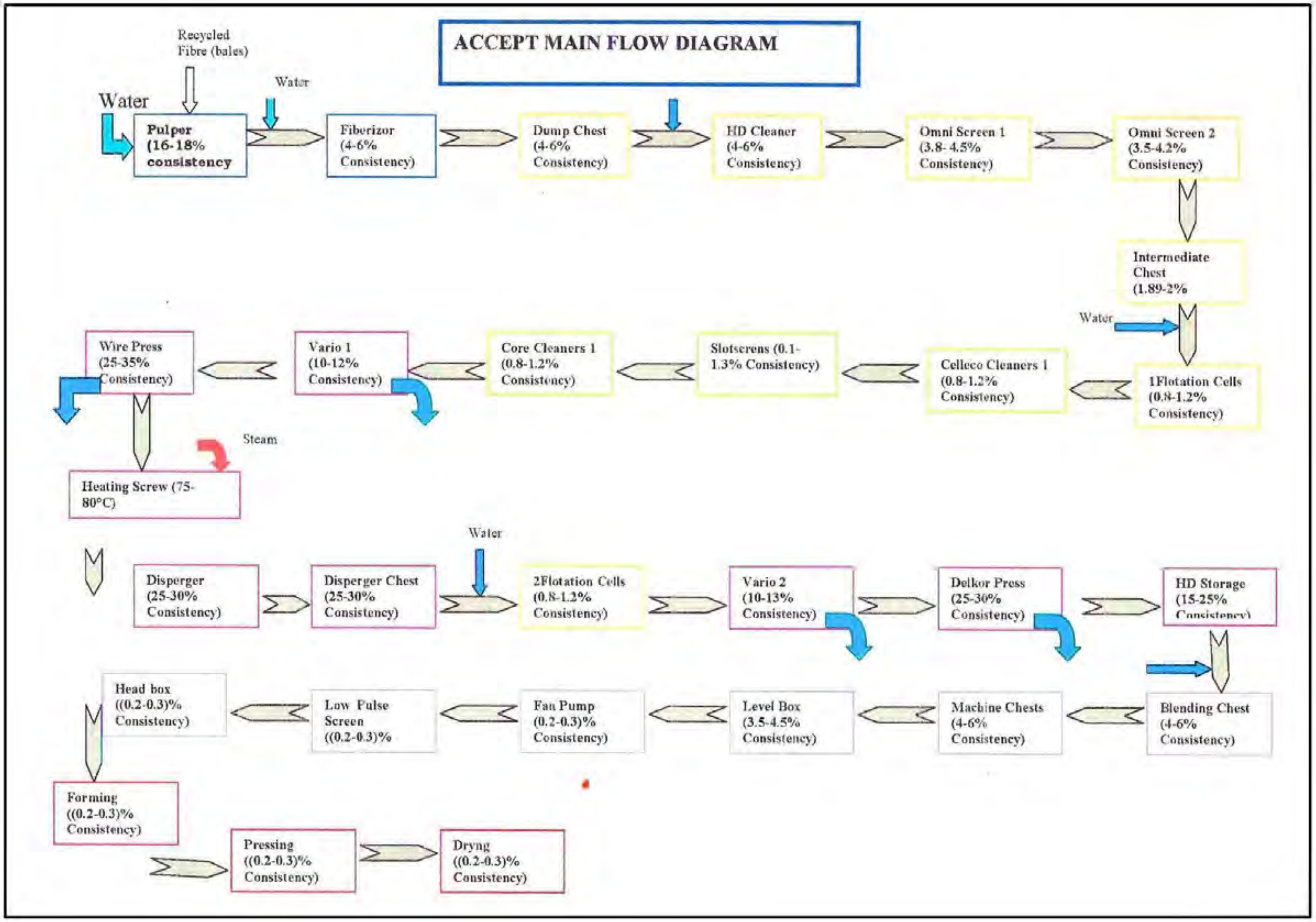


Figure 9.11: Process flow diagram – double-loop neutral office waste deinking plant. (Refer to Figure 5.2)

Table 9.1: Raw material breakdown for double-loop office waste deinking plant.

WASTE PAPER GRADE	Medium grade MG2 (tissue machine)	Medium grade MG2 (model raw materials)	High grade HG2 (tissue machine)	High grade HG2 (model raw materials)
SUPERMIX	55		60	
HL1	15	47	30	67
HL2	10	42		33
SBM	10	11		
Broke	10		10	
Total	100	100	100	100

9.3.2.2 Chemical additions

This mill does not use caustic soda, sodium silicate of hydrogen peroxide in the pulper. Essentially neutral deinking is carried out, which is more typical for deinking for tissue manufacture. A small amount of deinking surfactant (0.9 kg/t) is added into the pulper. This level is much lower than the range used in the laboratory deinking trials. Because neural networks should not work on extrapolated data, this level was set to the average of 0.62% used in the laboratory.

Additions of chemicals are measured in kilograms per ton of dry fibre. These addition levels are setpoints on the process control system, and are maintained at the specified levels by flow measurement and control valves. Kg/ton was converted to % for use in the models.

9.3.2.3 Pulping conditions

Pulping time was maintained constant. On the 16th July 2010 the pulping time was reduced from 960s (16 min) down to 840s (14 min). The pulping consistency was targeted at 16 to 18%, and varied a little around this range. Also on the 16th July, the pulping consistency target was reduced from 18% to 15%, but this is not reflected in the data as the pulping consistency was not modelled.

The pulper temperature is monitored and not controlled. It varied between 29 ºC and 37 ºC. On days when it was not recorded, the process average of 33 ºC was inserted.

9.3.2.4 Flotation conditions

The flotation temperature was known to be the same as the pulping temperature, and was taken to be constant at 33ºC.

The consistency in the flotation cell is not measured on a regular basis. The consistency was taken to be that indicated on the process control system, *viz.* 1.2%. This consistency is a calculated value based on a pre-dilution consistency (measured online) and a dilution ratio. However, *ad-hoc*. measurements taken during the time of the visit suggested that the consistency varied between 0.8% and 1.75%. Similarly, the feed flow rate to the flotation cells had a set point, but it also showed quite large short-term fluctuations, which were not recorded. The average flow rate was taken to be that of the set point on the process control system.

The flotation cells are Sulzer-Escher Wyss CFS/CF cells, with flotation air introduced tangentially through a step-diffuser at four points in the cell (Martin & Britz, 1995). The flotation sequence consists of two first stage cells in series (CFS cells), interspersed with cleaning and screening, followed by two series second stage cells (CF cells), whose rejects are processed in a secondary cell. The working volume of one cell was determined to be 2.1 m^3, by measurement of the equipment and calculation. The total volume was taken to be the sum of the first and second stage cells, as they were all connected in series. Thus total volume = 4 x 2.1 = 8.4 m^3. The residence time was thence calculated from the volume and the flow rate.

The flotation residence time was not immediately equated to the laboratory flotation time. As per the procedure discussed in Section 9.3.1.5, a pulper sample from the plant was floated in the laboratory under average conditions (as used for the midpoints in the Plackett-Burman runs) and at a consistency of 1.2%. The laboratory results were compared to the average conditions obtained in the plant. For this exercise, the residence time and brightness increases across the first flotation stage only were used. This corresponded to a flotation residence time of 0.9 min (2 cells at 4.2 m^3, equating to 0.9 minutes). The results for the two grades made by this plant are detailed in Appendix 6B and plotted in Figure 9.12. The brightness ratios showed a small but steady increase, whereas the ERIC and yield ratios showed a sharp drop followed by a steadily decreasing linear region.

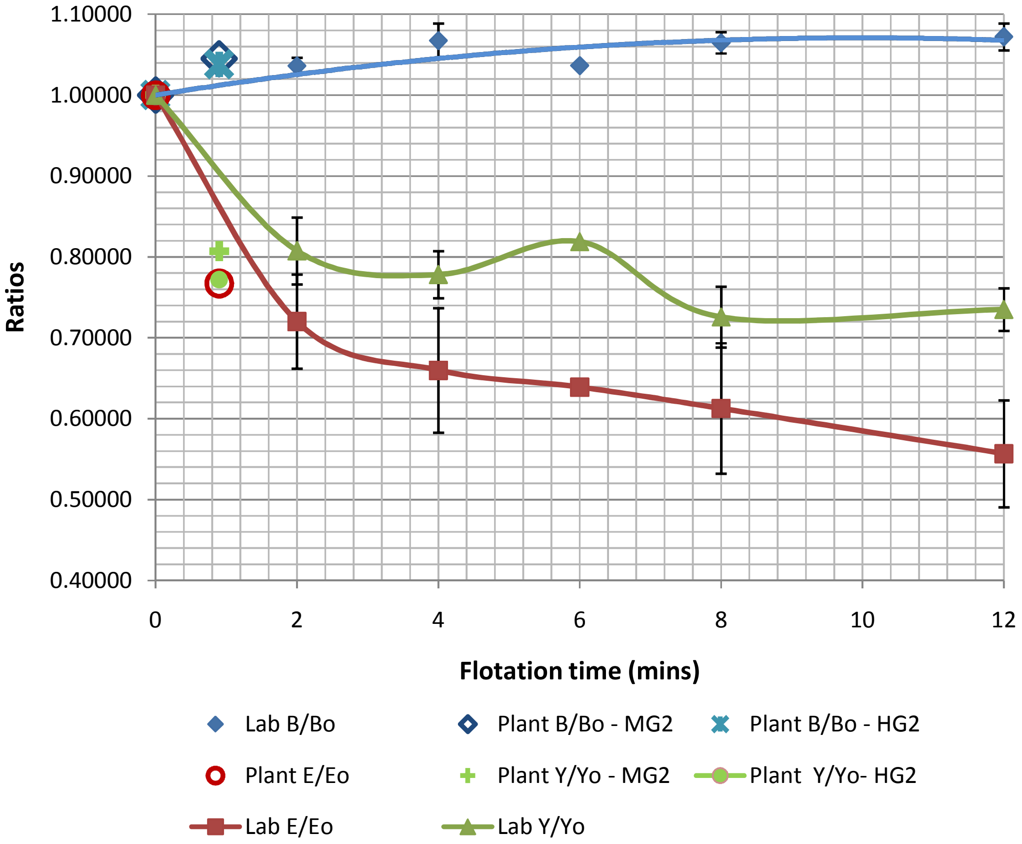


Figure 9.12: Comparison of brightness, ERIC and yield for laboratory to double-loop deinking plant flotation.

Thus, for brightness, a plant residence time of 0.9 minutes was equivalent to a laboratory flotation time of 3.67 minutes, *viz.* a factor of *ca.* 4.08. And for ERIC, a plant residence time of 0.9 minutes was equivalent to a laboratory flotation time of 1.6 minutes, *viz.* a factor of *ca.* 1.78. Finally, for yield, a plant residence time of 0.9 minutes was equivalent to a laboratory flotation time of 2.2 minutes, *viz.* a factor of *ca.* 2.44. These factors were used to adjust the flotation times in the model.

9.3.2.5 Pulp bleaching conditions

No bleaching agent in the form of hydrogen peroxide is added into the pulper. However, since the 17th May 2010, an interstage formamidine sulphinic acid (FAS) brightening has been carried out. The FAS is added at the heating screw before the disperger, which is located between the first and second stage flotation cells (Figure 9.11). The bleaching solution is a dilute solution of FAS and caustic soda in a ratio of

2:1 by mass of delivered product. The FAS is dosed at 2kg/t dry fibre, and a brightness increase of *ca.*1 % point is achieved. Because the bleaching agent was added in the middle of the process (*ie* not post-bleaching), an attempt was made to model this addition as an equivalent amount of hydrogen peroxide added at the pulper.

The relative bleaching performance of FAS systems, sodium hydrosulphite based systems (including Borol systems, refer to Section 9.3.3.5) and hydrogen peroxide for mixed office waste was obtained from supplier data (Bremner, 2010; Makaza, 2010). The data from the suppliers compared various mill case studies of bleaching performance. The results of these case studies have been combined and summarized in Figure 9.13 for the various bleaching systems. There is some variation in the data, as different mills and waste mixes are compared. Nevertheless the comparative performance is apparent from Figure 9.13.

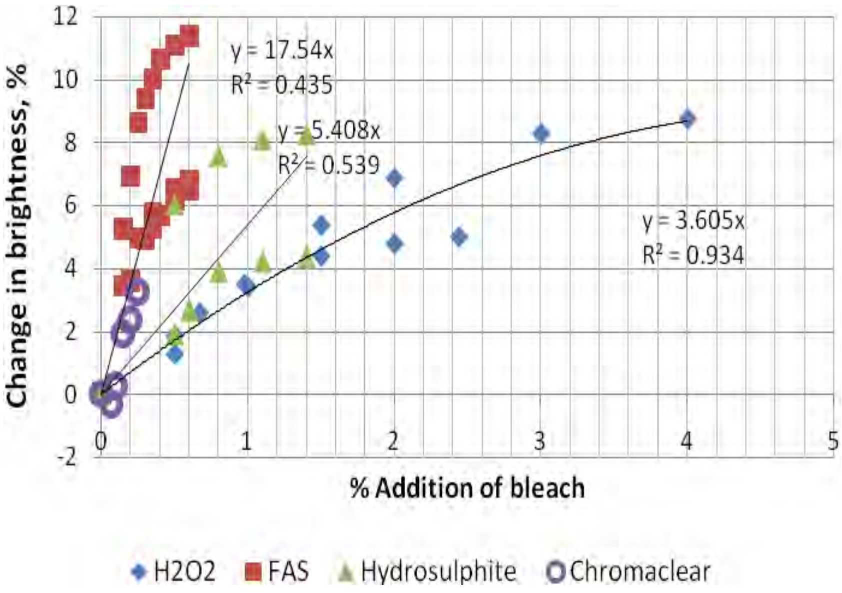


Figure 9.13: Comparative case studies of various office waste bleaching agents.

The brightness increase as a result of the FAS addition has been 1.1% on average, based on the collected data and a FAS addition rate of 0.2% (2 kg/t). However, according to the data in Figure 9.13, a 0.2% addition of FAS should increase the brightness by 3.5 percentage points. A 3.5% increase in brightness corresponds to a hydrogen peroxide addition rate of 0.9%. Thus, in terms of chemical addition at low addition rates, the FAS is 4.5 times as effective. Hence, in the model testing process, the 0.2% FAS will be equated to 0.9% hydrogen peroxide. The 0.1% sodium hydroxide added with the FAS was treated as an addition to the pulper.

9.3.2.6 Deinked fibre properties

The mill measures $UV_{excluded}$ whereas in the laboratory the $UV_{included}$ brightness was measured. A series of pulp pads were measured in the mill and in the research laboratory, to determine the correlation between the brightness measurements. This correlation shown in Figure 9.14 is very high, at $R^2 = 0.934$.

The mill measures pulper brightness, no brightness after flotation, brightness after first wash (Vario1) and brightness after the second wash and bleach (Vario2). ERIC is not measured. The plant brightness was adjusted thus:

$$\text{Predicted washed brightness} = 1.214 \times \text{plant final brightness} - 8.125 \qquad (4)$$

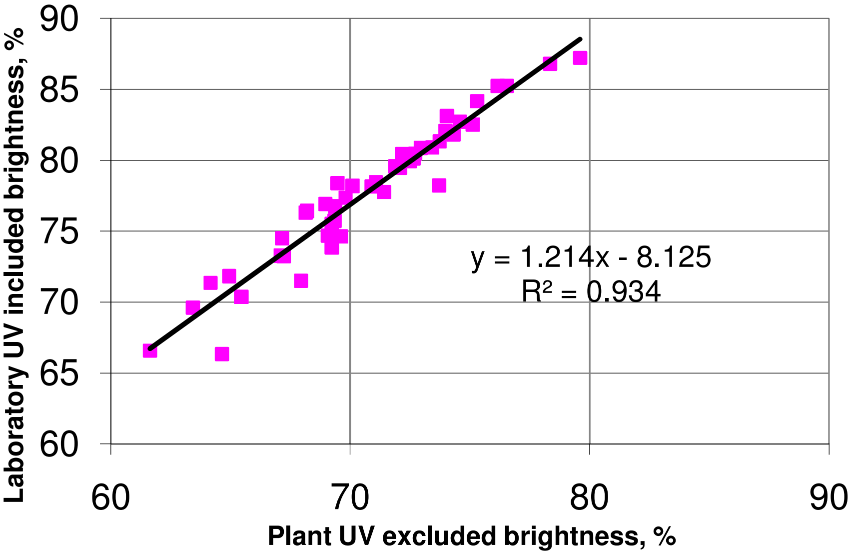


Figure 9.14: Correlation of laboratory and plant brightness measurements.

The process modelled in the laboratory consisted of pulping - flotation - washing, whereas in this plant the processes were pulping - flotation – washing – dispersion (FAS bleach) – flotation - washing. The fit of the model to the 2-stage flotation deinking plant was tested by using the combined flotation time of both stages and equating the interstage bleaching to an equivalent pulper bleaching with hydrogen peroxide and caustic soda.

9.3.2.7 Yield

The total *process yield* of the recycling plant is calculated by dividing the daily tissue production off the paper machine by the amount of waste fed to the waste plant. This total yield includes the losses due to heavy media separation (staples, metal, grit *etc.*), rejects from cleaners, flotation losses (ink sludge), tissue machine losses and process spillages. However the yield measured in the laboratory refers only to the fibres, fines and fillers lost during flotation.

The ink sludge losses by the recycling plant are determined by weighing the fibrous sludge as it is sent to the landfill side for disposal. A sample is taken once a day for the determination of moisture content, from which the daily sludge losses (and hence flotation yield) on a dry basis are calculated. This exercise had only been done for the five months prior to the collection of the data, and is summarized in Table 9.2.

Table 9.2: Monthly flotation yield calculation for recycling plant.

Month, 2010	Waste fibre input (10% moisture)	Fibrous sludge (dry tons)	Process yield	Flotation yield	Yield ratio
3	3060	795	62.5	71.1	1.14
4	2787	669	63.7	73.3	1.15
5	2906	726	64.2	72.3	1.13
6	2907	627	62.9	76.0	1.21
7	2591	646	64.7	72.3	1.12

The average ratio of flotation yield to process yield is 1.148. This ratio was applied to all the process yield data to generate an estimate for the flotation yield.

The final processed data is shown in Appendix 7.

9.3.3 Single-loop office paper deinking plant

The second office paper deinking plant is a single loop flotation and washing plant designed for tissue production (Carré & Galland, 2007). The main process steps are:

Pulping – flotation – washing – sodium dithionit bleaching process, with dissolved air flotation cleaning of the process water.

The chemistry is neutral with no surfactant added. A schematic of the process is shown in Figure 9.15.

9.3.3.1 Recycled paper inputs

The mill uses a mixture of HL1, SUPERMIX, ONP and SBM in various ratios, depending on the quality of tissue made. The current waste mixes are given in Table 9.3, in terms of furnish mix to the tissue machine.

Table 9.3: Raw material breakdown for single-loop office paper deinking plant.

WASTE PAPER GRADE	Medium grade MG1	Medium grade (model raw materials)	High grade HG1	High grade (model raw materials)	Low grade LG1	low grade (model raw materials)	Very high quality VHG1	Very high quality (model raw materials)
SUPERMIX	85		100	0	40	0	0	0
HL1	0	42.5	0	50	0	20	100	100
HL2	0	42.5	0	50	0	20	0	0
SBM/OMG	15	15	0	0	30	30	0	0
ONP (Flat news)	0	0	0	0	30	30	0	0
Total	100	100	100	100	100	100	100	100

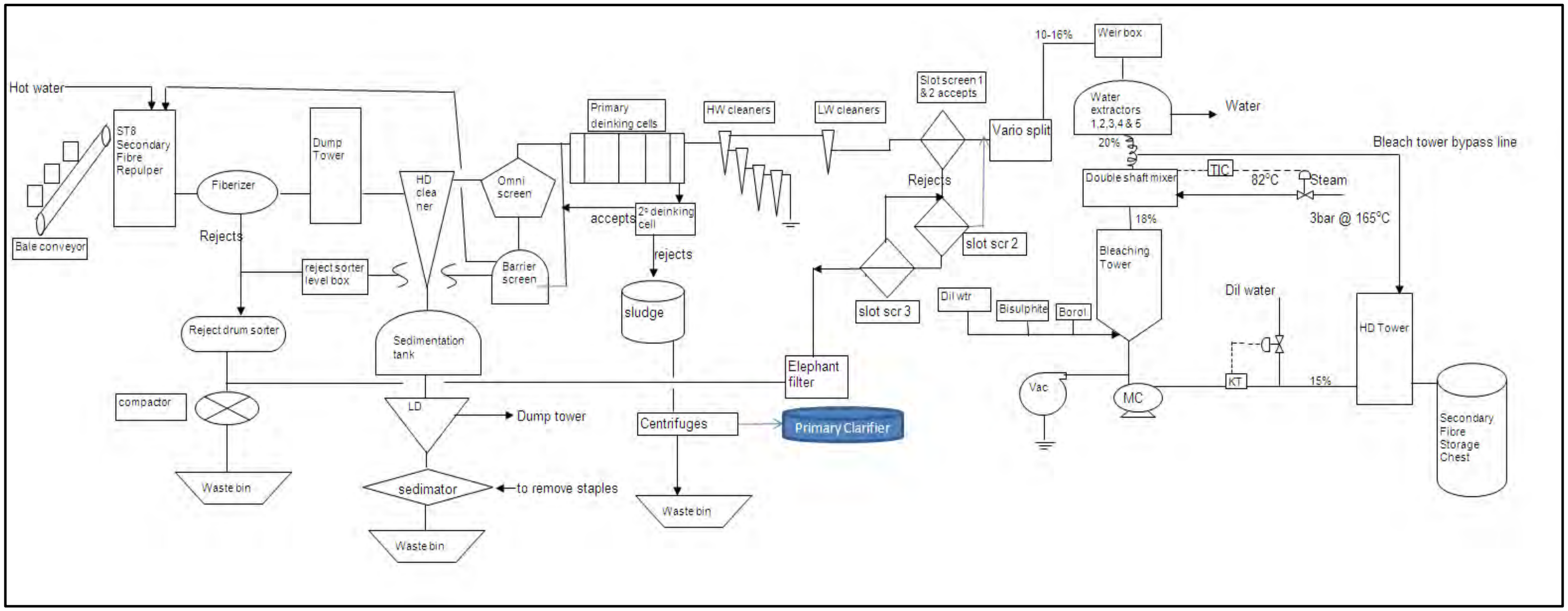


Figure 9.15: Process flow diagram - single-loop office paper deinking plant. (Refer to Figure 5.3)

Supermix is a 50:50 blend of HL1 and HL2, thus the breakdown of raw materials fed to the recycling plant in terms of the raw materials used in the modelling exercise (*viz.* ONP, OMG, HL1 and HL2) is shown in Table 9.3. The most popular grades are medium grade (MG1) and high grade (HG1), where "1" designates the single-loop process. The other grades (low grade LG1 and very high grade VHG1) are made infrequently and in small volume.

9.3.3.2 Chemical additions

This mill does not use caustic soda, sodium silicate, hydrogen peroxide or any surfactant in the pulper. There appears to be sufficient surfactant in circulation in the process water to ensure wetting of the fibre in slushing and froth formation in the flotation cell. Office waste papers typically contain a certain amount of surfactants which are released into the water upon pulping. This has been demonstrated in practice, particularly for rotogravure printed papers (Vernac, Carré & Beneventi, 2001). Surfactant is not normally necessary in the flotation of hydrophobic inks such as toner particles (Zhao, Deng & Zhu, 2004). Essentially neutral deinking is carried out. During October 2010 a trial surfactant was being added into the pulper. The purpose of this surfactant was to improve the slushing and increase the size on the plastic waste removed. It was assumed that this surfactant had no effect on the deinking process. The minimum addition rate used in the training data (*viz* 0.25%) was assigned to the surfactant added to the pulper. Additions of chemicals (if added) are measured in kilograms per ton of dry fibre. Setpoints on the process control system are maintained at the specified levels by flow measurement and control valves. Kg/ton was converted to % for use in the models.

9.3.3.3 Pulping conditions

Pulping time varied between 15 and 20 minutes, but was not recorded. An average of 18 minutes was assigned as the input to the model. The consistency was tested once per day, and remained fairly constant in the range of 16-18%.The pulper temperature has a setpoint of 65 ºC on the process control system, maintained by live steam injection. However, a short term monitoring of the temperature indicated that the practical range was 56 to 60 ºC region. A value of 60 ºC was assigned. The pulper pH was monitored on a daily basis, and ranged from 7 to 8.

9.3.3.4 Flotation conditions

The flotation temperature varied from 46 to 50 ºC, and was taken to be constant at 48ºC. The consistency in the flotation cell had only recently (from September 2010) been monitored on a regular basis. It varied between 0.9% and 1.4%, and the average for this period was 1.16%. This average was used for those periods when the flotation consistency was not measured. The feed flow rate to the flotation cells has a set point of 7000 l/min, which seemed to be fairly well controlled.

The flotation cells were originally Voith Tubular Multi-Injector cells, which were upgraded some time ago by dividing the cell into five units and retrofitting with the EcoCell® aeration element. This element contains a multistage micro-turbulence generator similar to the Escher Wyss aeration element (Kemper, 1999), as found on the double-loop deinking flotation cells.

The flotation sequence consists of a mixing cell, five flotation cells in series, and a secondary cell which refloats the rejects from the first stage cells. The volume of the main bank of float cells was estimated from drawings and measurements to be *ca*. 8.5 m^3 per cell, or 42.4 m^3 in total. At the end of September 2010, the pump which transfers stock from cell 2 to cell 3 broke down and cell number two had been by-passed. For this period the flotation volume was reduced by 1/5th to 33.9 m^3. The flotation residence time was accordingly calculated from the flotation volume and the volumetric throughput.

The relationship between laboratory and plant flotation efficiency was determined as in the previous section. The results are listed in Appendix 6C and are shown in Figure 9.16. The flotation efficiency probably varied somewhat with the different grades. However, a global average for all the grades was taken, for reasons of simplicity and unavailability of good plant date for all grades, especially the small volume grades made only occasionally. With reference to Figure 9.16, it can be seen that the plant performance exceeds the laboratory performance. Thus, the flotation time at maximum laboratory flotation performance was used, *viz.* 8 minutes by estimation of the maximum of the curve. The ratio of flotation times was thus *ca.* 1.3.

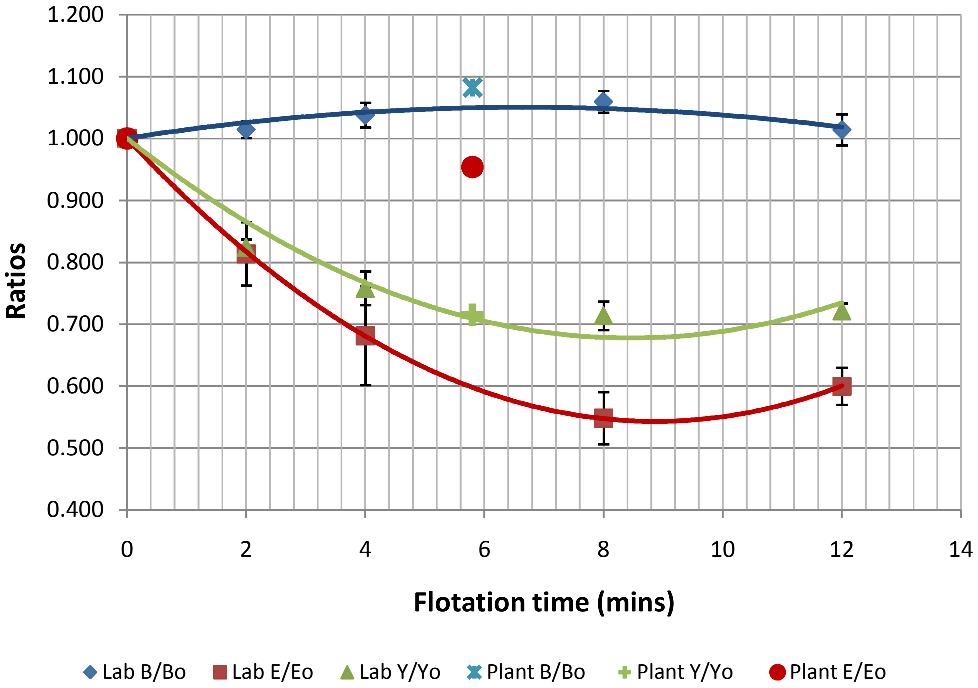


Figure 9.16: Comparison of brightness, ERIC and yield for laboratory to single-loop office paper deinking plant flotation.

In this case, the removal of ink as measured by the ERIC was much less for the plant than in the laboratory. Hence the flotation time factor was less than unity, in this case *ca.* 0.1.

There appeared to be little difference between the plant and the laboratory results when it came to the yield (Figure 9.16). Accordingly, a factor of 1 was applied.

The pH in the flotation cell had only recently (from September 2010) been monitored on a regular basis. It varied between 6.8 and 8.2, and the average for this period was 7.6. This average was used for those periods when the flotation pH was not measured.

9.3.3.5 Pulp bleaching conditions

No hydrogen peroxide is used in the pulper in the single-loop process, but a post bleaching is carried out after washing, prior to final storage. The bleaching system consists of a solution of sodium borohydride and sodium hydroxide (Chloraclear®, 12% active $NaBH_4$) which is co-fed at a ratio of 1:13 into the pulp with a sodium bisulphite solution (38% active). In this process, sodium hydrosulphite (sodium dithionate) is produced *in situ*. The process is essentially a sodium hydrosulphite bleaching process, with some superior efficiency claimed by the supplier (Bremner, 2010). With reference to Figure 9.13, the Chromaclear® system seems to perform similar to the FAS system in the double-loop process.

However, the addition of bleaching agent is done on an *ad hoc* basis, when it is required to boost the brightness into specification. There was no regular addition, and when added the amount was not recorded. This will thus be regarded as a post-bleaching and was not included in the model.

9.3.3.6 Deinked fibre properties

This mill also measures $UV_{excluded}$ brightness. The correlation between mill and research laboratory brightness is shown in Figure 9.17. Hence:

$$\text{Predicted brightness} = 1.185 \times \text{plant brightness} - 5.672 \qquad (5)$$

The mill routinely measured brightness on the pulper, before and after flotation, and after bleaching. Not all of these properties were measured all the time. Brightness after washing was not always measured. However sufficient measurements were made to obtain a correlation between floated and washed brightness, shown in Figure 9.18. Thus, where necessary, the washed brightness was predicted from the flotation brightness using the correlation in Figure 9.18. Thereafter, all the brightness values were scaled up using equation (5). As before, averages were inserted for missing data.

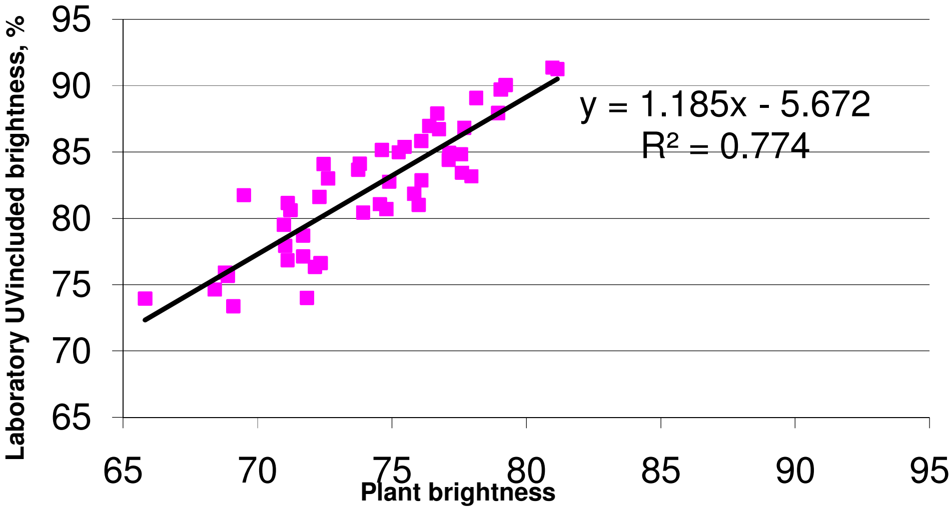


Figure 9.17: Correlation of laboratory and plant brightness measurements.

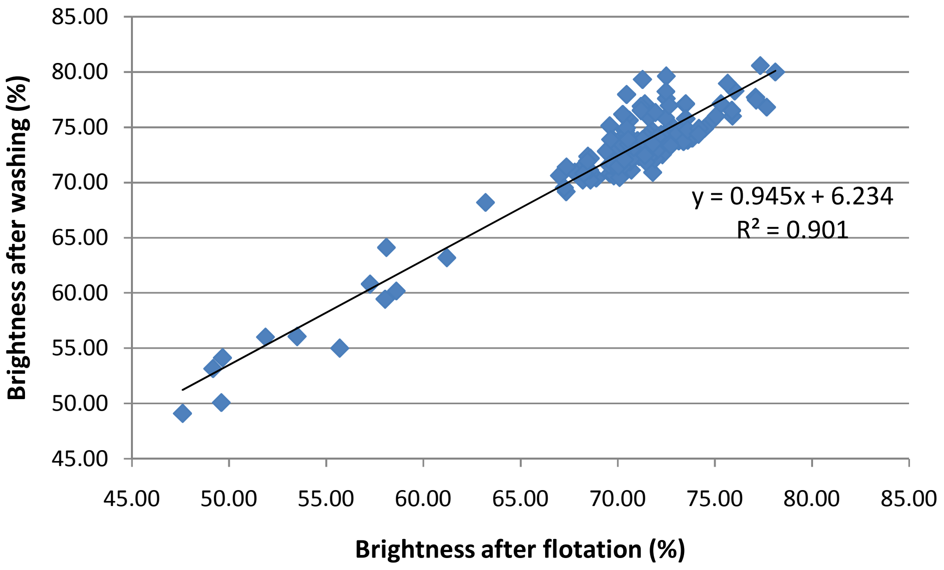


Figure 9.18: Correlation between washed brightness and floated brightness.

9.3.3.7 Yield

As in the previous cases, the flotation yield had to be deduced from the total process yield.

The process yield is calculated by the mill on a daily basis by consideration of the total production input (comprising waste input, addition of virgin fibre and broke) and tissue output.

With reference to Figure 9.15, it can be seen that the recycling plant losses consisted of three streams:

waste from the Fiberizer – comprising plastic, staples and some fibre;

waste from the High Density cleaner - comprising grit, staples and other heavy material;

solid material from the centrifuges - comprising rejects from the deinking cell.

It is this last stream that corresponds most closely to the flotation losses. The relative magnitude of these three streams was estimated from the average number of waste bins removed daily, as detailed in Table 9.4.

Table 9.4: Estimation of yield losses.

	HD cleaner rejects	Fiberizer rejects	Centrifuge solids
Volume of bin, m^3	6.0	12.0	12.0
Estimated Density, t/m^3	1.2	2.3	2.5
Average bins/day	0.3	1.0	5.0
Calculated wet mass	2.2	28.0	150.0
Consistency %	40	30	40
Calculated dry mass, t/d	0.9	7.0	60.0
Dry mass fraction	0.01	0.10	*ca* 0.9

Thus, 90% of the *total losses* are made up of *flotation losses*. Using this assumption and by mass balance, the flotation yield was estimated from the process yield according to the following formula:

$$\%\,Flotation\ yield = 100\left(1-\left(\frac{0.9\times total\ losses}{waste\ input}\right)\right) \tag{6}$$

where the total losses were calculated from knowledge of the total inputs and outputs *viz*. the process yield. The final process data, after all adjustments as discussed above have been made, is shown in Appendix 7. This data was used to test the performance of the neural networks.

9.4 Results of model testing and discussion

9.4.1 Brightness

The training data (as given in Appendix 3) were used to train a final set of neural networks, according to the methodology detailed in Section 8.3. For each final property, the full set of input variables (Appendix 3), and a reduced set of input variables (Section 8.7) were modelled. The number of neurons was varied from one to twenty, with four attempts for each structure; *viz.* eighty networks were generated for each of the final properties of brightness, ERIC and yield.

At the same time, the networks were tested with the modified plant data (Appendix 7) by determining the correlation and mean square error of actual versus predicted values. The networks were ranked in order of increasing mean square error. The top ten networks were retained as possible final models. The best networks and their performances are listed in Appendix 8.

For the reduced set of process parameters, the means of the predicted values of the top (Bright_FinalA_20_2), second (Bright_FinalA_5_1) and tenth (Bright_FinalA_3_3) ranked networks were plotted against the actual plant values in Figure 9.19.

Figure 9.20 is a similar plot for the networks trained with the full set of process parameters. In this case the networks are: first - BrightB_16_2, second - BrightB_13_2 and tenth - BrightB_11_3. It appears that the networks trained on the full range of process parameters gave slightly lower mean square errors and slightly higher correlations (Appendix 8A) than those trained on the reduced set of variables. However, the differences are not great, and the added practical complexities of working with the full set of parameters do not justify the slight improvements in prediction obtained. Thus, the neural networks based on the reduced set of process variables were preferred.

The variability of the plant data was quite high, but with the large number of data points acquired for most of the grades, the resulted standard error ($\sigma/\sqrt{n}$) was low. The calculated standard errors are shown in Appendix 8. Thus, only the average values were depicted in the graphs.

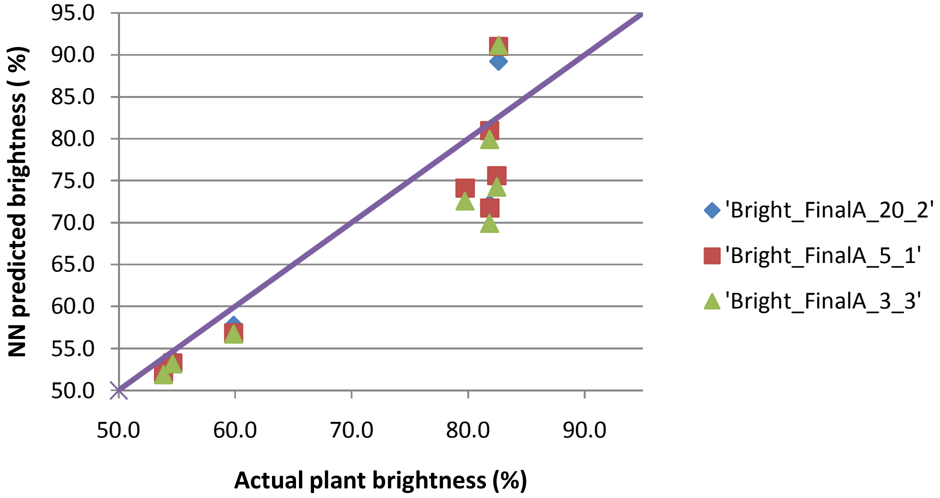


Figure 9.19: Brightness prediction performance of top (Bright_FinalA_20_2), second (Bright_FinalA_5_1) and 10th (Bright_FinalA_3_3) ranked neural networks with reduced inputs.

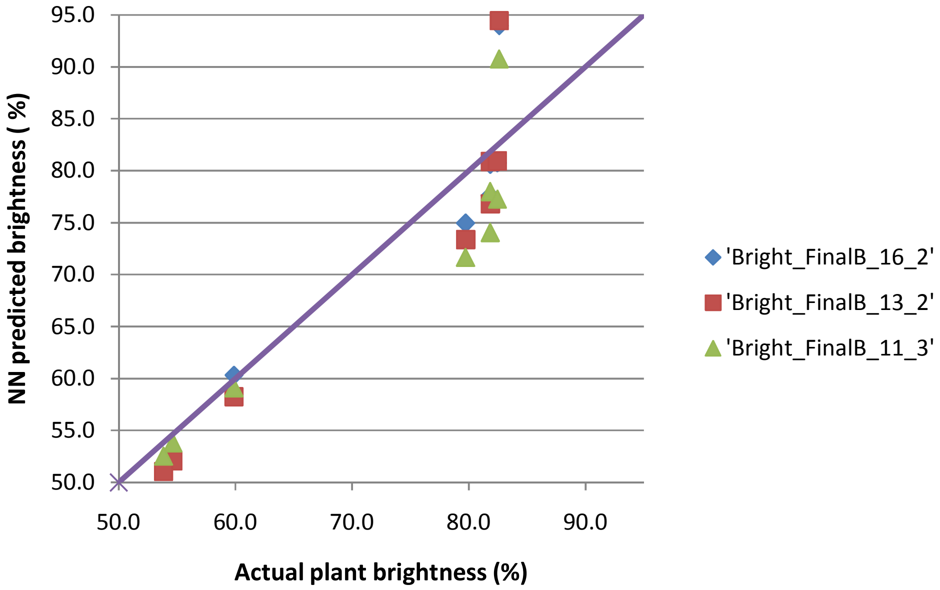


Figure 9.20: Brightness prediction performance of top (BrightB_16_2), second (BrightB_13_2),and 10th (BrightB_11_3) ranked neural networks with full set of inputs.

It is apparent from Figures 9.19 and 9.20, in terms of the deviations from the Y = X line, that there are only small differences between the top-ten networks. However the mean square errors (MSE) and correlations do show differences, listed in Appendix 8.

The predicted brightness of the best network was plotted against the plant actual brightness, for each grade of paper recycled in the three plants, and shown in Figure 9.21. Points lying on the Y = X line would denote a perfect prediction. It can be seen from Figure 9.21 that the predicted brightnesses of the newsprint and low-grade tissue grades were close to the plant actuals. These grades all contained medium to high levels of newsprint and/or magazine (refer to Tables 9.1 and 9.3) and were processed on single-loop deinking plants.

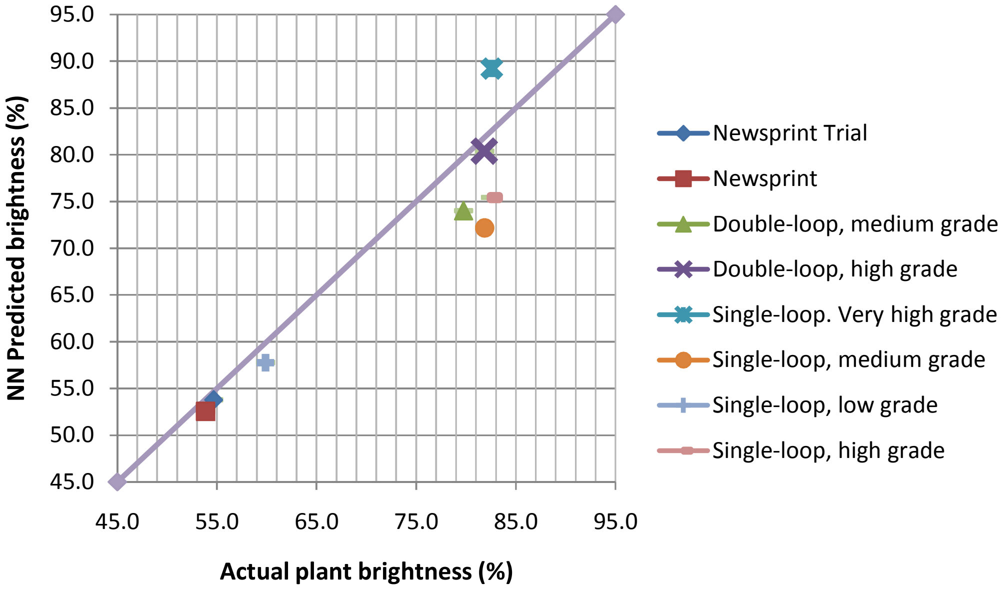


Figure 9.21: Brightness prediction performance of neural network Bright_FinalA_20_2 for different grades and plants.

On the other hand, grades (single-loop medium grade, single-loop high grade and double-loop medium grade, Table 9.1 and 9.3) containing high levels of office papers, in particular HL2, showed negative deviations from the Y = X line. In other words, the brightness achieved by the plants was higher than that achieved in the laboratory, and hence predicted by the neural networks. HL2 contains appreciable quantities of coloured materials, and it could be possible that the plant processes would be more efficient than the laboratory process in removing coloured materials. In addition, the plants have extra equipment (screens and cleaners, extra flotation and washing stages interspersed by dispersion) which could remove some ink and the full scale flotation cells appeared to be more efficient than the laboratory cell. This was apparent from the alignment work described in Section 9.3.2.4 and 9.3.3.4.

The one anomaly in Figure 9.21 is the very high grade pulp manufactured on the single-loop process. This grade has 100% HL1 as its raw material, and the neural networks accordingly predicted a very high brightness. In practice however the brightness achieved for this grade on the plant was only slightly higher than that achieved on the high grade. The reason for this is probably that the very high grade is manufactured sporadically in small quantities, interspersed between the lower quality high-volume grades. The process water streams would be carrying higher ink and contaminant loading from the lower quality grades, which would “contaminate” the very high quality grade with ink recirculating in the process water. It could be expected that an extended run of very high grade on the plant would yield higher brightness. This suggests the usefulness on the models in diagnosing unexpected results in a practical plant.

The response surfaces of the selected network (Bright_FinalA_20_2) are shown in Figures 9.22 to 9.24, for three representative standard grade mixes: ONP:OMG:HL1:HL2::25:25:25:25, ONP:OMG::50:50 and HL1:HL2::50:50.

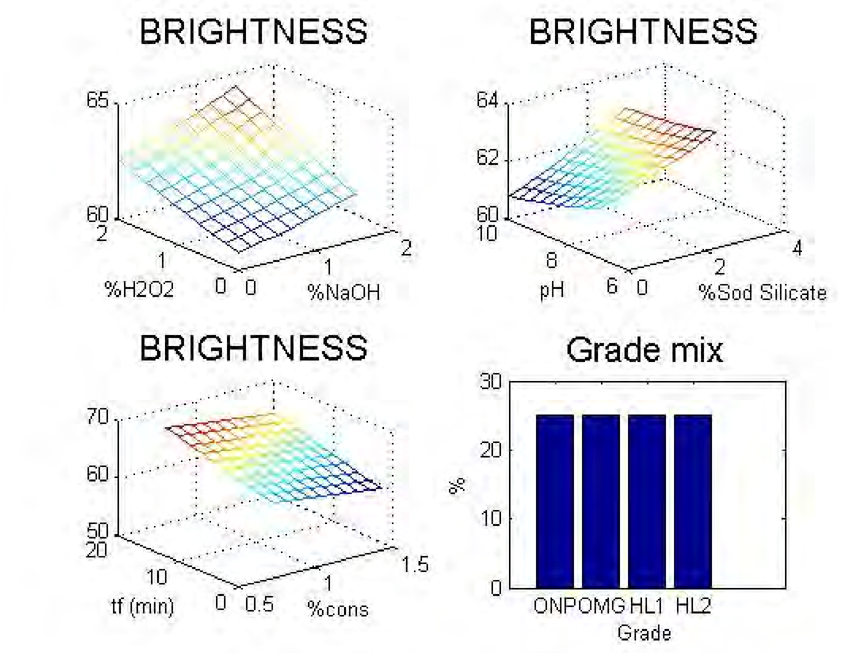


Figure 9.22: Bright_FinalA_20_2 network brightness response surface for a mixture of all grades.

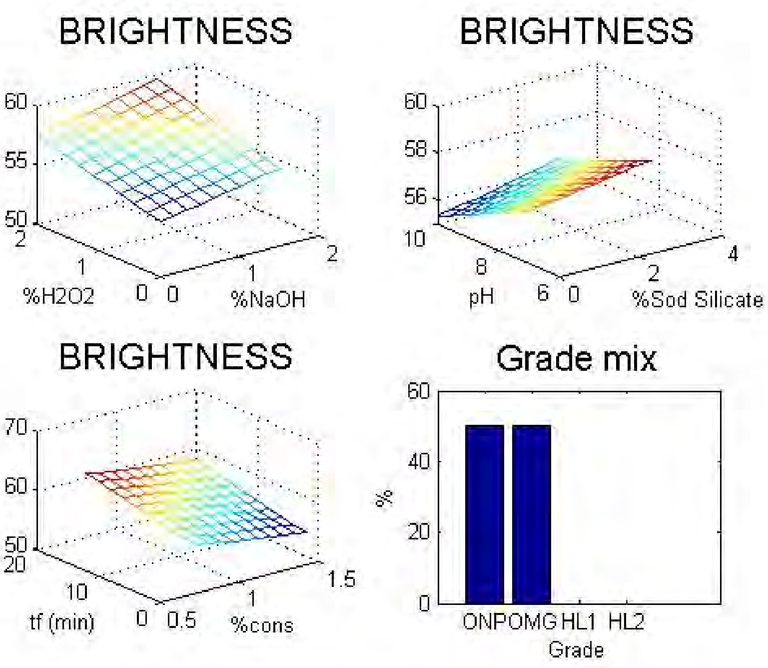


Figure 9.23: Bright_FinalA_20_2 network brightness response surface for a mixture of ONP and OMG grades.

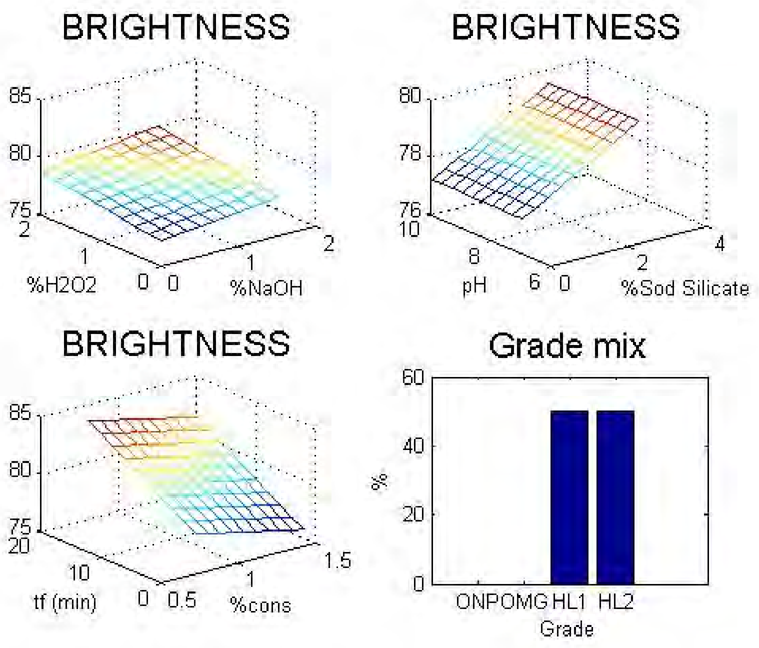


Figure 9.24: Bright_FinalA_20_2 network brightness response surface for a mixture of HL1 and HL2 grades.

The trends indicated in the response surfaces are as expected from what is known about the behaviour of deinking systems, *viz*. brightness increases with level of hydrogen peroxide addition, alkalinity and flotation time. Flotation consistency has a negative effect and flotation pH a neutral to negative effect. Figure 9.24 suggests that increasing alkalinity would have a small but positive effect on office paper deinking. In this case, judging from the shapes of the surfaces, is seems as if the neural network converged to a near-linear model.

9.4.2 Residual ink concentration (ERIC)

The variability in the ERIC values was greater than the brightness values, as shown and discussed in Section 7.3. This manifested as much lower correlations and higher mean squared errors in the neural network training processes (Appendix 8B). An additional problem was that the tissue mills did not measure ERIC. Practically, it was possible to obtain only limited plant ERIC data, by getting sample pads from the plants and testing them in the research laboratory (Appendix 6). Thus extensive plant ERIC data was only available for the newsprint mill, and it was not possible to obtain correlations over the whole deinking range, as was the case with brightness. Neural networks for the full set of input variables, a reduced set and a very reduced set were trained and tested against the plant data (Appendix 8B).The performance of the best models for each variable set is shown in Figure 9.25. To accommodate the wide range of the data, logarithmic axes have been used.

It can be seen from Figure 9.25 and Appendix 8B that again the best performance (lowest MSE) was obtained by the networks trained on the full set of process variables (ERIC_FinalB_14_4). As with brightness, the improvement in prediction was considered insufficient to justify the added complexity introduced by the full set of inputs. However, in this case a very reduced set of inputs, comprising only flotation time and flotation consistency proved to be marginally better that the reduced set of ten variables (Appendix 8B). Thus, network ERIC_FinalC_17_3 was chosen as the preferred network.

The prediction performance of network ERIC_FinalC_17_3 for the different paper grades and processing plants is shown in Figure 9.26.

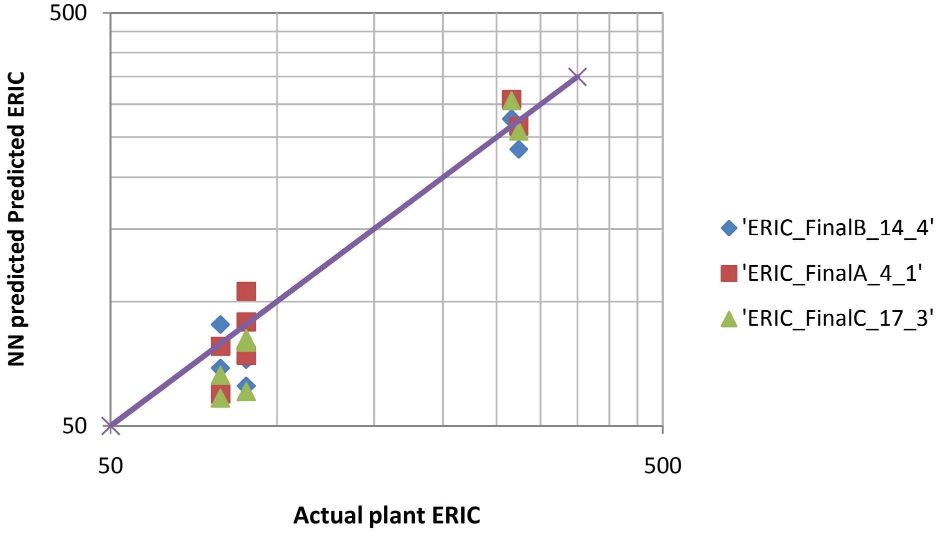


Figure 9.25: ERIC prediction performance of top ranked neural networks with different variable data sets. Full set – ERIC_FinalB_14_4, Reduced set - ERIC_FinalA_4_1 and very reduced set - ERIC_FinalC_17_3.

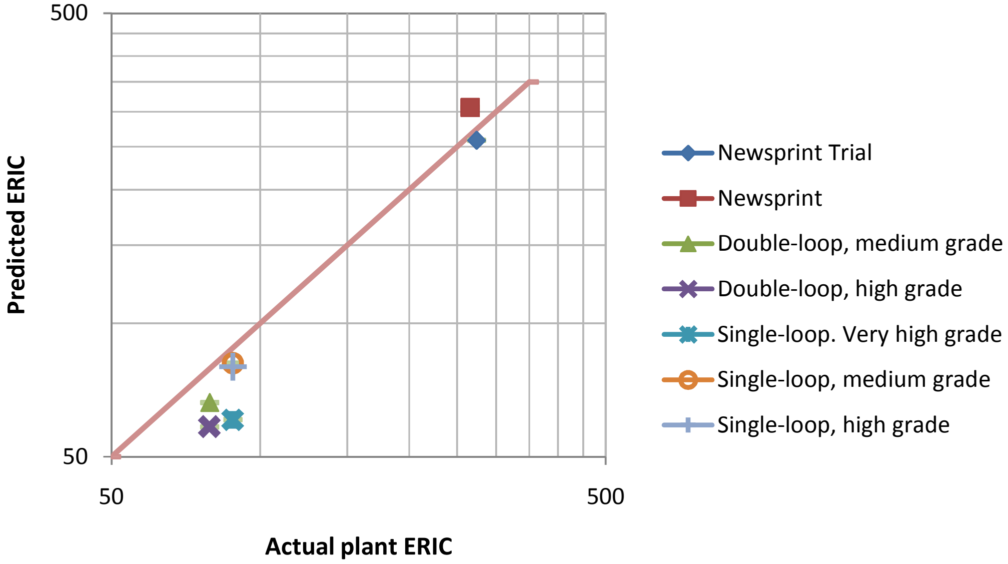


Figure 9.26: ERIC prediction performance of network ERIC_FinalC_17_3 for different paper grades and processing plants.

The prediction performance for the newsprint grades was again close to the plant values. However, as was the case for brightness, deviations were observed for the office waste paper grades. The ink loading of newsprint is much higher than that of office papers. Thus ink content will have a major effect on the brightness and ERIC of newsprint, and a relatively minor effect on the brightness and ERIC of the office papers *viz.* factors other than deinking were affecting the brightness and ERIC of the office papers.

In this case the network ERIC predictions were *lower* (*viz.* better ink removal) than the plant actuals. These figures suggested that the laboratory processes removed ink more effectively than the plant processes. In contrast, the results in Section 9.4.1 showed that the plant processes produced high brightness products. This could be attributed to the extra processing equipment in the plants which removes dirty contaminants other than ink which might otherwise negatively influence brightness. The response surfaces of the network Eric_FinalC_17_3 are shown in Figures 9.27 to 9.29.

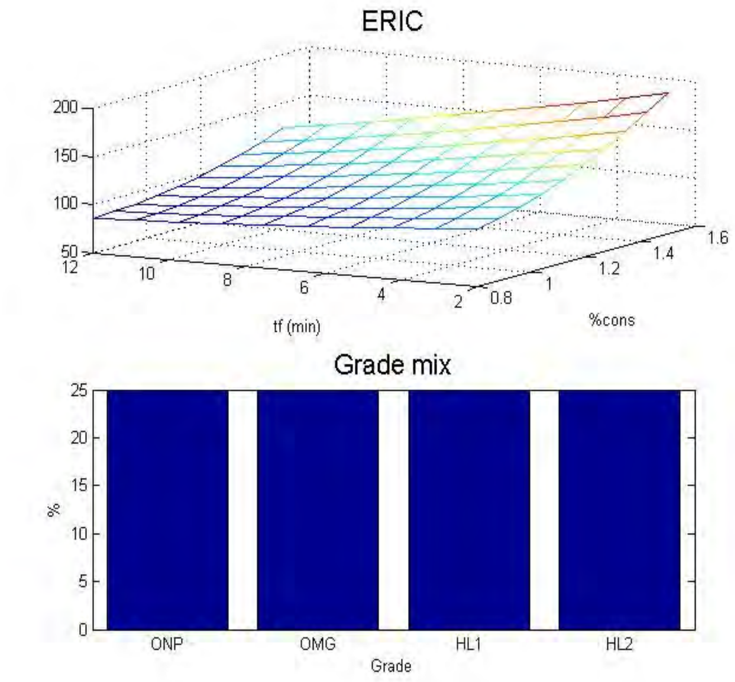


Figure 9.27: Eric_FinalC_17_3 network ERIC response surface for a mixture of all grades.

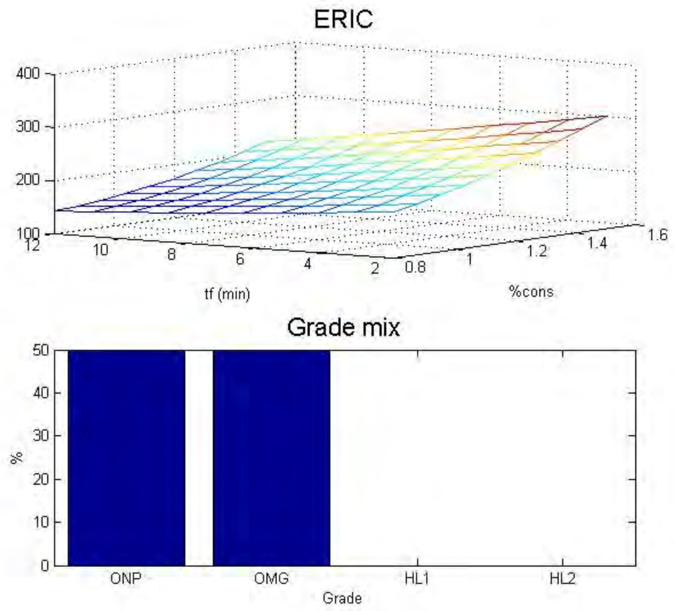


Figure 9.28: Eric_FinalC_17_3 network ERIC response surface for a mixture of ONP and OMG grades.

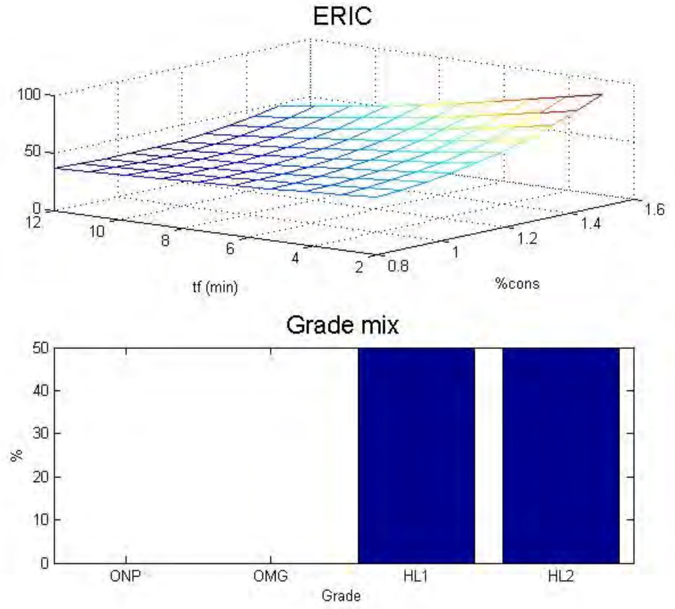


Figure 9.29: Eric_FinalC_17_3 network ERIC response surface for a mixture of HL1 and HL2 grades.

The response surfaces for all three of the representative grade mixes showed an increasing ink removal with increasing flotation time and decreasing flotation consistency. This is in agreement with known behaviour.

9.4.3 Yield

Comprehensive data was not available to calculate the estimated flotation yield for the plants. Consequently, average values had to be inserted for missing data. In addition, assumptions had to be made to estimate the flotation yields. These assumptions and estimations are detailed in Section 9.3.1.7, 9.3.2.7 and 9.3.3.7.

As for the brightness, the neural network predicted yields were evaluated against the estimated plant flotation yield data. This was also carried out for three combinations of input variables: a complete variable set, a reduced set and a very reduced set (Appendix 8C). The results for the ten best networks in each case are shown in Appendix 8C.

The correlations for the best networks are in the region of R = 0.8 based on the training data. Again the networks trained with the full variable set showed a slightly better prediction, as measured by the correlations and mean square errors. The correlations achieved are the lowest of the three properties modelled.

This is due to the fact that many factors other than those modelled can contribute to yield losses. For example, cleaner rejects, process spillages and washing losses were not accounted for in the laboratory. The prediction efficiency of the best network for each variable set is shown in Figure 9.30.

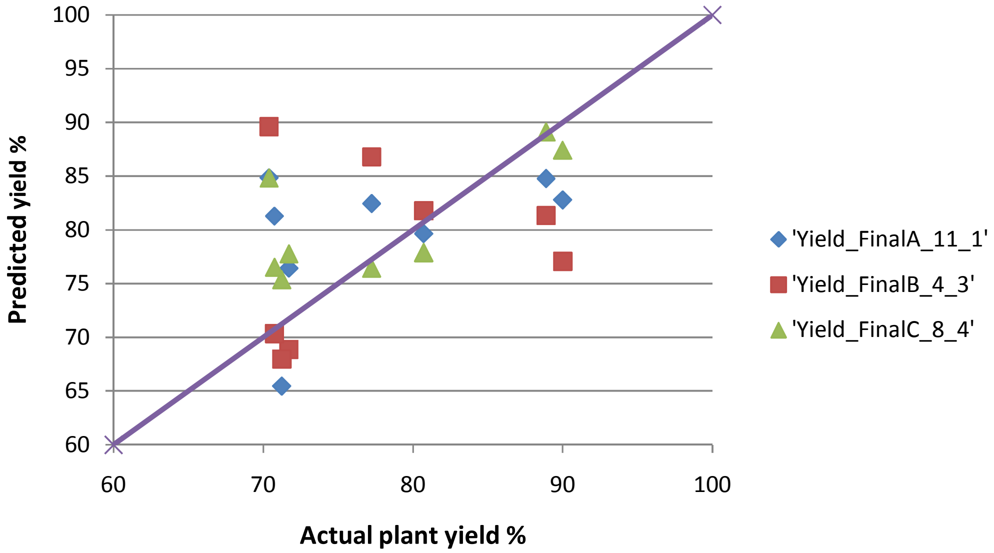


Figure 9.30: Yield prediction performance of top ranked neural networks for different variable data sets. Full set – Yield_FinalB_4_3, reduced set – Yield_FinalA_11_1, very reduced set – Yield_FinalC_8_4.

It can be seen in Figure 9.30 that the uncertainty is greatest at lower yields. The lower the yield the greater the probability that multiple losses have occurred, including random process spillages.

From the mean square error data (Appendix 8C) and Figure 9.30, it can be seen that the networks trained on the simplest set of variables (Yield_FinalC_8_4) again produced the best predications. The prediction performance of network Yield_FinalC_8_4 for the various grades and plants is shown in Figure 9.31. The low grade tissue made on the single-loop office waste plant was omitted due to lack of specific data.

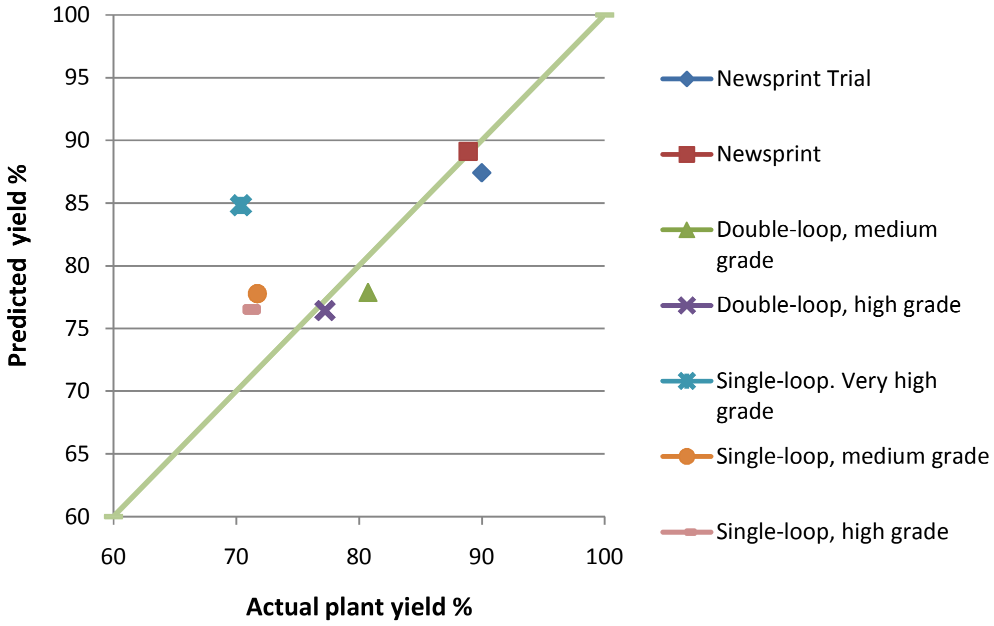


Figure 9.31: Yield prediction performance of top neural network (Yield_FinalC_8_4) for different paper grades and processing plants.

Inspection of Figure 9.31 shows that the major excursions from the Y = X line all occur in the single-loop office waste deinking plant: the plant yields are all much lower than predicted. This indicates either an error in the estimation of the yield for the single-loop office waste process or an unexplained process leakage at some point. This again highlights the possibility of the models being used to detect process abnormalities.

The response surfaces of the network Yield_FinalC_8_4 are shown in Figures 9.32 to 9.34.

The neural networks converged to almost linear response surfaces and demonstrated that yield is negatively affected by long flotation times and lower flotation consistencies. This conforms to known behaviour, and suggests that the yield was modelled fairly well by the networks, despite the uncertainties in the plant data.

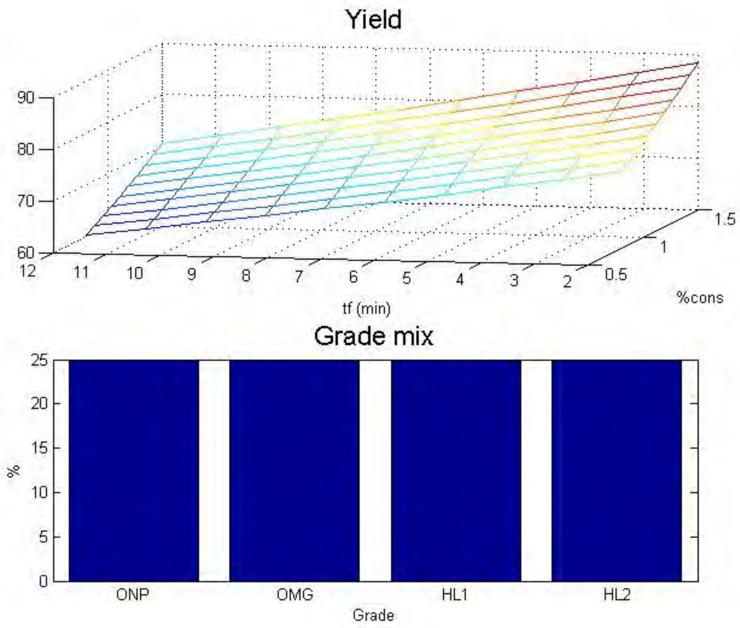


Figure 9.32: Yield_FinalC_8_4 network Yield response surface for a mixture of all grades.

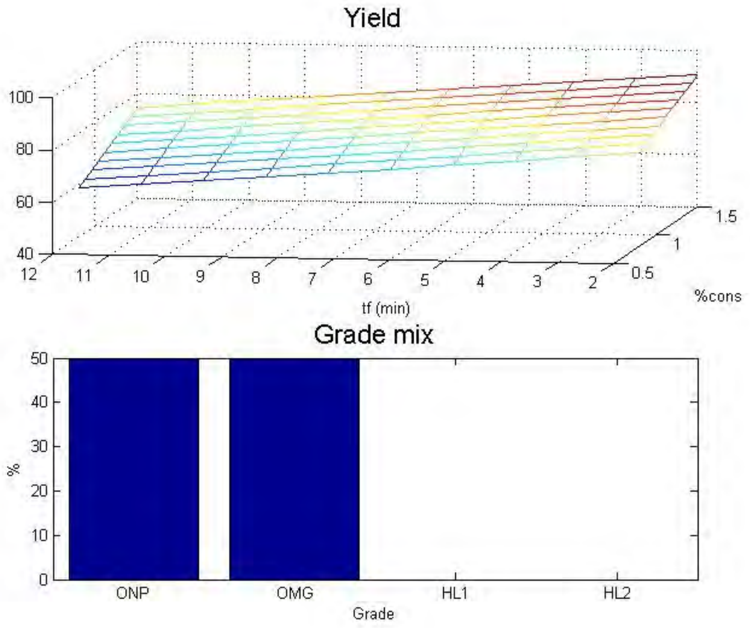


Figure 9.33: Yield_FinalC_8_4 network Yield response surface for a mixture of ONP and OMG grades.

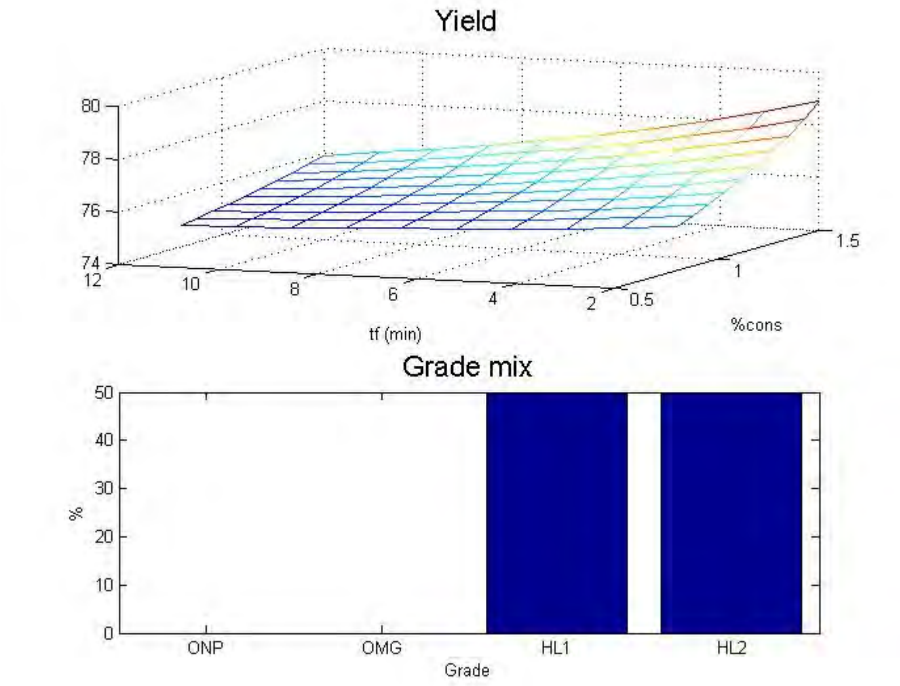


Figure 9.34: Yield_FinalC_8_4 network Yield response surface for a mixture of HL1 and HL2 grades.

Whilst the neural network predictions could not be used to accurately predict plant flotation yields, they could still be used to predict *changes* in yield which might occur if raw material or process changes were made.

The MATLAB code used to train and test the networks is given in Appendix 9.

The structures and layer weight matrices of the top performing networks are listed in Appendix 10.

A CD with electronic versions of the data and MATLAB files is included.

CHAPTER 10: FINAL CONCLUSIONS AND APPLICATIONS

10.1 Review of work done

A need was identified in the South African paper recycling industry for better control of deinking processes in the face of ever increasing variability in the recycled paper raw material stream fed to the recycling plants.

It was proposed to establish a global mathematical model which would enable recycling plants to predict how the processes would react to changing raw material streams without having to perform extensive experimental work. Also, there was a need to have alternative process parameters available for control in the event that the recycled paper mix could not be varied at will.

As it was not possible to experiment on the production plants, it was necessary to base the modelling on deinking experiments performed in the research laboratory. The many possible process parameters and chemical additions were screened using statistical experimental design techniques. It was possible to identify influential variables and eliminate those variables that had a limited effect on the process.

Four recycled paper grades as well as the influential process parameters were varied over a wide range in many random combinations to produce a data base of nearly 500 deinking runs.

This data base was used to train neural networks to predict brightness, residual ink content and flotation yield. The neural networks were tested and selected against actual process data collected from three different plants. The process plants encompassed single-loop and double-loop processes, and eight different grades of recycled pulp, ranging from low brightness newsprint to high brightness recycled office papers.

10.2 Conclusions

10.2.1 Screening of control variables

A statistically designed screening process, utilising Plackett-Burman experimental design techniques indicated that process parameters such as surfactant additions, flotation temperature, flotation pH and pulping time were not particularly influential in determining the brightness, residual ink concentration (ERIC) or yield of the flotation deinking process. On the other hand, flotation time and flotation consistency, bleaching conditions and alkalinity were most influential with respect to brightness, residual ink concentration and yield. Whilst pulping temperature was influential in determining the ERIC of magazine papers and HL1 and the washed brightness of HL2, it was rejected as a practical control variable. A ranking analysis with respect to brightness, residual ink concentration and yield resulted in the following list of process variables, in order of descending influence:

- Flotation time
- Flotation consistency
- NaOH addition level
- H_2O_2 addition level
- Sodium silicate addition level
- Surfactant addition to the pulper
- Pulping time
- Flotation pH

A subsequent sensitivity analysis carried out using neural networks confirmed the findings of the Plackett-Burman screening runs with respect to which process parameters were most influential.

However, the grade of recycled paper used as a raw material for deinking had an overriding influence on the optical properties. The order of influence on optical properties (brightness and ERIC) was in descending order:

- Heavy Letter 1
- Heavy Letter 2
- Magazines
- Newsprint

This order corresponds with the level of incoming brightness of the recycled paper.

The yield was determined predominantly by the flotation time and consistency, with alkalinity playing a role in the case of Heavy Letter 1. The largest yield loss was experienced by magazine grades, followed by newsprint and then office papers. The yield did not seem to be dependent solely on the filler content of the paper, as newsprint has lower levels of filler than office papers.

10.2.2 Data generation

The generation of nearly 500 deinking runs to form the data base for the training of the neural networks was performed continuously over a 17 month period. All of the process variables initially identified were varied over the full range used in the South African deinking industry. More data was collected for the variables that were most influential, whilst much less data was gathered for the least influential variables.

By careful selection of recycled paper raw material, the “noise” induced by raw material quality variations was minimised. This variability was tracked and monitored by performing midpoint runs at regular intervals. The coefficient of variation of the brightness generally remained below *ca*. 6%, with the variability of HL2 brightness peaking at 8.9%. On the other hand, the coefficient of variation of the ERIC was much higher, varying from 27% to 54%. The coefficient of variation of the yield data ranged between 6.8% for HL1 up to 22% for OMG, but generally in the region of 8-10%. Generally, the office recovered paper grades showed the greatest variability with respect to ERIC and lowest variability with respect to yield data.

10.2.3 Generation of neural networks

Neural networks were able to effectively model the laboratory processes to high levels of correlation. With reference to Table 10.1, laboratory brightness results were modelled with correlations greater than 95%.

Slightly lower correlations ($84\%<R<91\%$) were achieved for the ink removal (ERIC) in the laboratory. The lower correlations were probably due to the inherently higher variability of the ERIC results.

Although the variability of the laboratory flotation yield data was less than the ERIC data, weaker correlations ($R<80\%$) were found (Table 10.1). The agitation speed in the flotation cell was maintained constant throughout the experimental period, but it is presumed that variations in hydrodynamic factors (bubble size, bubble number) in the float cell, which were not included in the models, are responsible for the weaker yield correlations. Flotation time and consistency have the greatest influence on yield, whereas a greater variety of factors influence the optical properties, thereby diluting the effect of hydrodynamic factors.

Table 10.1: Summary of neural network performance. (Appendix 8)

Property modelled	Number of process parameters	Neural network correlation with lab data (R)	Neural network prediction of plant data (R)	Neural network prediction of plant data (MSE)
Brightness %	**10**	**0.951**	**0.922**	**53.5**
	15	0.954	0.940	26.0
Residual ink concentration ERIC, ppm	**6**	**0.841**	**0.937**	**1342**
	10	0.907	0.934	1370
	15	0.853	0.934	1021
Flotation yield %	**6**	**0.767**	**0.534**	**83.6**
	10	0.791	0.453	87.5
	15	0.790	0.425	101.2

Notes:

1. 15 process parameters: ONP, OMG, HL1, HL2, NaOH, sodium silicate, hydrogen peroxide, surfactant addition to pulper and flotation cell, pulping time and temperature, flotation time, flotation temperature, flotation consistency and flotation pH.
2. 10 process parameters: ONP, OMG, HL1, HL2, NaOH, sodium silicate, hydrogen peroxide, flotation time, flotation consistency and flotation pH.
3. 6 process parameters: ONP, OMG, HL1, HL2, flotation time and flotation consistency.

10.2.4 Prediction of neural networks

The plant brightness was predicted at R > 90% for 10 and 15 process parameters, only slightly lower than the correlations with the laboratory brightness data (Table 10.1).

On the other hand, the plant ERIC data was predicted with slightly higher correlations than the laboratory ERIC data (Table 10.1) for 6, 10 and 15 process parameters. The newsprint deinking plant routinely measured ERIC values. However, the ERIC data collected for the tissue deinking plants was very limited. A single average value was inserted for a range of plant conditions, which probably contributed to the slightly stronger correlations found with the plant data. Nevertheless, the laboratory correlations for ERIC were good, so it can be expected that good plant correlations would be achieved if more data were available.

The neural network correlations with the laboratory yield data were the lowest (R<80%) for 6, 10 and 15 process parameters, although still reasonable. However, the flotation yield was not directly measured by the plants, and had to be estimated from the incomplete data available. Some unit operations in a full scale plant can contribute to yield losses (*e.g.* hydrocyclone cleaning, screening, process spillages) and others can contribute to fibre savings (*e.g.* secondary flotation of removed ink, recirculation of fibrous filtrates). The effect of these operations could not be simulated in the laboratory process. Hence much weaker predictions (R< 55%) with the plant data were obtained using 6, 10 and 15 inputs.

Neural networks trained with the complete set of 15 process variables generally produced better correlations and lower mean square errors (MSE) than models with 10 or 6 process variables (Table 10.1). Yield was the exception to this trend, and was predicted best with only six variables. However, the networks based on the optimised set of 10 variables produced predictions which were almost as good as the 15 variable networks, but with the advantage of the much greater simplicity of fewer variables. Thus, the best networks were selected on the basis of prediction ability, but a small amount of prediction ability was sacrificed in favour of a simpler fewer-variable model. The selected models are indicated in bold type in Table 10.1.

10.3 Applications

The global neural network models effectively approximated the brightness and ERIC values produced by the plants studied. The yield was less effectively modelled.

The process of visiting the plants to gather data highlighted some possibilities for the application of the neural networks, elaborated below:

10.3.1 Process applications

The models developed in this research could be used for deinking plant *process optimisation*. A recent case study will illustrate this application. The brightness at a local newsprint deinking plant had been deteriorating in the recent past, and the author was called in to advise the mill. Based on the results of the research, the mill was informed that the alkalinity and bleaching conditions have a major influence on the brightness. After some discussion it emerged that the amount of caustic soda added to the pulper had been cut back for various reasons. The lower deinking alkalinity had possibly resulted in lower deinking efficiency and lower brightness. The mill was advised to increase the pulping alkalinity. At the time of writing the suggested changes had not yet been implemented at the mill.

These models could be of assistance in *troubleshooting* exercises. The models represent “standard” or average conditions, and deviations from predicted values can be indicative of some malfunctioning equipment or other process deviation. As an example, the very high grade tissue pulp manufactured on the single-loop process showed an anomalously low plant brightness for the high quality raw material used, compared to the neural network predicted brightness. It is possible that this could have been due to the low volumes manufactured and the effect of recirculating back water. Another example was the yield deviations of the single-loop tissue recycling process. This process displayed deviations from predicted values for all of its grades. This indicates that there is perhaps an undetected yield leakage from the system.

The models could also be used to *pre-empt the results of trials*. An example of this was the trial carried out in the newsprint mill, where the ratio of magazine to newsprint was increased to 60:40, from the usual 30:70. The result of this trial was that the brightness increased only marginally, despite the large change in furnish composition. This marginal change was also predicted by the neural networks. The use of the models pre-trial would have avoided the unnecessary costs and disruptions of trials on production plants.

10.3.2 Raw material changes

Recycling plants are sometime confronted with sudden raw material changes. A particular grade of recycled paper could suddenly become unavailable, and the plant is confronted with the need to change the ratio or even the grade mix of recycled paper raw material. These changes could be fed into the models to predict the outcome. In addition, the corresponding changes to the alkalinity or bleaching regime required to maintain the output quality could be determined in a short period of time. This would enable the plant management to make a rapid decision on the use of the changed raw materials.

10.4 Future work.

In any research work, time and resource constraints limit the amount that can be done. The following areas could form the basis of further work.

10.4.1 Unresolved questions

The main unresolved question in this research was the “gap” between the laboratory based model predictions and the plant brightness values. This was indicated by the deviations of the neural network predictions from the Y = X lines. An empirical attempt was made to bridge this gap by relating the laboratory-based data to the plant data through the flotation performance curve of brightness verses flotation residence time. It was hoped that by adjusting the flotation time in the model a near perfect fit would be obtained. This was only partially successful.

Most of the “gaps” occurred with the predictions for the office paper deinking plants, where the plant brightness was higher than the predicted brightness by up to 10 brightness points. It is known that toner inks produce large, difficult to float particles. The office paper recycling plants had extra equipment (screens, cleaners and dispersers) to eliminate the large ink particles. This equipment was not simulated in the laboratory, and hence not modelled. This would account for the consistent under-estimation of the final brightness by the models. This limitation needs to be taken into account when applying the models. It would be possible to apply a mathematical correction or bias to the output of the models to bring the predications in line with the actual values.

Another unresolved issue was the lack of sufficient plant ERIC data, particularly for the office paper recycling plants, to obtain a good test of the models against plant data. This was due to the fact that the ERIC was not measured by these plants, and practical obstacles prevented a large amount of data being collected.

The last unresolved question was the quality of the yield data from the plants. Although sufficient data was available, it did not correspond to the actual flotation yield, but to general and combined yield losses of the plants. Data corresponding to flotation yield had to be teased out of the data using indirect means and estimates, which negatively affected the quality of the data. It would be instructive for further work to obtain high quality data from the plants for ERIC and yield, and to re-test the models, to try to find a better fitting neural network.

10.4.2 Extensions of the model to other parameters

The experimental research work generated a large number handsheets. These handsheets could be further tested for filler content and sheet strengths, and models could be developed for these properties as well. These properties were initially excluded from the project due to resource constraints.

With the available data, it would be possible to model the pulping stage, flotation stage and washing stage separately, and combine them into a total model. This approach was not followed in this work, as the original concept was to produce a global model responding to raw material changes. However, the advantage of a more unit-operations based model would be that the units could possibly be built up into multistage processes, thereby allowing more possibilities for process design and modification.

The models developed were trained on laboratory data and tested and selected on the basis of aggregated plant data. They are thus suitable as static “management” models for the selection and modification of set points or operating regimes. The models were not trained on dynamic plant data, and were not intended for the control of short-term plant variations. However, it would be an interesting exercise to use the models in a short-term dynamic situation, to see how well they would control a plant.

10.4.3 Practical implementation

It is intended to use the neural networks produced in this study to develop a desk-top model which would enable plant personnel to proactively anticipate quality and process adjustments in response to changing recycled paper raw material conditions.

What would follow now is an information technology project process. A prototype has been developed which needs to be implemented, in the following steps (Tarassenko, 1998: 46-48):

10.4.3.1 Implement the prototype on customer hardware and software

The models currently exist in MATLAB format, requiring specific expertise and computing skills to input data and produce outputs. A software programming exercise is required to provide user interfaces to enable plant personnel with more general computing skills to access and use the models.

10.4.3.2 Acceptance testing

The models must be tested on plant data over a longer period of time and variety of conditions. This would make it possible to quantify confidence limits for the model. It would be advisable to repeat the laboratory-plant flotation alignment processes, specific to the plant, as discussed in Section 9.2 and to correct the data deficiencies for ERIC (if desired) and yield.

10.4.3.3 Handover and training

The use of these models to troubleshoot or optimise processes must be combined with extensive knowledge and experience in deinking processes. The models rely heavily on the underlying data base of laboratory work. An understanding of this data base and its limitations is essential to make effective use of the neural network models.

10.4.3.4 Maintenance

The system would need to be maintained. Bugs could develop and the operating environment could change, necessitating revisions and enhancements.

REFERENCES

Ackerman, C., Putz, H. J. & Goettsching, L. Effect of pulping conditions on deinking of wood-containing recovered paper grades. Pulp & Paper Canada, 100:4 (1999).

Ali, T., Fairbank, M., McArthur, D., Evans, T. & Whiting, P. 1988. The role of silicate in peroxide brightening of mechanical pulp. Part II: The effects of retention time and temperature. Journal of pulp and paper science. Vol. 14, No. 2, March 1988.

Ali, T., McLellan, F., Adiwinata, J., May, M. and Evans, T. 1994. Functional and performance characteristics of soluble silicates in deinking. Part I: Alkaline deinking of newsprint/magazine. Journal of Pulp and Paper Science. Vol. 20 No. 1, Jan. 1994. pp J3-8.

Anderson, J. 1993. High efficiency for clean deinking. Paper Technology. Sept. 1993. pp 12-16.

Andrew, J. E. 2007. Questionnaire to identify the research areas of focus for processing of South African recovered fibres. Forest and Forest Products Research Centre internal report. November 2007.

Aspler, J. 1991. Introduction to printing technology and ink chemistry. In: TECH '91-Recycling and deinking of newsprint and fine papers course. Toronto, Feb. 17-22. Montreal, Quebec, Canada. CPPA. Pp 1-26.

Azevedo, M. A. D., Drelich, J. and Miller, J. D. 1999. The effect of pH on pulping and flotation of mixed office waste paper. Journal of Pulp and paper Science. **25**:9. September 1999.

Barrentine, L. B. 1999. An Introduction to Design of Experiments. American Society for Quality, Milwaukee, Wisconsin. 1999.

Ben, Y and Dorris, G. M. 2000. Irreversable ink redeposition during repulping. Part II: ONP/OMG furnishes. Journal of Pulp and Paper Science: Vol. 26 No. 8. August 2000. pp 289-293.

Beneventi, D., Benesse, M., Carre, B., Julien Saint Amand, F., and Salgueiro, L. 2007. Modelling deinking selectivity in multistage flotation systems. Separation and Purification Technology. **54**: 77-87

Beneventi, D. and Carré, B. 2000. The mechanisms of flotation deinking and the role of fillers. Progress in Paper Recycling. February.

Beneventi, D., Carbo, A. C., Fabry, B., Pelach, M.A., Pujol, P.M. 2006. Modelling of flotation deinking: contribution of froth-removal height and silicate on ink removal and yield. Journal of Pulp and Paper Science. Vol. 32(2).

Beneventi, D., Carré, B., Hannuksela, T. and Rosencrance, S. 2007. Assessment of deinking chemistry performance: from laboratory flotation tests to the simulation of an industrial pre-flotation line. 8th. TAPPI Research Forum on Recycling. 2007.

Bennington, C. P. J., Sui, O. S. and Smith J. D. 1998. The effect of mechanical action on waste paper defibering and ink removal in repulping operations. Journal of Pulp and paper Science. Vol 24: 11. November 1998.

Bennington, C. P. J. and Wang, M. H. 2001. A kinetic model of ink detachment in the repulper. Journal of Pulp and Paper Science: Vol. 27, No. 10, October 2001.

Bergh, L. G. and Yianatos, J. B. 2002. Flotation column automation: state of the art. Control Engineering Practice. **11,** p67-72

Berg, S.R, Johnson, D.A. and Thompson, E.V. 1997. Toner detachment during repulping of laser-printed office copy paper. TAPPI Journa.. Vol. 80(4).

Bloom, F. 2006. A mathematical model of continuous flotation deinking. Mathematical and Computer Modelling of Dynamical Systems. **12**: No. 4, August: 277-311

Bloom, F. and Heindel, T. J. 1997. A Theoretical model of flotation deinking efficiency. Journal of Colloid and Interface Science. **190**:182-197.

Borchardt, J.K. 2003. [online]. Recent developments in paper deinking technology. Taken from: http://www.pulpandpapercanada.com/news/recent-developments-in-paper-deinking-technology/1000127971/. Accessed 15/06/2011

Borchardt, J. K. 1997. The use of surfactants in deinking paper for paper recycling. Current Opinion in Interface Science, 2(4), 402-408. 1997

Borchardt, J. K. 1995. [Chemistry of unit operations in paper deinking mills.] In: Plastics, rubber and paper recycling. Chapter 27, pp 323-341. American Chemical Society. 1995

Borchardt, J. K. 1993, Possible deinking mechanisms and potential analogies to laundering. Progress in paper recycling, February 1993.

Borchardt, J.K. 1993b. Effect of process variables in laboratory deinking experiments. Tappi Journal. Vol. 76, No. 11.

Borchardt, J. K. and Lott, V.G. 1996. Deinking toner containing furnishes. Part 4: The role of microscopic ink particles in deinking office paper. TAPPI Proceedings of 1996 Recycling Symposium. New Orleans. Pg 107-124

Bremner, M. 2010. Pers. Comm.. to W. J. Pauck. Managing Director PaperChem. Chromaclear Premix Bleaching Technology (Dow Chemicals).

Brereton, R.G. 2006. Chemometrics – Data Analysis for the Laboratory and Chemical Plant. John Wiley & Sons, Ltd. University of Bristol, UK.

Brouillette, F., Daneault, C. and Dorris, G. 2001. Effect of initial repulping pH on the deflaking rate of recovered papers. Preprints 6th Research Forum on Recycling. Magog, QC.Oct. 1-4. Pp. 29-36.

Brouillette, F., Paradis, J. and Lafrenière, S. Pilot paper machine production of newsprint using high filler loads and dry strength technologies. Pulp & Paper Canada. September/October 2010.

Bureau of International Recycling. 2009. BIR Annual Report [online]. Accessed at http://www.bir.org. [22 Feb. 2011]

Carrasco, F., Pelach, M. A. and Mutje, P. 1999. Deinking of high quality offset papers: influence of consistency, agitation speed and air flow rate in the flotation stage. Tappi Journal. 82:3

Carré, B. and Galland, G. 2007. Overview of deinking technology. 8th CTP/PTS Deinking Training Course. Grenoble, May 29-31.

Carré, B., Galland, G and Julien Saint Amand, F. 1994. Estimation of ink detachment and removal. Progress in Paper Recycling. November 1994. Vol 4, pg 80-87.

Carré, B., Galland, G., Vernac, Y. and Suty,H. 1996. The effect of hydrogen peroxide bleaching on ink detachment during pulping and kneading. Revue A.T.I.P Vol. 50, No. 3. May/June.

Carré, B. and Magnin, L. 2004. Digital Prints: A survey of the various deinkability behaviours. 7th Research Forum on Recycling PAPTAC – TAPPI. September 27-29. Quebec, Canada.

Carré, B. and Magnin, L., Galland, G. and Vernac, Y. 2000. Deinking difficulties related to ink formulation, printing process and type of paper. TAPPI Journal. Vol. 83(6)

Carré, B. and Magnin, L., Galland, G. 2003. [online] Printing processes and deinkability. Das Papier 2003 – T195. Available at: http://epub.zellcheming.de/index.php?timestamp=1268527903&do=download&document_id=190&sessionid=3ea4e*af4b9c331fafb89. Accessed on 15/06/2011

Crosby, J. 1999. Personal communication to J. Pauck. Deinking plant superintendant. Mondi Merebank. P.O Box 17001, Merebank, Durban, 4001. 1999.

Crosby, J. 2008. Personal communication to J. Pauck. Former deinking plant superintendant. Mondi Merebank. P.O Box 17001, Merebank, Durban, 4001October 2008.

Crosfield. 1993. Soluble silicates and their applications. Crosfields Technical Information, Issue No. 1, July 1993. Crosfield Group, Warrington, England, WA5 1AB.

Cubillos, F. A. and Lima, E. L. 1998. Adaptive hybrid neural models for process control. Computers Chem. Engng vol.22, Suppl., pp. S989-S992. Elsevier Science Ltd. Great Britain.

Cubillos, F. A. and Lima, E. L. 1997. Identification and optimising control of a rougher flotation circuit using an adaptable hybrid-neural model. Minerals Engineering. **10**, No. 7,pp. 707-721.

Dash, B. and Patel, M. 1997. Recent advances in deinking technology. Indian Pulp and Paper Technical Association. **9**(1): 61-70.

Dayhoff, J. E. 1990. Neural Network Architectures – an Introduction. Van Nostrand Reinhold. 1990

Demuth, H., Beale M. and Hagan M. 2009. MATLAB Version 6.0.3 (Release R2009a) - Neural Network Toolbox 6 Users Guide. The MathWorks, Inc., Natwick, MA 01760-2098.

Dionne, Y. 1994. In mill optimisation of deinking chemicals by laboratory experiment. Paper Technology: Jan./Feb. 1994. pp37-42.

Dorris, G. M. 1999. Ink detachment and flotation efficiency in ONP/OMG Blends. Part 1: Effect of specimen preparation procedure on estimates. Journal of Pulp and Paper Science. Vol 25(1), January 1999.

Dobias, B., Klar, W., Schwinger, K., 1992. [Flotation of pigments and inks from waste paper]. Innovations in Flotation Technology, 499-511, 1992.

Edwards, P. J., Murry, A. F., Papadopoulos, G., Wallace, R., Barnard, J. and Smith, G. 1999. The application of neural networks to the papermaking industry. IEEE Transactions on Neural Networks. Vol. 10, No. 6, November 1999.

Eriksson, L., Hagberg, P., Johansson, E., Rannar, S., Whelehan, O., Astrom, A. and Lindgren, T. 2001. Multivariate process monitoring of a newsprint mill. Application to modeling and predicting COD load resulting from deinking of recycled paper. Journal of Chemometrics: **15**: 337-352

European Declaration on Paper Recycling 2006 – 2010. Monitoring Report 2007. *European Recovered Paper Council*. Available at: http://www.intergraf.eu/Content/ContentFolders/PressReleases/2008-09_ERPC_AnnualReport_2007.pdf. Retrieved 2009-11-29

Fabry, B. and Carré, B. 2004. A new approach to characterize pulping processes for deinking. 11th PTS/CTP Deinking Symposium. Leipzig. Pp 17.1-23

Fabry, B., Carré, B and Crémon, P. 2001. Pulping optimisation: effect of pulping parameters on defibering, ink detachment and ink removal. Proc. From 6th PAPTAC Research Forum on Recycling. Vol.: none. Pp 37-44.

Fabry, B., Carré, B. and Galland, G. 2005. New pulping strategy for DIP for tissue making. Tissue World. France. Pp 1-6.

Falcone, J S. 1982. The effect of degree of polymerisation of silicates on their interactions with cations in solution. In: Soluble Silicates – ACS Symposium Series 194, ed. J S Falcone Jr. 182nd National Meeting of the ACS, New York, August 1981. American Chemical Society, 1982.

Forouzi, S. and Meech, J. A. 1999. An adaptive artificial neural network to model a Cu/Pb/Zn flotation circuit. Proceedings of the Second International Conference on Intelligent Processing and Manufacturing of Materials. 1999. Vol 2: 967-974.

Ferguson, L. D. 1993. Laboratory deinking practices. Pulp & Paper Canada. 94(4).

Ferguson, L. D. 1992a. Deinking chemistry: part 1. TAPPI J., 75(7):75(1992)

Ferguson, L. D. 1992b. Deinking chemistry: part 2. TAPPI J., 75(8): 75(1992)

Ferguson, L. D. 1991. The role of pulper chemistry in deinking., TAPPI 1991 Pulping Conference Proceedings, TAPPI Press, Atlanta.

Figueiredo, L. S.,Ribeiro, J. C. T., da Costa, E. F. and da Costa, A. O. S. 2008. Predicting the characteristics of white liquor by modeling and simulation of the causticising process using artificial neural networks. Proceedings: ABTCP conference. Sao Paulo, Brazil. October 2008.

Finch, J. A. and Hardie, C. A. 1999. An example of innovation from the waste management industry: deinking flotation cells. Minerals Engineering. Vol. 12, no. 5, pp. 467-475.

Froass, W. C., Francis, R. C., Dence, C. W. and Lefevre, G. 1997. The interactions of calcium, magnesium and silicate ions under alkaline conditions. Journal of Pulp and Paper Science: Vol. 23 No. 7. July 1997. pp J318-325.

Galland, G., Vernac, Y. and Carré, G. 1997a. The advantages of combining neutral and alkaline deinkinh, Part I: comparison of deinking of offset and flexo printed paper. Pulp and Paper Canada. Vol. 98(6).

Galland, G., Vernac, Y. and Carré, G. 1997b. The advantages of combining neutral and alkaline deinkinh, Part II: comparison of various processes for deinking mixtures containing waterbased printed paper in the CTP pilot plant. Pulp and Paper Canada. Vol. 98(7)

Gehr, V., Reinholdt, T. and Koberi, D. 2000. A new smart brightness control concept for more consistent pulp qualities. Proceedings of the PTS-CTP deinking symposium, Paper 11. Munich, 9-12th May.

Goettsching, L. and Pakarinen, H. 2000. In: L. Goetsching and H. Pakarinen (ed.). Recycled Fibre and Deinking. Papermaking Science and Technology Series. Book 7. Helsinki, Finland. Fapet OY.

Govender, P. 2008. Personal communication to J. Pauck. Production manager, Mondi Merebank. P.O Box 17001, Merebank, Durban, 4001. October 2008.

Grant, J and Blain ,T. 1995. Short sequence recycling: The factors affecting ink agglomeration and stability. Proceedings 3rd Research Forum on recycling, 1995. CPPA., Montreal, Que., Canada. pp 247-255.

Gupta, H., Liu, P., and Svoronos, S. A. 1999. Hybrid first-principles/neural networks model for column flotation. AIChE Journal. **45,** No. 3.

Hach, M. and Joachimides, T. 1991. The influence of bleaching on color in deinked pulps. Proceedings TAPPI 1991 Pulping Conference. Pg 801-812.

Hagan, M. T., Demuth, H. B. and Beale, M. 1996. Neural Network Design. PWS Publishing Company, Boston, MA 02116-4324.

Hajek, M. 2008. Neural Networks lecture notes. Department of Computer Science. University of KwaZulu Natal.

Hajek, M. 2010. Personal communication to J Pauck. Department of Computer Science. University of KwaZulu Natal. 3 March 2010.

Hannuksela, T. and Rosencrance, S. No Date. Deinking Chemistry. [online] http://www.cost-e46.eu.org/files/Deinking%20primer/Deinking%20Chemistry-final.pdf. Assessed 17/06/2011

Haykin, S. 1994. Neural Networks - A Comprehensive Foundation. Macmillan College Publishing Company, Inc. 113 Sylvan Avenue, Englewood Cliffs, NJ 07632

Haynes, D. 2008. A decade of deciphering the “Summer Effect”. PaperAge. May/June 2008.

Haynes, R. D. 2000. Measuring ink content: from pulper to deinked pulp. TAPPI Recycling Symposium. Washington D.C. Vol. 2, pp. 677-691

Harper, R. 2009. Personal communication to J Pauck. Manager at Mondi Recycling, 231 Maydon Road, Durban. 15 Jan. 2009.

Heindel, T.J.1999. Fundamentals of flotation deinking. TAPPI Journal, Vol. 82: No. 3, p 115-124.

Heindel, T. J. 1997. The fundamentals of flotation deinking. IPST Technical paper series number 656.

Hladnik, A., Bolanča, I. and Bolanča, Z. 2006. Characteristics of recycled firbres from digital prints using solid and liquid toner. [online] http://www2.grafica.ntf.uni-lj.si/fileadmin/uporabniki/ot216/adnik/Isng_06.pdf. accessed: 19/11/2010.

Hodouin, D., Jamsa-Jounela, S. –L., Carvalho, M. T., Bergh, L. 2001. Control Engineering Practice. **9**, pp 995-1005.

Huang, S. H. and Zhang, H.-C. 1995. Neural-expert hybrid approach for intelligent manufacturing: A survey. Computers in Industry. **26**, pp 107-126.

Hunold, H., Krauthauf, T., Müller, J. and Putz, H.J. 1997. Effect of air volume and air bubble size distribution on flotation in injector-aerated deinking cells. Journal of Pulp and Paper Science. Vol. 23, No. 12. December.pp 3555-3560.

Hunt, J. 2008. Paper Recycling in South Africa. Available from: www.enviropaedia.com/topic/default.php?topic_id=184 [Accessed November 2008]

Johansson, B., Wickman, M. and Ström, G. 1996. The mechanism of offset ink particles agglomeration in a calcium-fatty acid collector system. Journal of Pulp and Paper Science: Vol. 22 No. 10. Oct. 1996. pp J381-385.

Johansson, B. and Ström, G. 1999. Floatability of model offset ink. Appita Journal. Vol. 52 No. 1. Jan. 1999. pp37-40.

Johnson, D.A. and Thompson, E.V. 1995. Fiber and toner detachment during repulping of mixed office waste containing photocopied and laser-printed paper. TAPPI Journal. Vol. 78., No. 2.

Jordan, B.D. and Popson, S.J. 1994. Measuring the concentration of residual ink in recycled newsprint. Journal of Pulp and Paper Science. Vol. 20. No. 6. June.

Julien Saint Amand, F. 1999. Hydrodynamics of deinking flotation. International Journal of Mineral Processing. 56: 277-316.

Julien Saint Amand, F., Perrin, B. J. and Sabater, J.A. 1993. Advanced deinking supervision using a new sensor for on-line speck measurements. Tappi Journal. Vol. 76, No. 5.

Kanhekar, S. K., Agnihotri, P. K., Sharma, C. and Bansal, M. C. 2005. Effects of surfactants in flotation deinking of old newsprint. IPPTA Journal. Vol. 17(3):63-67.

Kemper, M. 1999. State-of-the-art and new technologies in flotation deinking. Int. J. Miner. Process. 56(1999): 317-333.

Koh, P. T. L. & Schwartz, M. P. 2003. CFD modelling of bubble–particle collision rates and efficiencies in a flotation cell. Mineral Engineering **16,** No. 11, pp:1055-1059.

Krumrine, P H. 1982. Sodium silicate in chemical flooding processes for recovery of crude oils. In: Soluble Silicates – ACS Symposium Series 194, ed. J S Falcone Labidi, J., Pelach, M. A., Turon, X. and Mutje, P. 2007. Predicting flotation efficiency using neural networks. Chemical Engineering and Processing. **46**, pp 314-322.

Körkkö, M. and Laitinen, O. 2008. [online]. Deinking Primer Pulping. Fibre and Particle Engineering Laboratory, University of Oulu. Available from http://www.cost-e46.eu.org/files/Deinking%20primer/Deinking%20Primer%20-%20Pulping.pdf. Accessed on 3 Mar. 2011

Labidi, J., Pelach, M. A., Turon, X. and Mutje, P. 2007. Predicting flotation efficiency using neural networks. Chemical Engineering and Processing. **46**, p. 314-322.

Lakshmana Reddy, B.H., Nayak, R.G. and Vasanthakumar Pai, K. 2008. Neutral flotation deinking – A new opportunity for Indian paper industries. IPPTA Journal. Vol. 20, No. 1. Jan.-Mar.

Laperrière L. and Wasik L. 2000. Implementation of a Neural Network Modelling Module in a Commercial Software Simulation Package, CD-ROM proceedings of TAPPI Engineering Conference, Atlanta, USA, September 17-21, 2000

Larsson, A. 1987. Surface chemistry in flotation deinking. Paper Technology and Industry. Feb. 1987. pp 383-390.

Larsson, A., Stenius, P., Odberg, L. 1984. Sv. Papperstidning 88(3),R2(1985) and 87(18),R165(1984).

Le Nuy, C., Haveri, M and Pakarinen, H. 2001. Impact of RCF raw materials quality on deinking performance. Pilot and mill scale study. Preprints 6th Research Forum on Recycling. Magog, QC. Oct. 1-4. Vol. none. Pg 191-196

Levesque, M., Dessureault, P., Carabin, P. and Barbe, M. C. 1998a. Measurement of deinked pulp quality and deinking efficiency, part 2: Impact of specimen preparation procedures ink content results. Pulp and Paper Canada. 99:5.

Levesque, M., Dessureault, P., Carabin, P. and Barbe, M. C. 1998b. Measurement of deinked pulp quality and deinking efficiency, part 1: Impact of specimen preparation procedures on ISO brightness results. Pulp and Paper Canada. 99:6.

Letcher, M. K. and Sutman, F. J. 1991. The effects of magazine and filler on the flotation deinking of newsprint. Proceedings 1st Research Forum on Recycling, Toronto, Oct. 1991. CPPA, Montreal, 1991.

Licht, H. and Leighton, W.G. 1991. A practical guide to deinking chemistry. 77th Annual Meeting of the Technical Section of the Canadian Pulp and Paper Association. Montreal, Canada. Februaray 1991.

Liphard, M., Hornfeck, K. & Schreck, B. 1991. The surface chemical aspects of filler flotation in waste paper recycling. Proceedings 1st Research Forum on Recycling. Toronto, Oct. 1991 Pp 55-64, Canadian Pulp and Paper Association, Quebec, Canada.

Magnin, L.,Angelier, M.C., and Galland, G. 2000. Comparison of various oxidizing and reducing agents to bleach wood free recycled fibres. Proceedings of the PTS-CTP Deinking Symposium. Paper 12, Munich.

Mahagaonkar M, Banham P & Stack K. 1997. The effects of different furnishes and flotation conditions on the deinking of newsprint. Progress in Paper Recycling. February 1997, pp 50-57.

Mahagaonkar, M., Banham, P. and Stack, K. 1996. The role of different alkalis in the deinking process. Appita Journal: Vol 49 No. 6. Nov. 1996. pp403-410.

Mahagaonkar M, Stack K. and Banham P. 1998. The effects of coated magazines on deinking of newsprint after pulping and flotation. TAPPI Journal. Vol. 81(12).

Mak, N. and Stevens, J., S. 1993. Characteristics of fatty acid as an effective flotation deinking collector. Proceedings 2nd. Research Forum on Recycling. Canadian Pulp and Paper Association, Quebec, Canada. 5-7 October 1993 Montreal. CPPA 1993: 145-152.

Makaza, A. R. 2010. Pers. Comm.. to W. J. Pauck. Technical Sales Representative, SA Paper Chemicals. Degussa-Hüls Degafas bleaching technology. 2000.

Marchildon, L., Daneault, C., Lapointe, M. and Pelletier, C. 1993. Hydrogen peroxide, a plus to obtain an adequately white de-inked pulp at proper tint. Pulp and Paper Canada. Vol. 94(5).

Martin, T. and Britz, H. 1995. The EcoCell, an example of synergy effects in flotation cell development. Twogether. Voith-Sulzer, Volume 1. November 1995.

Mathur I. 1994. Preferred method of removal of filler from deinked pulp. Proceedings: 1994 Recycling Symposium. Pp 53-57. Tappi Press, Atlanta, Georgia. 1994.

Mathur I. 1991. Chelant optimisation in deinking formulation. First research forum on recycling, Toronto, October 1991. Omni Continental, Vancouver, Canada. Pp 115-123.

McCool, M.A. 1993. Flotation Deinking. In: R. J. Spangenberg (ed.) Secondary Fibre Recycling. Atlanta, GA. U.S.A. Tappi Press. pp. 177-198.

McCormick, D. 1990. Chemistry of flotation and washing for deinking newsprint part I. Proceedings 1990 Tappi Pulping Conference. Tappi press, Atlanta, Georgia. 1990.

McCormick, D. 1991. Chemistry of flotation and washing for deinking newsprint: part II, particle interactions and systems. Tappi 1991 Papermakers Conference, pgs 141-155. Tappi Press, Atlanta, Georgia. 1991

Merza, J. and Haynes, R. D. 2001. Batch pulping versus drum pulping: the impact on deinking performance. Proc. 6th PAPTAC Research Forum on Recycling. 2001. pp. 45-51.

Moe, S. T. and Røring, A. 2001. Theory and practice of flotation deinking. Taken from: http://www.chemeng.ntnu.no/research/paper/Publications/2001/moe%26roring.pdf. Accessed 19/11/2010.

Oliveira, A. P. and Thorem, M. L. 1996. The influence of some metallic cations on deinking flotation. Colloids Surfaces A: Physicochemical Engineering Aspects, 110(1996). Pp 75-85.

Olson, C.R. and Letscher, M.K. 1992. Increasing use of secondary fibre: an overview of deinking chemistry and stickies control. APPITA Journal. Vol. 45, No. 2.

Pala, H., Mota, M., Gama, F. M. 2007. Laboratory paper pulp deinking: an evaluation based on Image Analysis, ISO brightness and ERIC. Appita Journal. 60:2. 2007

PAMSA. 2007. Paper … The Power to Move You. A Perspective on South Africa. 2007. Paper Manufacturers Association of South Africa brochure. 2007.

Pan, R., Paulsen, F. G.,Johnson, D. A., Bousfield, D. W., and Thompson, E. V. 1996. A global model for predicting flotation efficiency. Part 1: model results and experimental studies. TAPPI JOURNAL. Vol 79 (4).

Pan, R., Paulsen, F. G. Kocer, H., Neraz, R., Johnson, D. A., Bousfield, D. W., and Thompson, E. V. 1994. A global model for predicting flotation efficiency. Part II: particle size and flotation rate predictions, and experimental studies and comparisons. TAPPI Recycling Symposium. 1994, p 291-301.

Pauck, W. J. 2003. The role of sodium silicate in newsprint deinking. Masters dissertation. School of Pure and Applied Chemistry, University of Natal.

Pescantin, M., Gu, Y. and Edwards, L. 1999. Syntesis and design of optimum deinking systems. Paper Technology. Vol 40, no. 2, pp. 35-40.

Peters, H., Remigio, T., Evans, T. and Dagenais, M. 2007. Interaction of flotation cell operating variables. Taken from: http://www.tappi.org/content/events/07recycle/papers/peters.pdf. accessed 23/11/2010.

Pirttinen, E. and Stenius, P. 2000. The effects of chemical conditions on newsprint ink detachment and fragmentation. TAPPI Journal. November 2000.

Pletka, J., Gosiewska, A., Chee, K.Y., McGuire, J.P., Drelich, J. and Groleau, L. 2000. Interfacial effects of a polyalkylene oxide/fatty acid surfactant blend in flotation deinking of mixed office papers. Progress in Paper Recycling. Feb. 2000. Pg 40-48.

PRASA. 2008. Paper Recycling Association of South Africa. 2008. RSA Forecast statistics. Available from: www.prasa.co.za [Accessed November 2008]

PRASA. 2009. Paper Recycling Association of South Africa. South African Paper Recycling Facts for 2008. Available at: www.prasa.co.za [Accessed Nov. 2009]

Putz, H., J., Schaffrath, H., J. and Goettsching, L. 1993. Deinking of oil and water-borne printing inks: A new flotation deinking model. Pulp and Paper Canada 94:7 (1993), pp 16-21

Rao, R., Bourdelin, M. and Stenius, P. 1999. The influence of surfactant structure on ink detachment. Appita Journal: Vol. 52 No. 3. May 1999. pp192-196.

Rao, R., Johansson, B., Pirtinnen, E and Stenius, P. 1998. Understanding of the processes that control the deinkability of news offset inks. COST E1 Final

Conference: Improvement of Recyclability and the Recycling Paper Industry of the Future. Madrid. Nov. 24-26. Pg 175-187.

Rao, R., N. and Stenius, P. 1998. Mechanisms of ink release from model surfaces and fibre. Journal of Pulp and Paper Science:Vol. 24 No. 6. June 1998. pp 183-187.

Read B. R. 1986. Deinking Chemical and Their Effects. North Western Branch Papers 1986 No. 2, Institution of chemical Engineers.

Read, B. R. 1991. The Chemistry of Flotation Deinking. Proceedings of 1991 Tappi Pulping Conference, Tappi Press, Atlanta, Georgia, 1991.

“2006 Recovered Paper Annual Statistics" [online]. 2006. Paper Industry Association Council. Available at: http://stats.paperrecycles.org/. Retrieved 29-11-2009.

“2007 Recovered Paper Annual Statistics” [online]. 2007. Available at: http://stats.paperrecycles.org/index.php?graph=corrcont&x=37&y=9. Retrieved 29-11-2009.

Renders, A. 1993. Hydrogen peroxide and related chemical additives in deinking processes. Tappi Journal: Vol. 76 No. 11. Nov. 1993. pp 155-161.

Renders, A., Chauveheid, E. and Dionne, P., Y. 1996. The use of chemical additives in deinking. Paper Technology: March 1996. pp39-47.

RISI. 2008a. World Recovered Paper Statistics by Region 2006-2007. [online]. 2008. Available at: http://www.risiinfo.com.

RISI. 2008b. World Pulp production by Grade 2006-2007. [online]. 2008. Available at: http://www.risiinfo.com.

Roberts, J (ed.) 2007. The state of the paper industry - A collaborative report by the Steering Committee of the Environmental Paper Network. [online]. Accessed at http://www.environmentalpaper.com/documents/StateOfPaperIndsm.pdf. [22 Feb. 2011]

Røring, A. and Haynes, R.D. 1998. What are the benefits and barriers of neutral deinking? Progress in Paper Recycling. Volume 7. May. Pp 73-79

Rudd, J.B. 1991. Using a neural network system for advanced process control. Tappi Journal. Oct. 1991

Rughooputh, H. C. S., and Rughooputh, S. D. D. 2002. Neural network process vision systems for flotation process. Kybernetes. **31** 3/4.

Santos, A., Carre, B. & Roring, A. 1996. Contribution to a better understanding of the basic mechanisms involved in the pulping and flotation of offset ink particles. Proceedings: 1996 Recycling Symposium. Pp 339-347. Tappi Press, Atlanta, Georgia, 1996.

Scheldorf, J. M. and Strand, B. C. 1996. Simulation of ink removal at a newsprint deinking facility. TAPPI JOURNAL. **79** no. 12.

Schlang, M., Lang, B., Poppe, T., Runkler, T. and Weinzierl, K. 2001. Current and future development in neural computation in steel processing. Control Engineering Practice. **9** p 975-986

Schulze, H.J. 1991. The fundamentals of flotation deinking in comparison to mineral flotation. Proceedings First Research Forum on Recycling. Toronto, 29-31 Oct. Montreal, Quebec, Canada. CPPA. pp. 27-39.

Schriver, E. 1990. Mill chemistry must be considered before making deink line decision. Pulp and Paper, March 1990.

Shen, J., Abubakr, S. and Springer, A. M. 1995. The influence of clay addition on flotation deinking. Proceedings 1995 Tappi Recycling Symposium. pp 257-267. Tappi Press, Atlanta, Georgia. 1995.

Singh, A., Louw, J. J., and Hulbert, D. G. 2003. Flotation stabilisation and optimisation. The Journal of The South African Institute of Mining and Metallurgy. November 2003.

Smith, B. A. and Broeren, L. A. 1996. A tool for process optimization: neural network software. In: Recycling Symposium. New Orleans, 1996, pp 163-187.

South African Paper Recovery Information for 2008. 2009. PRASA information pamphlet.

South African Standard Grade Definitions for Recovered Paper. [online]. http://www.prasa.co.za/sa-standard-grade-definitions. Feb. 2009. Accessed 7 July 2011.

Spence, K., Venditti, R. and Rojas, O.J. 2009. Sugar Surfactants in Paper Recycling. Nordic Pulp and Paper Research Journal, 24(1), 107-111.

Steyn, J. 2008. Personal communication to J. Pauck, Process Development Manager, Nampak Tissue. October 2008.

Steyn, J. 2009. Personal communication to J. Pauck, Process Development Manager, Nampak Tissue. July 2009.

Sundblad, P. and Mattila, P. 2001. Hydrogen peroxide decomposition in deinking mills. Pulp and Paper Canada. Vol. 102, No. 5. 2001. p 46-48.

Schwinger, K. and Dobias, B. 1991. The influence of calcium ions on the loss of fibre in the flotation deinking process. Proceedings 1st Research Forum on Recycling. Toronto, Oct. 1991 Pp 73-80, Canadian Pulp and Paper Association, Quebec, Canada.

Tarassenko, L. 1998. A Guide to Neural Computing Applications. Hodder Headline Group, London. 1998.

Theander, K. and Pugh, R.J. 2004. Surface chemical concepts of flotation de-inking. Colloids and Surfaces A: Physiochem. Eng. Aspects 240(2004):111-130.

Turvey, R. W. 1987. Stock loss as a function of water hardness in deinking. Paper Technology and Industry, Feb. 1987. pp 366-368.

Turvey, R. W. 1990. The role of calcium ions in flotation deinking. PITA Annual Conference 1990 – Technology of Secondary Fibre. Mar. 1990, Manchester, UK.

Turvey, R. W. 1991. Why do fibres float?. Proceedings 1st Research Forum on Recycling. Toronto, Oct. 1991 Pp 55-64, Canadian Pulp and Paper Association, Quebec, Canada.

Tayler, C., Allen, J., Hill, G., Lapierre, G., Merza, J and Haynes, R.D. 2006. A 10-day mill trial of near-neutral sulphite deinking, Part I: deinked pulp optical and physical properties. Pulp and Paper Canada. Vol. 107(4).

Vahlroos, S., Körkkö, M., Rosencrance, S. and Niinimäki, J. 2007. Comparison of DIP bleachability between traditional soap and reduced alkaline chemistries. 8th TAPPI Research Forum on Recycling.

Venditti, R. 2010. Personal communication to J Pauck. Department of Forest Biomaterials, North Carolina state University. PO Box 8005, Raleigh NC, 27695-8005, USA.

Verikas, A., Malmqvist, K., Bacauskiene, L. and Bergman, L. 2000. Monitoring the deinking process through neural network based colour image analysis. Neural computing and Applications. **9**, pp 142-151.

Vernac, Y., Carré, B., and Beneventi, D. 2001. Reduction of flotation losses, Part 2: detrimental effect of released surfactants on flotation efficiency. Pulp and Paper Canada. Vol. 102(7). Pg 26.

Weigl, J., Scheidt, W., Phan-Tri, D. and Grossmann, H. 1987. Water hardness and its effects on deinking. Proceedings of PTS Deinking Symposium: Munich, 1987. pp25-29.

Wold, S., Sjöström, M., and Eriksson, L. 2001. PLS-regression: a basic tool of chemometrics. Chemometrics and Intelligent Laboratory Systems. **58**, pp. 109-130.

World trade in waste paper. 2001. Taken from www.paperloop.com/pp_mag/paperhelp/9_2_1.html. 11/01/2001.

Zabala, J. M. and McCool, M. A. 1988. Deinking at Papelera Peninsular and the philosophy of deinking system design. Tappi Journal, August 1988. Page 62-68. Tappi Press, Atlanta, Georgia. 1988.

Zhang, Q. and Stanley, S. J. 1999. Real-time water treatment process control with artificial neural networks. Journal of Environmental Engineering. **Feb.**

Zhao, Y., Deng, Y. and Zhu, J.Y. 2004. Roles of surfactants in flotation deinking. Progress in Paper Recycling. Vol. 14(1), November 2004.

APPENDIX 1A(i) – PLACKETT-BURMAN DESIGN AND RESULTS FOR NEWSPRINT

	PULPING						FLOTATION								
RUN	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Y**			
NO.	**%NaOH**	**% Sod Sil**	**%H_2O_2**	**% Surf-p**	**t_p, min**	**T_p, deg C**	**T_f, deg C**	**% cons**	**pH**	**% Surf-f**	**t_f, min**		**WASHED BRT**	**WASHED ERIC**	**% YIELD**
1	0.67	0	1	0.25	5	35	45	1.3	10	0	20	271.20	52.2	271.2	88.0
2	0.67	2	0	0.75	5	35	30	1.3	10	0.5	5	289.60	45.2	289.6	88.9
3	0	2	1	0.25	15	35	30	0.8	10	0.5	20	318.30	47.3	318.3	49.1
4	0.67	0	1	0.75	5	50	30	0.8	8	0.5	20	216.20	52.7	216.2	77.6
5	0.67	2	0	0.75	15	35	45	0.8	8	0	20	184.50	49.1	184.5	72.2
6	0.67	2	1	0.25	15	50	30	1.3	8	0	5	484.70	47.8	484.7	92.4
7	0	2	1	0.75	5	50	45	0.8	10	0	5	265.20	52.4	265.2	90.5
8	0	0	1	0.75	15	35	45	1.3	8	0.5	5	899.70	40.8	899.7	88.8
9	0	0	0	0.75	15	50	30	1.3	10	0	20	675.30	44.2	675.3	84.3
10	0.67	0	0	0.25	15	50	45	0.8	10	0.5	5	491.40	44.9	491.4	82.2
11	0	2	0	0.25	5	50	45	1.3	8	0.5	20	261.00	49.5	261.0	71.9
12	0	0	0	0.25	5	35	30	0.8	8	0	5	467.00	46.3	467.0	82.0
13	0	2	0	0.75	15	50	30	0.8	8	0.5	5	403.70	46.7	403.7	79.4
14	0	0	1	0.25	15	50	45	0.8	8	0	20	461.20	47.7	461.2	48.1
15	0.67	0	0	0.75	5	50	45	1.3	8	0	5	496.10	44.8	496.1	91.5
16	0	2	0	0.25	15	35	45	1.3	10	0	5	631.00	42.5	631.0	95.9
17	0	0	1	0.25	5	50	30	1.3	10	0.5	5	685.60	44.0	685.6	87.5
18	0	0	0	0.75	5	35	45	0.8	10	0.5	20	392.30	47.4	392.3	57.2
19	0.67	0	0	0.25	15	35	30	1.3	8	0.5	20	388.70	46.3	388.7	74.3
20	0.67	2	0	0.25	5	50	30	0.8	10	0	20	211.80	47.7	211.8	52.5
21	0.67	2	1	0.25	5	35	45	0.8	8	0.5	5	343.00	52.1	343.0	84.3
22	0	2	1	0.75	5	35	30	1.3	8	0	20	247.30	53.6	247.3	72.8
23	0.67	0	1	0.75	15	35	30	0.8	10	0	5	373.30	49.0	373.3	89.8
24	0.67	2	1	0.75	15	50	45	1.3	10	0.5	20	334.00	51.5	334.0	93.1
ΣY+	4084.50	3974.10	4899.70	4777.20	5645.80	4986.20	5030.60	5664.20	4939.00	5023.50	3961.80				
ΣY-	5707.60	5818.00	4892.40	5014.90	4146.30	4805.90	4761.50	4127.90	4853.10	4768.60	5830.30				
Yavg+	340.38	331.18	408.31	398.10	470.48	415.52	419.22	472.02	411.58	418.63	330.15				
Yavg-	475.63	484.83	407.70	417.91	345.53	400.49	396.79	343.99	404.43	397.38	485.86				
EFFECT	-135.26	-153.66	0.61	-19.81	124.96	15.03	22.43	128.03	7.16	21.24	-155.71				

APPENDIX 1A(ii): NET EFFECTS FOR 12-RUN AND 24-RUN REFLECTED DESIGN - NEWSPRINT

		A	B	C	D	E	F	G	H	I	J	K
		%NaOH	**% Sod Silicate**	**%H_2O_2**	**% $Surf_p$**	**t_p, min**	**T_p, deg C**	**T_f, deg C**	**% flotation consistency**	**pH**	**% $Surf_f$**	**t_f, min**
24 Run	WASHED BRIGHTNESS	1.73	2.10	3.05	0.77	-2.52	0.18	0.36	-1.74	-0.78	-0.75	2.74
24 Run	WASHED ERIC	-135	-154	0.6	-19	-125	15	22	128	7	21	-156
24 Run	% YIELD	6.6	-0.7	2.5	6.5	0.4	0.7	2.8	13.7	1.96	-2.1	-17.7
12 Run	WASHED BRIGHTNESS	1.89	1.70	2.34	0.60	-4.07	1.79	0.91	-2.18	-0.03	-1.94	2.96
12 Run	WASHED ERIC	-271	-307	1.22	-39.6	-250	30	45	256	14	42	-311
12 Run	% YIELD	5.8	6.3	0.83	6.11	5.0	4.9	3.2	10.1	0.34	-8.5	-13.6

APPENDIX 1B(i) – PLACKETT-BURMAN DESIGN AND RESULTS FOR MAGAZINES

	PULPING						FLOTATION								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Y**	RESULTS		
NO.	**%NaOH**	**% Sod Sil**	**%H2O2**	**% Surf-p**	**tp, min**	**Tp, deg C**	**Tf, deg C**	**% cons**	**pH**	**% Surf-f**	**tf, min**		**WASHED BRT**	**WASHED ERIC**	**% YIELD**
1	0.67	0	1	0.25	5	35	45	1.3	10	0	20	70.76	70.76	56.53	46.65
2	0.67	2	0	0.75	5	35	30	1.3	10	0.5	5	64.05	64.05	81.80	70.14
3	0	2	1	0.25	15	35	30	0.8	10	0.5	20	63.53	63.53	76.05	63.18
4	0.67	0	1	0.75	5	50	30	0.8	8	0.5	20	69.24	69.24	73.31	29.09
5	0.67	2	0	0.75	15	35	45	0.8	8	0	20	61.77	61.77	89.60	35.00
6	0.67	2	1	0.25	15	50	30	1.3	8	0	5	63.13	63.13	130.77	69.79
7	0	2	1	0.75	5	50	45	0.8	10	0	5	63.77	63.77	100.80	52.54
8	0	0	1	0.75	15	35	45	1.3	8	0.5	5	68.89	68.89	75.34	58.18
9	0	0	0	0.75	15	50	30	1.3	10	0	20	64.77	64.77	74.04	50.10
10	0.67	0	0	0.25	15	50	45	0.8	10	0.5	5	60.18	60.18	115.15	54.42
11	0	2	0	0.25	5	50	45	1.3	8	0.5	20	65.62	65.62	72.73	47.32
12	0	0	0	0.25	5	35	30	0.8	8	0	5	64.10	64.10	102.40	55.11
13	0	2	0	0.75	15	50	30	0.8	8	0.5	5	60.36	60.36	120.15	46.95
14	0	0	1	0.25	15	50	45	0.8	8	0	20	64.00	64.00	83.26	46.12
15	0.67	0	0	0.75	5	50	45	1.3	8	0	5	59.50	59.50	113.33	60.19
16	0	2	0	0.25	15	35	45	1.3	10	0	5	59.21	59.21	116.78	77.10
17	0	0	1	0.25	5	50	30	1.3	10	0.5	5	61.38	61.38	123.65	73.65
18	0	0	0	0.75	5	35	45	0.8	10	0.5	20	64.44	64.44	72.45	28.79
19	0.67	0	0	0.25	15	35	30	1.3	8	0.5	20	61.13	61.13	79.95	50.37
20	0.67	2	0	0.25	5	50	30	0.8	10	0	20	63.98	61.22	72.85	48.50
21	0.67	2	1	0.25	5	35	45	0.8	8	0.5	5	95.6075	64.39	87.08	41.35
22	0	2	1	0.75	5	35	30	1.3	8	0	20	64.8375	66.39	67.46	51.66
23	0.67	0	1	0.75	15	35	30	0.8	10	0	5	117.3225	60.16	102.50	53.43
24	0.67	2	1	0.75	15	50	45	1.3	10	0.5	20	59	67.10	68.80	43.13
ΣY+	762.61	760.53	782.74	770.43	754.23	760.26	769.62	771.93	760.56	770.30	779.96				
ΣY-	766.46	768.55	746.34	758.64	774.85	768.82	759.46	757.15	768.52	758.77	749.11				
Yavg+	63.55	63.38	65.23	64.20	62.85	63.35	64.13	64.33	63.38	64.19	65.00				
Yavg-	63.87	64.05	62.20	63.22	64.57	64.07	63.29	63.10	64.04	63.23	62.43				
EFFECT	-0.32	-0.67	3.03	0.98	-1.72	-0.71	0.85	1.23	-0.66	0.96	2.57				

APPENDIX 1B(ii): NET EFFECTS FOR 12-RUN AND 24-RUN REFLECTED DESIGN - MAGAZINES

		A	B	C	D	E	F	G	H	I	J	K
		%NaOH	**% Sod Silicate**	**%H_2O_2**	**% $Surf_p$**	**t_p, min**	**T_p, deg C**	**T_f, deg C**	**% flotation consistency**	**pH**	**% $Surf_f$**	**t_f, min**
24 Run	WASHED BRIGHTNESS	-0.32	-0.67	3.03	0.98	-1.72	-0.71	0.85	1.23	-0.66	0.96	2.57
24 Run	WASHED ERIC	-1.1	1.1	-5.5	-6.5	9.0	12	-4.4	-2.9	-2.8	-5.3	-32
24 Run	% YIELD	-4.1	3.4	0.4	-7.9	3.6	-0.8	-5.9	11.9	5.9	-3.3	-14.4
12 Run	WASHED BRT	0.26	-2.68	3.14	0.86	-2.54	-1.06	0.36	2.44	-0.95	0.54	1.93
12 Run	WASHED ERIC	-2.2	2.2	-11	-12.9	18	24	-8.9	-5.7	-5.7	-10.6	-64
12 Run	% YIELD	-3.6	7.4	1.22	-6.9	4.9	-4.2	-7.2	8.8	7.1	-2.2	-14.8

APPENDIX 1C(i) – PLACKETT-BURMAN DESIGN AND RESULTS FOR HEAVY LETTER 1

	PULPING					FLOTATION									
	A	B	C	D	E	F	G	H	I	J	K	Y	RESULTS		
NO.	%NaOH	% Sod Sil	%H2O2	% Surf-p	tp, min	Tp, deg C	Tf, deg C	% cons	pH	% Surf-f	tf, min		WASHED BRT	WASHED ERIC	% YIELD
1	0.67	0	1	0.25	5	35	45	1.3	10	0	20	87.65	93.23	69.64	87.65
2	0.67	2	0	0.75	5	35	30	1.3	10	0.5	5	94.68	91.50	60.60	94.68
3	0	2	1	0.25	15	35	30	0.8	10	0.5	20	91.35	92.82	101.71	91.35
4	0.67	0	1	0.75	5	50	30	0.8	8	0.5	20	88.35	91.27	89.92	88.35
5	0.67	2	0	0.75	15	35	45	0.8	8	0	20	83.14	99.92	52.53	83.14
6	0.67	2	1	0.25	15	50	30	1.3	8	0	5	93.26	95.58	75.05	93.26
7	0	2	1	0.75	5	50	45	0.8	10	0	5	92.23	91.58	111.02	92.23
8	0	0	1	0.75	15	35	45	1.3	8	0.5	5	95.97	94.30	84.02	95.97
9	0	0	0	0.75	15	50	30	1.3	10	0	20	91.54	90.29	102.93	91.54
10	0.67	0	0	0.25	15	50	45	0.8	10	0.5	5	88.88	87.56	106.74	88.88
11	0	2	0	0.25	5	50	45	1.3	8	0.5	20	86.48	96.31	63.70	86.48
12	0	0	0	0.25	5	35	30	0.8	8	0	5	92.38	88.51	76.89	92.38
13	0	2	0	0.75	15	50	30	0.8	8	0.5	5	90.97	92.63	102.91	90.97
14	0	0	1	0.25	15	50	45	0.8	8	0	20	83.65	91.25	98.86	83.65
15	0.67	0	0	0.75	5	50	45	1.3	8	0	5	86.65	89.56	90.19	86.65
16	0	2	0	0.25	15	35	45	1.3	10	0	5	92.75	90.41	86.73	92.75
17	0	0	1	0.25	5	50	30	1.3	10	0.5	5	83.43	94.68	81.66	83.43
18	0	0	0	0.75	5	35	45	0.8	10	0.5	20	84.85	95.77	64.96	84.85
19	0.67	0	0	0.25	15	35	30	1.3	8	0.5	20	85.86	95.72	78.41	85.86
20	0.67	2	0	0.25	5	50	30	0.8	10	0	20	85.95	91.77	84.66	85.95
21	0.67	2	1	0.25	5	35	45	0.8	8	0.5	5	82.15	91.80	74.91	82.15
22	0	2	1	0.75	5	35	30	1.3	8	0	20	92.16	90.96	89.48	92.16
23	0.67	0	1	0.75	15	35	30	0.8	10	0	5	71.02	94.44	91.08	71.02
24	0.67	2	1	0.75	15	50	45	1.3	10	0.5	20	85.09	100.00	48.79	85.09
ΣY+	1032.67	1070.21	1046.31	1056.65	1053.47	1056.49	1049.49	1075.51	1049.41	1058.07	1046.07				
ΣY-	1077.77	1040.23	1064.12	1053.79	1056.96	1053.95	1060.95	1034.92	1061.02	1052.37	1064.37				
Yavg+	86.06	89.18	87.19	88.05	87.79	88.04	87.46	89.63	87.45	88.17	87.17				
Yavg-	89.81	86.69	88.68	87.82	88.08	87.83	88.41	86.24	88.42	87.70	88.70				
EFFECT	-3.76	2.50	-1.48	0.24	-0.29	0.21	-0.95	3.38	-0.97	0.47	-1.52				

APPENDIX 1C(ii): NET EFFECTS FOR 12-RUN AND 24-RUN REFLECTED DESIGN – HEAVY LETTER 1

		A	B	C	D	E	F	G	H	I	J	K
		%NaOH	% Sod Silicate	%H_2O_2	% $Surf_p$	t_p, min	T_p, deg C	T_f, deg C	% flotation consistency	pH	% $Surf_f$	t_f, min
24 Run	**WASHED BRIGHTNESS**	1.07	1.56	1.00	1.05	1.50	-0.58	0.96	1.10	-0.32	1.41	2.23
24 Run	**WASHED ERIC**	-11.86	-6.93	3.74	-0.88	6.01	10.46	-6.94	-10.42	2.81	-5.89	-8.02
24 Run	**% YIELD**	-3.76	2.50	-1.48	0.24	-0.29	0.21	-0.95	3.38	-0.97	0.47	-1.52
12 Run	**WASHED BRIGHTNESS**	2.14	3.12	1.99	2.10	2.99	-1.15	1.92	2.2	-0.63	2.81	4.46
12 Run	**WASHED ERIC**	-23.7	-13.9	7.5	-1.76	12.0	20.9	-13.9	-20.8	5.6	-11.8	-16.0
12 Run	**% YIELD**	-7.52	5.0	-2.97	0.48	-0.58	0.42	-1.91	6.8	-1.9	0.95	-3.05

APPENDIX 1D(i)– PLACKETT-BURMAN DESIGN AND RESULTS FOR HEAVY LETTER 2

	PULPING						FLOTATION								
	A	B	C	D	E	F	G	H	I	J	K	Y			
NO.	**%NaOH**	**% Sod Silicate**	**%H2O2**	**% Surf-p**	**tp, min**	**Tp, deg C**	**Tf, deg C**	**% cons**	**pH**	**% Surf-f**	**tf, min**		**WASHED BRT**	**WASHED ERIC**	**% YIELD**
1	0.67	0	1	0.25	5	35	45	1.3	10	0	20	73.58	73.58	53.30	67.84
2	0.67	2	0	0.75	5	35	30	1.3	10	0.5	5	74.98	74.98	69.47	85.73
3	0	2	1	0.25	15	35	30	0.8	10	0.5	20	78.33	78.33	56.85	75.48
4	0.67	0	1	0.75	5	50	30	0.8	8	0.5	20	80.06	80.06	63.24	67.92
5	0.67	2	0	0.75	15	35	45	0.8	8	0	20	68.34	68.34	61.02	66.08
6	0.67	2	1	0.25	15	50	30	1.3	8	0	5	87.99	87.99	75.59	84.90
7	0	2	1	0.75	5	50	45	0.8	10	0	5	73.54	73.54	59.29	85.44
8	0	0	1	0.75	15	35	45	1.3	8	0.5	5	65.19	65.19	83.10	94.41
9	0	0	0	0.75	15	50	30	1.3	10	0	20	68.71	68.71	78.77	90.31
10	0.67	0	0	0.25	15	50	45	0.8	10	0.5	5	70.11	70.11	62.57	83.77
11	0	2	0	0.25	5	50	45	1.3	8	0.5	20	78.91	78.91	38.67	79.48
12	0	0	0	0.25	5	35	30	0.8	8	0	5	69.84	69.84	55.83	87.76
13	0	2	0	0.75	15	50	30	0.8	8	0.5	5	66.61	66.61	45.78	85.18
14	0	0	1	0.25	15	50	45	0.8	8	0	20	70.68	70.68	42.04	77.38
15	0.67	0	0	0.75	5	50	45	1.3	8	0	5	69.47	69.47	65.36	91.59
16	0	2	0	0.25	15	35	45	1.3	10	0	5	68.50	68.50	67.59	95.00
17	0	0	1	0.25	5	50	30	1.3	10	0.5	5	70.73	70.73	74.43	92.93
18	0	0	0	0.75	5	35	45	0.8	10	0.5	20	67.84	67.84	63.24	94.62
19	0.67	0	0	0.25	15	35	30	1.3	8	0.5	20	63.31	63.31	62.86	93.17
20	0.67	2	0	0.25	5	50	30	0.8	10	0	20	66.15	66.15	49.28	86.32
21	0.67	2	1	0.25	5	35	45	0.8	8	0.5	5	64.03	64.03	63.86	94.47
22	0	2	1	0.75	5	35	30	1.3	8	0	20	64.58	64.58	61.44	89.38
23	0.67	0	1	0.75	15	35	30	0.8	10	0	5	67.87	67.87	64.47	102.78
24	0.67	2	1	0.75	15	50	45	1.3	10	0.5	20	65.75	65.75	65.14	95.15
ΣY+	851.64	857.71	862.32	832.95	841.39	868.71	835.93	851.70	846.09	845.85	846.23				
ΣY-	843.45	837.38	832.76	862.14	853.70	826.38	859.16	843.39	848.99	849.23	848.86				
Y_{avg+}	70.97	71.48	71.86	69.41	70.12	72.39	69.66	70.97	70.51	70.49	70.52				
Y_{avg-}	70.29	69.78	69.40	71.84	71.14	68.86	71.60	70.28	70.75	70.77	70.74				
EFFECT	0.68	1.69	2.46	-2.43	-1.03	3.53	-1.94	0.69	-0.24	-0.28	-0.22				

APPENDIX 1D(ii): NET EFFECTS FOR 12-RUN AND 24-RUN REFLECTED DESIGN – HEAVY LETTER 2

		A	B	C	D	E	F	G	H	I	J	K
		%NaOH	**% Sod Silicate**	**%H2O2**	**% Surf$_p$**	**t_p, min**	**T_p, deg C**	**T_f, deg C**	**% flotation consistency**	**pH**	**% Surf$_f$**	**t_f, min**
24 Run	**WASHED BRIGHTNESS**	0.68	1.69	2.46	-2.43	-1.03	3.53	-1.94	0.69	-0.24	-0.28	-0.22
24 Run	**WASHED ERIC**	2.43	-4.60	3.53	6.45	4.03	-3.57	-2.74	9.02	3.80	1.27	-7.62
24 Run	**% YIELD**	-2.30	-1.82	-0.91	2.51	1.68	-2.20	-1.39	4.39	3.64	1.46	-8.40
12 Run	**WASHED BRIGHTNESS**	1.36	3.39	4.93	-4.87	-2.05	7.06	-3.87	1.38	-0.48	-0.56	-0.44
12 Run	**WASHED ERIC**	4.9	-9.2	7.1	12.9	8.1	-7.1	-5.5	18.0	7.6	2.5	-15.3
12 Run	**% YIELD**	-4.6	-3.6	-1.8	5.0	3.4	-4.3	-2.8	8.8	7.3	2.9	-16.8

APPENDIX 2 – FACTOR RANK ANALYSIS

		WASHED BRT				WASHED ERIC				YIELD						
No.	**Factor**	**ONP**	**OMG**	**HL1**	**HL2**	**ONP**	**OMG**	**HL1**	**HL2**	**ONP**	**OMG**	**HL1**	**HL2**	**Mean**	**Greatest**	**Least**
11	**tf, min**	2	2	1	11	1	1	4	2	1	1	4	1	2.58	1	11
8	**% cons**	5	4	5	7	4	8	3	1	2	2	2	2	3.75	1	8
1	**%NaOH**	6	11	6	8	3	10	1	10	3	6	1	5	5.83	1	11
3	**%H2O2**	1	1	8	2	11	5	9	8	6	11	5	11	6.50	1	11
6	**Tp, deg C**	11	8	10	1	9	2	2	7	10	10	11	6	7.25	1	11
2	**% Sod Sil**	4	9	2	5	2	11	6	4	9	8	3	7	5.83	2	11
4	**% Surf-p**	8	5	7	3	8	4	11	3	4	3	10	4	5.83	3	11
5	**tp, min**	3	3	3	6	5	3	7	5	11	7	9	8	5.83	3	11
9	**pH**	7	10	11	10	10	9	10	6	8	5	6	3	7.92	3	11
7	**Tf, deg C**	10	7	9	4	6	7	5	9	5	4	7	10	6.92	4	10
10	**% Surf-f**	9	6	4	9	7	6	8	11	7	9	8	9	7.75	4	11

Notes:

1. Highest rank = 1, lowest rank = 11.
2. The means were calculated across all grades for all output properties.

APPENDIX 3: DEINKING TRAINING DATA

		No.	1	2	3	4	5	6	7	8	9	10
		Date	09/05/27	09/05/28	09/06/01	09/06/02	09/06/02	09/06/03	09/06/05	09/06/08	09/06/04	09/06/04
		Sample ID	ONP1	ONP2	ONP3	ONP4	ONP5	ONP6	ONP7	ONP8	ONP9	ONP10
Waste paper grades		**ONP**	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
		OMG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		HL1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		HL2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pulping conditions	**%NaOH**	1.50	0.67	0.67	0.00	0.67	0.67	0.67	0.00	0.00	0.00	0.67
	% Sod Silicate	3.00	0.00	2.00	2.00	0.00	2.00	2.00	2.00	0.00	0.00	0.00
	%H2O2	2.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	0.00
	% Surf-p	1.00	0.25	0.75	0.25	0.75	0.75	0.25	0.75	0.75	0.75	0.25
	tp (min)	15.00	5.00	5.00	15.00	5.00	15.00	15.00	5.00	15.00	15.00	15.00
	Tp (^{o}C)	43.00	35.00	35.00	35.00	50.00	35.00	50.00	50.00	35.00	50.00	50.00
Flotation conditions	**Tf (^{0}C)**	38.00	45.00	30.00	30.00	30.00	45.00	30.00	45.00	45.00	30.00	45.00
	% consistency	1.30	1.30	1.30	0.80	0.80	0.80	1.30	0.80	1.30	1.30	0.80
	pH	10.00	10.00	10.00	10.00	8.00	8.00	8.00	10.00	8.00	10.00	10.00
	% Surf-f	0.25	0.00	0.50	0.50	0.50	0.00	0.00	0.00	0.50	0.00	0.50
	tf (min)	12.00	20.00	5.00	20.00	20.00	20.00	5.00	5.00	5.00	20.00	5.00
Outputs	**BRIGHTNESS**	PULPER	42.0	40.3	37.1	39.2	40.2	40.0	43.0	34.9	33.4	35.2
		FLOATED	49.8	43.1	46.8	52.2	48.3	44.0	49.9	37.7	42.6	42.9
		WASHED	52.2	45.2	47.3	52.7	49.1	47.8	52.4	40.8	44.2	44.9
	ERIC	PULPER	834	715	1028	994	615	904	797	1619	1721	1352
		FLOATED	373	386	386	246	217	552	353	1270	789	614
		WASHED	271	290	318	216	185	485	265	900	675	491
	Yield		88	89	49	78	72	92	91	89	84	82

APPENDIX 3: DEINKING TRAINING DATA

11	12	13	14	15	16	17	18	19	20	21	22	23
09/06/29	09/06/29	09/06/09	09/06/10	09/06/10	09/06/11	09/06/11	09/06/12	09/06/17	09/06/17	09/06/18	09/06/18	09/06/30
ONP11	ONP12	ONP13	ONP14	ONP15	ONP16	ONP17	ONP18	ONP19	ONP20	ONP21	ONP22	ONP23
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.67	0.67	0.67	0.00	0.67
2.00	0.00	2.00	0.00	0.00	2.00	0.00	0.00	0.00	2.00	2.00	2.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00
0.25	0.25	0.75	0.25	0.75	0.25	0.25	0.75	0.25	0.25	0.25	0.75	0.75
5.00	5.00	15.00	15.00	5.00	15.00	5.00	5.00	15.00	5.00	5.00	5.00	15.00
50.00	35.00	50.00	50.00	50.00	35.00	50.00	35.00	35.00	50.00	35.00	35.00	35.00
45.00	30.00	30.00	45.00	45.00	45.00	30.00	45.00	30.00	30.00	45.00	30.00	30.00
1.30	0.80	0.80	0.80	1.30	1.30	1.30	0.80	1.30	0.80	0.80	1.30	0.80
8.00	8.00	8.00	8.00	8.00	10.00	10.00	10.00	8.00	10.00	8.00	8.00	10.00
0.50	0.00	0.50	0.00	0.00	0.00	0.50	0.50	0.50	0.00	0.50	0.00	0.00
20.00	5.00	5.00	20.00	5.00	5.00	5.00	20.00	20.00	20.00	5.00	20.00	5.00
39.3	37.1	40.3	33.5	38.9	39.1	37.4	36.0	35.2	38.1	40.6	42.0	37.6
48.7	46.2	45.0	48.0	40.9	39.1	39.0	47.5	44.6	46.6	48.9	52.4	47.4
49.5	46.3	46.7	47.7	44.8	42.5	44.0	47.4	46.3	47.7	52.1	53.6	49.0
908	1184	888	1732	948	1042	1279	1343	1389	944	945	855	1109
302	527	504	489	721	852	996	400	489	245	477	304	439
261	467	404	461	496	631	686	392	389	212	343	247	373
72	82	79	48	92	96	88	57	74	52	84	73	90

APPENDIX 3: DEINKING TRAINING DATA

24	25	26	27	28	29	30	31	32	33	34	35	36
09/06/30	09/06/03	09/06/22	09/06/23	09/06/23	09/06/24	09/06/24	09/06/25	09/06/25	09/06/26	09/06/26	09/07/01	09/07/01
ONP24	ONPMID0	ONPMID1	ONPMID2	ONPMID3	ONPMID4	ONPMID5	OMG1	OMG2	OMG3	OMG4	OMG5	OMG6
100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.67	0.34	0.34	0.34	0.34	0.34	0.34	0.67	0.67	0.00	0.67	0.67	0.67
2.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	2.00	2.00	0.00	2.00	2.00
1.00	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.00	1.00	1.00	0.00	1.00
0.75	0.50	0.50	0.50	0.50	0.50	0.50	0.25	0.75	0.25	0.75	0.75	0.25
15.00	10.00	10.00	10.00	10.00	10.00	10.00	5.00	5.00	15.00	5.00	15.00	15.00
50.00	43.00	43.00	43.00	43.00	43.00	43.00	35.00	35.00	35.00	50.00	35.00	50.00
45.00	38.00	38.00	38.00	38.00	38.00	38.00	45.00	30.00	30.00	30.00	45.00	30.00
1.30	1.05	1.05	1.05	1.05	1.05	1.05	1.30	1.30	0.80	0.80	0.80	1.30
10.00	9.00	9.00	9.00	9.00	9.00	9.00	10.00	10.00	10.00	8.00	8.00	8.00
0.50	0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.50	0.50	0.50	0.00	0.00
20.00	12.50	12.50	12.50	12.50	12.50	12.50	20.00	5.00	20.00	20.00	20.00	5.00
42.2	38.2	39.0	38.2	37.9	39.4	38.2	46.4	46.9	42.2	44.6	42.0	45.0
49.6	48.6	50.0	49.4	49.5	50.3	49.6	68.8	61.9	63.5	66.8	62.2	61.5
51.5	50.8	51.7	51.5	51.5	52.5	51.0	70.8	64.0	63.5	69.2	61.8	63.1
826	1098	1041	1117	1131	1081	1122	558	557	606	591	636	682
384	357	348	360	361	345	370	84	100	89	87	103	160
334	287	294	282	291	260	307	57	82	76	73	90	131
93	83	70	68	67	70	71	47	70	63	29	35	70

APPENDIX 3: DEINKING TRAINING DATA

37	38	39	40	41	42	43	44	45	46	47	48	49
09/07/02	09/07/02	09/07/03	09/07/03	09/07/07	09/07/08	09/07/09	09/07/09	09/07/09	09/07/10	09/07/10	09/07/10	09/07/13
OMG7	OMG8	OMG9	OMG10	OMG11	OMG12	OMG13	OMG14	OMG15	OMG16	OMG17	OMG18	OMG19
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.67
2.00	0.00	0.00	0.00	2.00	0.00	2.00	0.00	0.00	2.00	0.00	0.00	0.00
1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00
0.75	0.75	0.75	0.25	0.25	0.25	0.75	0.25	0.75	0.25	0.25	0.75	0.25
5.00	15.00	15.00	15.00	5.00	5.00	15.00	15.00	5.00	15.00	5.00	5.00	15.00
50.00	35.00	50.00	50.00	50.00	35.00	50.00	50.00	50.00	35.00	50.00	35.00	35.00
45.00	45.00	30.00	45.00	45.00	30.00	30.00	45.00	45.00	45.00	30.00	45.00	30.00
0.80	1.30	1.30	0.80	1.30	0.80	0.80	0.80	1.30	1.30	1.30	0.80	1.30
10.00	8.00	10.00	10.00	8.00	8.00	8.00	8.00	8.00	10.00	10.00	10.00	8.00
0.00	0.50	0.00	0.50	0.50	0.00	0.50	0.00	0.00	0.00	0.50	0.50	0.50
5.00	5.00	20.00	5.00	20.00	5.00	5.00	20.00	5.00	5.00	5.00	20.00	20.00
44.6	45.7	45.8	43.7	43.3	47.1	43.4	44.3	44.2	42.9	44.9	46.2	42.8
62.8	68.5	65.9	59.6	65.9	63.7	61.3	64.9	58.4	57.9	58.7	65.0	61.4
63.8	68.9	64.8	60.2	65.6	64.1	60.4	64.0	59.5	59.2	61.4	64.4	61.1
647	729	640	673	600	638	669	566	591	671	588	532	704
104	94	69	121	62	110	130	80	132	146	147	86	76
101	75	74	115	73	102	120	83	113	117	124	72	80
53	58	50	54	47	55	47	46	60	77	74	29	50

APPENDIX 3: DEINKING TRAINING DATA

50	51	52	53	54	55	56	57	58	59	60	61	62
09/07/13	09/07/14	09/07/14	09/07/15	09/07/15	09/07/03	09/07/07	09/07/08	09/07/16	09/07/16	09/07/16	09/07/20	09/07/20
OMG20	OMG21	OMG22	OMG23	OMG24	OMGMID1	OMGMID2	OMGMID3	OMGMID4	OMGMID5	OMGMID6	HL1-1	HL1-2
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.67	0.67	0.00	0.67	0.67	0.34	0.34	0.34	0.34	0.34	0.34	0.67	0.67
2.00	2.00	2.00	0.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	2.00
0.00	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.00
0.25	0.25	0.75	0.75	0.75	0.50	0.50	0.50	0.50	0.50	0.50	0.25	0.75
5.00	5.00	5.00	15.00	15.00	10.00	10.00	10.00	10.00	10.00	10.00	5.00	5.00
50.00	35.00	35.00	35.00	50.00	43.00	43.00	43.00	43.00	43.00	43.00	35.00	35.00
30.00	45.00	30.00	30.00	45.00	38.00	38.00	38.00	38.00	38.00	38.00	45.00	30.00
0.80	0.80	1.30	0.80	1.30	1.05	1.05	1.05	1.05	1.05	1.05	1.30	1.30
10.00	8.00	8.00	10.00	10.00	9.00	9.00	9.00	9.00	9.00	9.00	10.00	10.00
0.00	0.50	0.00	0.00	0.50	0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.50
20.00	5.00	20.00	5.00	20.00	12.50	12.50	12.50	12.50	12.50	12.50	20.00	5.00
51.0	43.3	44.8	43.4	44.4	46.1	42.5	43.6	43.1	44.8	44.3	88.5	87.3
62.1	64.0	66.1	59.5	66.4	68.4	65.3	66.6	64.4	66.7	65.7	91.9	92.4
61.2	64.4	66.4	60.2	67.1	66.7	64.6	66.1	64.8	66.8	65.1	93.2	91.5
564	589	585	612	618	579	707	738	654	591	589	112	90
64	96	65	117	59	62	73	62	68	60	67	73	52
73	87	67	103	69	75	76	63	69	69	65	70	61
49	41	52	53	43	40	53	47	53	46	45	88	95

APPENDIX 3: DEINKING TRAINING DATA

63	64	65	66	67	68	69	70	71	72	73	74	75
09/07/21	09/07/22	09/07/22	09/07/23	09/07/23	09/07/24	09/07/24	09/07/27	09/07/27	09/07/27	09/07/29	09/07/29	09/07/30
HL1-3	HL1-4	HL1-5	HL1-6	HL1-7	HL1-8	HL1-9	HL1-10	HL1-11	HL1-12	HL1-13	HL1-14	HL1-15
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.67	0.67	0.67	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.67
2.00	0.00	2.00	2.00	2.00	0.00	0.00	0.00	2.00	0.00	2.00	0.00	0.00
1.00	1.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
0.25	0.75	0.75	0.25	0.75	0.75	0.75	0.25	0.25	0.25	0.75	0.25	0.75
15.00	5.00	15.00	15.00	5.00	15.00	15.00	15.00	5.00	5.00	15.00	15.00	5.00
35.00	50.00	35.00	50.00	50.00	35.00	50.00	50.00	50.00	35.00	50.00	50.00	50.00
30.00	30.00	45.00	30.00	45.00	45.00	30.00	45.00	45.00	30.00	30.00	45.00	45.00
0.80	0.80	0.80	1.30	0.80	1.30	1.30	0.80	1.30	0.80	0.80	0.80	1.30
10.00	8.00	8.00	8.00	10.00	8.00	10.00	10.00	8.00	8.00	8.00	8.00	8.00
0.50	0.50	0.00	0.00	0.00	0.50	0.00	0.50	0.50	0.00	0.50	0.00	0.00
20.00	20.00	20.00	5.00	5.00	5.00	20.00	5.00	20.00	5.00	5.00	20.00	5.00
92.2	88.5	96.6	92.2	85.8	92.3	88.5	88.2	91.6	89.8	88.7	85.3	90.4
95.0	91.9	99.0	92.5	87.9	92.2	88.0	87.9	95.7	93.5	91.5	90.1	93.4
92.8	91.3	99.9	95.6	91.6	94.3	90.3	87.6	96.3	88.5	92.6	91.2	89.6
94	124	85	102	139	101	127	118	101	93	121	145	110
89	107	62	88	135	83	110	112	70	87	117	133	86
102	90	53	75	111	84	103	107	64	77	103	99	90
91	88	83	93	92	96	92	89	86	92	91	84	87

APPENDIX 3: DEINKING TRAINING DATA

76	77	78	79	80	81	82	83	84	85	86	87	88
09/07/30	09/07/31	09/07/31	09/07/31	09/08/03	09/08/03	09/08/04	09/08/04	09/08/05	09/07/21	09/07/28	09/07/28	09/07/28
HL1-16	HL1-17	HL1-18	HL1-19	HL1-20	HL1-21	HL1-22	HL1-23	HL1-24	HL1MID1	HL1MID2	HL1MID3	HL1MID4
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.67	0.67	0.67	0.00	0.67	0.67	0.34	0.34	0.34	0.34
2.00	0.00	0.00	0.00	2.00	2.00	2.00	0.00	2.00	1.00	1.00	1.00	1.00
0.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50
0.25	0.25	0.75	0.25	0.25	0.25	0.75	0.75	0.75	0.50	0.50	0.50	0.50
15.00	5.00	5.00	15.00	5.00	5.00	5.00	15.00	15.00	10.00	10.00	10.00	10.00
35.00	50.00	35.00	35.00	50.00	35.00	35.00	35.00	50.00	43.00	43.00	43.00	43.00
45.00	30.00	45.00	30.00	30.00	45.00	30.00	30.00	45.00	38.00	38.00	38.00	38.00
1.30	1.30	0.80	1.30	0.80	0.80	1.30	0.80	1.30	1.05	1.05	1.05	1.05
10.00	10.00	10.00	8.00	10.00	8.00	8.00	10.00	10.00	9.00	9.00	9.00	9.00
0.00	0.50	0.50	0.50	0.00	0.50	0.00	0.00	0.50	0.25	0.25	0.25	0.25
5.00	5.00	20.00	20.00	20.00	5.00	20.00	5.00	20.00	12.50	12.50	12.50	12.50
92.2	90.7	92.7	91.4	91.4	91.5	83.1	90.6	93.5	81.2	89.5	91.0	88.0
90.0	92.9	95.3	93.7	95.4	94.1	89.4	92.9	96.7	90.4	91.8	90.8	94.3
90.4	94.7	95.8	95.7	91.8	91.8	91.0	94.4	100.0	88.3	92.0	92.5	92.8
112	113	89	106	109	102	155	105	89	165	126	93	113
96	88	75	75	89	92	112	103	57	118	87	63	84
87	82	65	78	85	75	89	91	49	96	81	65	74
93	83	85	86	86	82	92	71	85	71	86	90	92

APPENDIX 3: DEINKING TRAINING DATA

89	90	91	92	93	94	95	96	97	98	99	100	101
09/08/05	09/08/05		09/08/14		09/08/17	09/08/17	09/08/18	09/08/18	09/08/19	09/08/19	09/08/19	09/08/20
HL1MID5	HL1MID6	HL2-1	HL2-2	HL2-3	HL2-4	HL2-5	HL2-6	HL2-7	HL2-8	HL2-9	HL2-10	HL2-11
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.34	0.34	0.67	0.67	0.00	0.67	0.67	0.67	0.00	0.00	0.00	0.67	0.00
1.00	1.00	0.00	2.00	2.00	0.00	2.00	2.00	2.00	0.00	0.00	0.00	2.00
0.50	0.50	1.00	0.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00
0.50	0.50	0.25	0.75	0.25	0.75	0.75	0.25	0.75	0.75	0.75	0.25	0.25
10.00	10.00	5.00	5.00	15.00	5.00	15.00	15.00	5.00	15.00	15.00	15.00	5.00
43.00	43.00	35.00	35.00	35.00	50.00	35.00	50.00	50.00	35.00	50.00	50.00	50.00
38.00	38.00	45.00	30.00	30.00	30.00	45.00	30.00	45.00	45.00	30.00	45.00	45.00
1.05	1.05	1.30	1.30	0.80	0.80	0.80	1.30	0.80	1.30	1.30	0.80	1.30
9.00	9.00	10.00	10.00	10.00	8.00	8.00	8.00	10.00	8.00	10.00	10.00	8.00
0.25	0.25	0.00	0.50	0.50	0.50	0.00	0.00	0.00	0.50	0.00	0.50	0.50
12.50	12.50	20.00	5.00	20.00	20.00	20.00	5.00	5.00	5.00	20.00	5.00	20.00
93.6	84.7	67.8	73.7	76.3	75.4	63.4	82.3	69.1	60.0	65.7	63.7	74.3
96.6	92.7	72.0	73.3	77.0	80.2	65.9	83.7	69.9	61.6	67.3	67.9	76.2
95.8	94.3	73.6	75.0	78.3	80.1	68.3	88.0	73.5	65.2	68.7	70.1	78.9
111	128	98	94	84	100	121	115	101	113	104	104	77
80	93	51	65	60	68	78	91	62	94	86	55	33
75	78	53	69	57	63	61	76	59	83	79	63	39
95	87	68	86	75	68	66	85	85	94	90	84	79

APPENDIX 3: DEINKING TRAINING DATA

102	103	104	105	106	107	108	109	110	111	112	113	114
09/08/20	09/08/21	09/08/21	09/08/24	09/08/25	09/08/25	09/08/26	09/08/26	09/08/26	09/08/27	09/08/27	09/08/27	09/08/28
HL2-12	HL2-13	HL2-14	HL2-15	HL2-16	HL2-17	HL2-18	HL2-19	HL2-20	HL2-21	HL2-22	HL2-23	HL2-24
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.67	0.67	0.67	0.00	0.67	0.67
0.00	2.00	0.00	0.00	2.00	0.00	0.00	0.00	2.00	2.00	2.00	0.00	2.00
0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
0.25	0.75	0.25	0.75	0.25	0.25	0.75	0.25	0.25	0.25	0.75	0.75	0.75
5.00	15.00	15.00	5.00	15.00	5.00	5.00	15.00	5.00	5.00	5.00	15.00	15.00
35.00	50.00	50.00	50.00	35.00	50.00	35.00	35.00	50.00	35.00	35.00	35.00	50.00
30.00	30.00	45.00	45.00	45.00	30.00	45.00	30.00	30.00	45.00	30.00	30.00	45.00
0.80	0.80	0.80	1.30	1.30	1.30	0.80	1.30	0.80	0.80	1.30	0.80	1.30
8.00	8.00	8.00	8.00	10.00	10.00	10.00	8.00	10.00	8.00	8.00	10.00	10.00
0.00	0.50	0.00	0.00	0.00	0.50	0.50	0.50	0.00	0.50	0.00	0.00	0.50
5.00	5.00	20.00	5.00	5.00	5.00	20.00	20.00	20.00	5.00	20.00	5.00	20.00
65.6	62.4	66.4	66.9	66.1	66.5	64.3	60.4	61.7	61.8	64.0	63.5	60.8
67.7	65.2	69.1	65.9	65.3	68.6	64.4	59.9	63.8	62.8	62.7	65.7	62.2
69.8	66.6	70.7	69.5	68.5	70.7	67.8	63.3	66.2	64.0	64.6	67.9	65.8
79	96	90	83	97	89	77	97	82	85	73	94	86
48	39	35	73	85	87	73	91	44	84	80	86	90
56	46	42	65	68	74	63	63	49	64	61	64	65
88	85	77	92	95	93	95	93	86	94	89	103	95

APPENDIX 3: DEINKING TRAINING DATA

115	116	117	118	119	120	121	122	123	124	125	126	127
09/08/10	09/08/11	09/08/20	09/08/20	09/08/28	09/08/28	09/09/07	09/09/07	09/09/08	09/09/08	09/09/09	09/09/09	09/09/10
HL2MID1	HL2MID2	HL2MID3	HL2MID4	HL2MID5	HL2MID6	ONPOMG5 050.1	ONPOMG5 050.2	ONPOMG5 050.3	ONPOMG5 050.4	ONPOMG5 050.5	ONPOMG5 050.6	ONPOMG5 050.7
0.00	0.00	0.00	0.00	0.00	0.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
0.00	0.00	0.00	0.00	0.00	0.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.34	0.34	0.34	0.34	0.34	0.34	0.88	1.36	1.29	1.33	1.29	1.24	1.27
1.00	1.00	1.00	1.00	1.00	1.00	0.20	1.60	0.60	0.90	1.90	2.70	0.20
0.50	0.50	0.50	0.50	0.50	0.50	0.30	1.70	1.30	1.50	1.30	1.10	1.20
0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.50	0.70	0.40	0.50	0.80	0.70
10.00	10.00	10.00	10.00	10.00	10.00	14.00	13.00	5.00	13.00	5.00	7.00	14.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.05	1.05	1.05	1.05	1.05	1.05	0.80	0.90	1.10	0.80	0.90	0.90	1.00
9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.50	12.50	12.50	12.50	12.50	12.50	12.00	5.00	6.00	5.00	10.00	11.00	6.00
64.9	64.3	64.7	65.3	64.0	58.4	39.5	37.6	42.1	46.6	44.7	44.6	46.3
67.5	66.4	67.5	68.0	65.7	60.0	53.0	47.9	53.6	58.4	58.7	59.4	57.3
68.7	69.5	68.6	69.9	67.6	62.0	54.0	50.6	56.3	59.8	60.3	59.8	59.2
112	118	80	82	87	83	847	935	657	598	672	606	703
61	59	28	30	47	53	169	353	208	117	121	97	163
52	53	37	38	39	37	153	245	151	99	95	87	129
66	72	77	71	78	63	51	76	76	76	69	61	78

APPENDIX 3: DEINKING TRAINING DATA

128	129	130	131	132	133	134	135	136	137	138	139	140
09/09/10	09/09/11	09/09/11	09/09/14	09/09/14	09/09/15	09/09/15	09/09/16	09/09/16	09/09/16	09/09/17	09/09/17	09/09/17
ONPOMG5050.8	ONPOMG5050.9	ONPOMG5050.10	ONPOMG5050.11	ONPOMG5050.12	ONPOMG7525.13	ONPOMG7525.14	ONPOMG7525.15	ONPOMG7525.16	ONPOMG7525.17	ONPOMG7525.18	ONPMID.7	HL1HL25050.1
50.00	50.00	50.00	50.00	50.00	75.00	75.00	75.00	75.00	75.00	75.00	100.00	0.00
50.00	50.00	50.00	50.00	50.00	25.00	25.00	25.00	25.00	25.00	25.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00
0.88	0.96	1.31	1.07	1.31	1.27	0.77	1.24	1.22	1.15	0.77	0.34	1.33
1.60	2.90	1.50	0.90	2.80	2.90	0.80	0.90	1.20	1.10	0.10	1.00	2.10
0.30	0.40	1.40	0.60	1.40	1.20	0.20	1.10	1.00	0.80	0.20	0.50	1.50
0.50	0.70	0.90	0.30	0.80	1.00	0.80	0.70	0.80	0.40	0.70	0.50	0.50
6.00	7.00	14.00	9.00	11.00	6.00	11.00	15.00	10.00	7.00	5.00	10.00	11.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.80	1.20	1.20	1.00	1.30	0.80	1.00	1.10	1.00	0.90	0.90	1.00	1.10
9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
4.00	4.00	3.00	4.00	8.00	6.00	10.00	4.00	10.00	11.00	8.00	12.50	11.00
45.8	45.1	42.0	44.3	44.1	42.4	43.0	43.4	42.1	40.6	40.9	38.5	73.4
56.8	53.4	46.8	55.8	57.8	55.3	52.0	49.1	55.2	54.2	51.8	50.7	75.6
58.0	56.3	49.2	57.5	59.2	57.3	53.8	51.8	56.2	55.9	53.3	51.7	77.4
639	606	645	742	726	788	695	690	959	881	801	1043	106
147	210	314	224	177	208	134	262	211	174	180	285	42
116	150	220	171	154	143	117	188	180	155	161	255	33
82	85	82	77	75	94	67	88	63	59	59	70	80

APPENDIX 3: DEINKING TRAINING DATA

141	142	143	144	145	146	147	148	149	150	151	152	153
09/09/18	09/09/18	09/09/21	09/09/21	09/09/21	09/09/22	09/09/22	09/09/23	09/09/23	09/09/28	09/09/28	09/09/28	09/09/29
HL1HL2505 0.2	HL1HL2 5050.3	HL1HL2505 0.4	HL1HL2505 0.5	HL1HL2505 0.6	HL1HL2505 0.7	HL1HL2505 0.8	HL1HL2505 0.9	HL1HL2505 0.10	HL1HL2505 0.11	HL1HL2505 0.12	HL1HL2505 0.13	HL1HL2505 0.14
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	67.00	67.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	33.00	33.00
0.90	0.10	0.60	0.90	0.50	1.10	0.80	0.10	0.90	1.30	0.60	0.70	1.20
0.50	2.80	2.30	1.00	1.50	1.90	1.80	0.40	0.40	2.70	0.30	1.10	0.80
1.40	1.90	0.20	0.40	1.50	1.70	0.30	0.00	1.20	0.60	1.90	1.50	0.60
0.60	0.70	0.90	0.70	0.50	0.70	0.80	0.30	0.50	1.00	1.00	0.70	0.90
10.00	9.00	10.00	5.00	15.00	10.00	8.00	14.00	5.00	10.00	15.00	7.00	15.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.20	0.90	0.90	0.80	1.10	0.90	1.00	1.20	1.20	1.10	0.80	1.20	1.10
9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	12.00	8.00	7.00	6.00	11.00	5.00	3.00	6.00	6.00	5.00	10.00	9.00
72.1	69.9	72.4	70.0	68.8	75.1	72.7	66.6	72.1	75.1	73.8	74.5	77.6
72.5	72.1	73.3	72.4	71.4	75.6	74.2	66.5	72.9	75.9	76.7	76.4	75.9
73.8	72.8	74.3	72.7	74.6	77.3	75.3	68.3	73.8	75.2	76.8	73.1	79.8
107	89	127	128	118	94	97	102	90	126	135	115	114
54	43	65	75	75	51	62	65	53	74	81	80	44
41	38	61	65	61	35	42	52	43	57	71	70	31
85	76	84	80	81	77	79	88	79	82	85	85	63

APPENDIX 3: DEINKING TRAINING DATA

154	155	156	157	158	159	160	161	162	163	164	165	166
09/09/29	09/09/30	09/09/30	09/09/30	09/10/01	1 0ct	09/09/22	09/09/29	09/10/02	09/10/02	09/10/05	09/10/05	09/10/05
HL1HL2505 0.15	HL1HL2505 0.16	HL1HL2505 0.17	HL1HL2505 0.18	HL1HL2505 0.19	HL1HL2505 0.20	HL1MID	HL1MID	ONPHL1.1	ONPHL1.2	ONPHL1.3	ONPHL1.4	ONPHL1.5
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	50.00	50.00	50.00	50.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
67.00	67.00	67.00	67.00	67.00	67.00	100.00	100.00	50.00	50.00	50.00	50.00	50.00
33.00	33.00	33.00	33.00	33.00	33.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.90	0.30	1.40	0.20	0.40	0.40	0.50	0.50	0.10	1.20	0.90	0.30	1.20
0.20	0.80	0.10	0.00	2.50	1.30	1.00	1.00	2.00	2.80	0.50	2.60	1.50
0.50	1.10	0.70	1.50	1.20	0.80	0.50	0.50	0.50	1.70	1.60	0.99	0.80
1.00	0.40	0.50	0.90	0.50	0.60	0.50	0.50	0.90	0.30	0.80	0.50	0.40
8.00	6.00	9.00	11.00	8.00	6.00	10.00	10.00	11.00	15.00	5.00	5.00	9.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.90	0.90	1.00	0.90	1.20	1.10	1.05	1.05	1.30	0.93	1.00	1.20	1.30
9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00	5.00	10.00	5.00	2.00	3.00	12.50	12.50	6.00	4.00	3.00	6.00	12.00
76.2	76.5	76.7	79.8	81.4	80.2	98.8	99.1	49.2	53.0	53.3	54.0	53.8
79.6	79.4	82.6	81.9	82.5	83.3	102.1	100.8	55.5	60.5	60.6	63.6	64.7
79.9	78.8	83.8	83.7	80.9	84.3	99.3	96.6	59.1	65.5	66.0	65.5	68.6
99	91	99	109	106	108	88	95	646	695	509	480	550
54	45	42	49	64	54	39	46	411	381	336	259	211
43	42	31	46	52	51	40	47	261	215	206	193	141
86	86	77	89	74	83	90	91	88	80	87	78	65

APPENDIX 3: DEINKING TRAINING DATA

167	168	169	170	171	172	173	174	175	176	177	178	179
09/10/06	09/10/06	09/10/06	09/10/07	09/10/07	09/10/07	09/10/08	09/10/08	09/10/08	09/10/09	09/10/09	09/10/09	09/10/12
ONPHL1.6	ONPHL1.7	ONPHL1.8	ONPHL1.9	ONPHL1.10	ONPHL1.11	ONPHL1.12	ONPMID	HL2MID	ONPHL2.1	ONPHL2.2	ONPHL2.3	ONPHL2.4
50.00	50.00	50.00	50.00	50.00	50.00	50.00	100.00	0.00	50.00	50.00	50.00	50.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	50.00	50.00	50.00	50.00
1.00	0.40	1.40	0.80	0.60	0.00	0.70	0.34	0.34	1.00	0.80	1.10	1.32
2.00	0.70	0.20	1.00	0.80	0.00	1.10	1.00	1.00	0.60	0.80	2.50	1.70
0.00	0.70	1.80	1.50	0.30	0.00	1.10	0.50	0.50	0.90	0.70	1.70	0.10
0.25	0.40	0.60	1.00	0.90	0.30	0.30	0.50	0.50	0.30	0.50	0.90	0.60
14.00	14.00	10.00	8.00	7.00	9.00	13.00	10.00	10.00	8.00	11.00	15.00	10.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.20	0.80	1.10	1.20	0.80	1.00	1.20	1.00	1.04	0.90	1.10	1.00	1.20
9.00	9.00	9.00	9.00	9.00	7.80	7.70	8.70	8.90	8.90	8.84	8.85	9.71
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00
7.00	8.00	7.00	5.00	2.00	11.00	5.00	12.50	12.50	2.00	7.00	8.00	6.00
48.8	53.6	57.8	56.3	52.9	51.6	53.0	40.3	55.2	43.2	44.9	44.0	41.1
53.9	64.9	67.6	66.6	60.3	61.3	61.9	52.8	55.1	44.9	49.9	50.0	41.4
57.8	66.7	70.8	71.4	62.8	63.1	65.7	53.8	56.9	50.1	53.6	54.1	47.8
526	535	453	484	538	556	545	894	129	721	678	687	643
288	197	166	196	312	188	310	232	96	644	365	421	621
177	129	101	130	220	147	194	210	64	394	222	237	310
76	97	76	75	79	58	73	62	75	94	84	77	93

APPENDIX 3: DEINKING TRAINING DATA

180	181	182	183	184	185	186	187	188	189	190	191	192
09/10/12	09/10/12	09/10/13	09/10/13	09/10/13	09/10/14	09/10/14	09/10/14	09/10/15	09/10/15	09/10/16	09/10/16	09/10/16
ONPHL2.5	ONPHL2.6	ONPHL2.7	ONPHL2.8	ONPHL2.9	ONPHL2.10	ONPHL2.11	ONPHL2.12	OMGMID	HL1MID	OMGHL1.1	OMGHL1.2	OMGHL1.3
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	50.00	50.00	50.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	50.00	50.00	50.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	0.00	0.00	0.00	0.00
0.30	0.90	0.90	1.20	0.20	1.11	1.21	0.51	0.34	0.34	0.50	0.91	1.42
0.10	0.50	0.60	0.20	0.70	2.00	1.10	3.00	1.00	1.00	0.90	1.50	2.80
1.70	1.40	0.70	1.30	1.60	1.10	0.50	2.00	0.50	0.50	0.10	1.20	1.00
0.80	0.80	0.90	0.60	0.80	0.30	0.70	0.40	0.50	0.50	0.50	0.60	0.90
7.00	5.00	13.00	13.00	9.00	13.00	6.00	5.00	10.00	10.00	13.00	7.00	14.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.08	0.80	1.20	1.08	1.18	0.90	1.10	1.00	1.04	1.04	1.00	1.00	0.89
7.11	8.20	8.30	7.40	9.40	9.70	9.70	9.30	9.10	8.85	8.10	10.00	9.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00
8.00	3.00	3.00	11.00	5.00	8.00	4.00	12.00	12.50	12.50	7.00	2.00	9.00
42.9	45.1	43.8	44.5	44.3	44.3	41.6	45.5	43.5	99.5	67.3	57.9	72.7
49.3	44.8	45.0	49.1	46.1	49.2	43.5	47.3	65.6	104.5	76.9	62.3	85.7
52.7	49.1	50.7	53.3	50.1	52.6	48.1	52.0	66.5	101.5	76.0	65.9	88.1
727	614	619	670	642	648	682	577	655	84	316	329	263
437	616	628	420	524	427	610	544	76	32	108	247	72
297	377	333	252	312	261	355	350	66	40	75	189	51
71	70	91	80	81	83	85	95	53	88	76	77	79

APPENDIX 3: DEINKING TRAINING DATA

193	194	195	196	197	198	199	200	201	202	203	204	205
09/10/16	09/10/19	09/10/19	09/10/19	09/10/20	09/10/20	09/10/20	09/10/21	09/10/22	09/10/22	09/10/23	09/10/23	09/10/23
OMGHL1.4	OMGHL1.5	OMGHL1.6	OMGHL1.7	OMGHL1.8	OMGHL1.9	OMGHL1.10	OMGHL1.11	OMGHL1.12	HL2MID	OMGHL2.1	OMGHL2.2	OMGHL2.3
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	50.00	50.00	50.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	50.00	50.00	50.00
0.51	0.41	0.71	0.00	0.30	0.71	0.60	1.32	0.41	0.34	0.71	0.41	0.81
0.30	1.90	2.10	1.10	0.20	1.30	0.30	0.40	2.60	1.00	1.50	0.40	0.60
1.90	1.50	0.40	1.30	1.90	1.30	2.00	1.70	2.00	0.50	0.60	1.90	1.20
0.25	0.60	0.70	1.00	0.40	0.50	0.40	0.80	1.00	0.50	0.40	0.50	0.60
8.00	10.00	6.00	8.00	9.00	10.00	11.00	5.00	13.00	10.00	8.00	6.00	5.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.20	1.10	1.30	0.80	1.10	1.00	0.80	1.20	0.89	1.04	1.20	1.11	0.83
8.50	9.00	7.80	7.20	7.60	9.80	9.00	9.80	9.50	8.85	7.40	8.00	7.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
11.00	10.00	8.00	12.00	6.00	10.00	5.00	8.00	6.00	12.50	5.00	10.00	12.00
68.4	61.4	58.1	58.9	71.5	70.3	70.6	55.4	57.6	54.1	47.7	47.6	47.9
82.8	69.2	66.1	71.1	83.9	84.2	82.7	64.1	66.0	54.0	49.7	56.0	57.3
82.7	72.2	69.5	71.6	85.0	85.3	83.2	68.2	69.7	56.1	53.7	59.2	60.1
253	284	338	330	238	285	262	288	281	111	346	311	331
63	134	181	109	74	67	78	128	112	100	293	116	117
50	97	133	72	56	54	67	114	90	59	224	100	79
72	91	79	78	70	73	74	71	81	85	84	70	63

APPENDIX 3: DEINKING TRAINING DATA

206	207	208	209	210	211	212	213	214	215	216	217	218
09/10/26	09/10/26	09/10/26	09/10/27	09/10/27	09/10/27	09/10/28	09/10/28	09/10/28	09/10/28	09/10/29	09/10/29	09/10/29
OMGHL2.4	OMGHL2.5	OMGHL2.6	OMGHL2.7	OMGHL2.8	OMGHL2.9	OMGHL2.10	OMGHL2.11	OMGHL2.12	OMGHL2.13	OMGHL2.14	ONPMID	OMGMID
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	100.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	0.00
0.50	0.70	1.42	0.10	1.42	1.11	0.30	1.52	0.51	0.20	0.51	0.34	0.34
0.50	2.70	2.90	1.00	3.00	1.80	0.10	1.20	0.30	0.80	0.70	1.00	1.00
0.70	1.80	1.70	0.70	0.50	1.60	1.50	1.10	2.00	1.20	0.20	0.50	0.50
0.50	0.60	0.50	0.90	0.40	0.90	0.60	0.80	0.70	0.30	0.40	0.50	0.50
13.00	15.00	14.00	10.00	9.00	9.00	8.00	14.00	9.00	12.00	13.00	10.00	10.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.93	0.92	1.00	1.11	0.92	0.92	1.20	1.11	0.83	1.02	0.93	1.04	1.04
7.00	8.30	8.65	10.00	9.50	9.00	9.50	7.30	8.60	9.25	8.10	8.70	9.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
3.00	2.00	7.00	6.00	9.00	6.00	11.00	6.00	4.00	10.00	3.00	12.50	12.50
50.4	48.3	48.8	49.4	48.4	49.6	49.0	46.0	47.6	50.7	49.0	39.5	49.3
56.7	51.6	57.7	51.3	57.9	56.1	51.1	52.2	54.7	56.6	53.2	50.9	72.1
59.5	55.3	60.3	54.2	60.4	59.0	55.0	55.1	58.3	60.4	56.3	52.2	71.5
340	409	341	297	332	309	304	309	300	309	312	1039	423
172	286	121	248	109	141	247	158	135	163	181	323	48
118	179	79	180	70	96	181	104	98	109	123	290	41
80	88	65	87	76	81	81	65	68	86	82	76	58

APPENDIX 3: DEINKING TRAINING DATA

219	220	221	222	223	224	225	226	227	228	229	230	231
09/10/29	09/11/02	09/10/30	09/10/30	09/10/30	09/11/02	09/11/02	09/11/03	09/11/03	09/11/03	09/11/04	09/11/04	09/11/04
HL1MID	HL2MID	ONPOMGH L2. 1	ONPOMGH L2.2	ONPOMGH L2.3	ONPOMGH L2.4	ONPOMGH L2.5	ONPOMGH L2.6	ONPOMGH L2.7	ONPOMGH L2.8	ONPOMGH L2.9	ONPOMGH L2.10	ONPOMGH L2.11
0.00	0.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00
0.00	0.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	100.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
0.34	0.34	1.31	1.01	1.00	0.80	0.40	0.90	0.50	0.60	0.10	1.30	0.40
1.00	1.00	0.90	0.70	2.10	0.80	1.40	0.40	0.10	0.30	2.40	1.50	0.60
0.50	0.50	0.60	0.70	0.90	1.40	1.70	0.30	0.30	1.40	1.80	1.40	0.30
0.50	0.50	0.90	0.30	0.60	0.40	0.40	0.50	0.40	0.80	0.60	0.50	0.30
10.00	10.00	10.00	11.00	13.00	12.00	6.00	9.00	6.00	12.00	5.00	8.00	13.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.04	1.04	1.20	1.29	1.20	1.10	0.80	1.00	1.10	1.10	1.20	1.20	1.00
8.90	8.90	7.10	7.40	7.90	9.70	7.20	8.80	7.50	9.30	7.60	7.40	9.20
0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.50	12.50	12.00	9.00	5.00	11.00	4.00	4.00	2.00	8.00	8.00	9.00	7.00
95.9	65.1	43.6	44.8	46.4	47.1	45.6	44.1	46.2	47.0	48.9	47.7	48.0
100.2	67.9	53.5	53.8	53.6	59.0	52.5	48.2	50.8	55.4	58.0	56.9	56.6
98.9	70.4	56.3	56.7	57.0	61.6	55.8	51.2	53.2	58.5	59.5	59.4	58.4
65	121	515	493	495	566	742	503	475	554	481	492	514
29	58	172	157	225	191	366	265	306	219	182	153	163
33	54	114	108	143	127	250	179	203	142	138	106	116
88	66	69	69	77	66	92	72	78	70	79	74	58

APPENDIX 3: DEINKING TRAINING DATA

232	233	234	235	236	237	238	239	240	241	242	243	244
09/11/05	09/11/05	09/11/06	09/11/09	09/11/09	09/11/10	09/11/09	09/11/10	09/11/10	09/11/11	09/11/11	09/11/11	09/11/12
ONPOMGH L2.12	ONPOMGH L2.13	ONPOMGH L2.14	ONPOMGH L2.15	ONPMID	OMGMID	HL1MID	ONPOMGH L1.1	ONPOMGH L1.2	ONPOMGH L1.3	ONPOMGH L1.4	ONPOMGH L1.5	ONPOMGH L1.6
34.00	34.00	34.00	34.00	100.00	0.00	0.00	34.00	34.00	34.00	34.00	34.00	34.00
33.00	33.00	33.00	33.00	0.00	100.00	0.00	33.00	33.00	33.00	33.00	33.00	33.00
0.00	0.00	0.00	0.00	0.00	0.00	100.00	33.00	33.00	33.00	33.00	33.00	33.00
33.00	33.00	33.00	33.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.80	0.50	1.20	1.40	0.34	0.34	0.34	1.51	0.30	1.40	0.00	0.80	0.10
0.00	2.00	2.60	1.60	1.00	1.00	1.00	1.40	2.90	1.30	1.00	1.60	0.00
1.80	1.90	0.10	0.40	0.50	0.50	0.50	0.30	1.50	1.40	0.80	0.10	1.60
0.60	0.50	0.90	0.60	0.50	0.50	0.50	0.70	0.25	0.70	0.90	1.00	0.40
9.00	12.00	9.00	7.00	10.00	10.00	10.00	6.00	10.00	8.00	7.00	9.00	14.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.02	1.20	1.20	0.83	1.04	1.04	1.04	0.93	0.92	1.02	1.12	0.84	0.84
9.40	7.20	9.00	7.00	8.60	9.10	9.10	10.00	7.00	7.70	8.90	7.70	8.20
0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
3.00	2.00	10.00	4.00	12.50	12.50	12.50	11.00	5.00	10.00	4.00	8.00	5.00
45.6	50.4	45.2	44.7	39.4	42.2	95.0	51.3	54.1	50.0	51.8	51.1	49.8
52.5	52.1	54.2	53.3	51.6	63.1	101.6	61.4	64.5	65.5	59.4	63.3	58.6
55.9	56.5	56.1	56.5	52.6	62.8	98.4	64.8	66.9	66.7	61.5	64.8	61.2
504	481	492	558	1087	549	84	433	434	473	468	470	517
252	380	150	227	320	69	34	141	169	134	222	110	228
171	244	113	149	290	62	40	93	121	103	168	87	159
61	87	69	68	71	50	93	65	77	61	79	48	64

APPENDIX 3: DEINKING TRAINING DATA

245	246	247	248	249	250	251	252	253	254	255	256	257
09/11/12	09/11/12	09/11/13	09/11/13	09/11/16	09/11/16	09/11/16	09/11/17	09/11/17	09/11/17	09/11/17	09/11/19	09/11/19
ONPOMGH L1.7	ONPOMGH L1.8	ONPOMGH L1.9	ONPOMGH L1.10	ONPOMGH L1.11	ONPOMGH L1.12	ONPOMGH L1.13	ONPOMGH L1.14	ONPOMGH L1.15	HL1MID	HL2MID	ONPHL1HL 2.1	ONPHL1HL 2.2
34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	0.00	0.00	34.00	34.00
33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	0.00	0.00	0.00	0.00
33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	100.00	0.00	33.00	33.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	33.00	33.00
0.20	0.30	0.60	0.20	1.00	0.20	0.10	0.10	0.40	0.34	0.34	1.50	0.00
0.60	0.60	0.80	2.40	2.80	0.90	1.80	0.40	1.80	1.00	1.00	2.40	1.20
0.20	1.30	0.90	0.30	1.70	1.10	1.80	0.50	0.70	0.50	0.50	0.00	0.40
0.70	0.30	0.40	0.30	0.60	0.50	0.70	0.60	0.40	0.50	0.50	0.30	1.00
7.00	8.00	15.00	11.00	12.00	5.00	11.00	14.00	12.00	10.00	10.00	9.00	13.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.30	0.93	0.93	1.30	1.00	0.84	1.00	1.03	0.93	1.04	1.04	0.83	0.84
8.70	9.10	9.10	8.70	8.80	7.30	9.00	7.70	9.50	9.10	9.10	9.60	7.20
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00
8.00	3.00	7.00	12.00	5.00	2.00	10.00	6.00	7.00	12.50	12.50	6.00	11.00
52.5	53.3	50.3	51.5	53.7	52.1	52.3	49.7	51.6	95.2	55.4	52.6	54.0
62.3	61.8	62.8	62.2	34.5	60.0	66.1	60.0	62.8	104.5	54.9	56.6	58.8
63.6	64.5	64.5	64.1	67.3	61.9	68.0	62.7	65.5	102.5	56.3	58.8	59.9
443	426	472	485	466	454	496	495	506	145	51	314	357
157	199	164	149	186	239	137	180	142	35	31	144	125
130	148	124	113	132	189	109	129	107	35	32	102	87
61	70	63	76	77	73	69	71	66	93	78	78	64

APPENDIX 3: DEINKING TRAINING DATA

258	259	260	261	262	263	264	265	266	267	268	269	270
09/11/19	09/11/19	09/11/20	09/11/20	09/11/20	09/11/23	09/11/23	09/11/23	09/11/25	09/11/24	09/11/24	09/11/24	09/11/24
ONPHL1HL 2.3	ONPHL1HL 2.4	ONPHL1HL 2.5	ONPHL1HL 2.6	ONPHL1HL 2.7	ONPHL1HL 2.8	ONPHL1HL 2.9	ONPHL1HL 2.10	ONPHL1HL 2.11	ONPHL1HL 2.12	ONPHL1HL 2.13	ONPHL1HL 2.14	ONPHL1HL 2.15
34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00	34.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
0.90	1.30	0.50	0.70	0.60	1.00	0.30	0.90	0.50	1.00	1.40	1.00	0.40
0.80	0.60	2.40	1.10	2.50	0.20	1.40	0.40	1.40	2.20	0.70	0.10	2.10
0.10	0.70	0.90	1.20	1.30	0.70	0.20	1.20	1.50	1.20	0.60	1.80	0.20
0.60	0.70	0.40	1.00	0.70	0.50	0.60	0.60	1.00	0.60	0.50	0.60	0.90
5.00	6.00	12.00	11.00	11.00	13.00	10.00	12.00	5.00	15.00	10.00	8.00	10.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.20	1.20	1.20	1.02	1.20	1.02	1.30	1.02	0.83	1.11	0.93	0.83	0.93
9.00	8.10	9.90	9.20	9.70	7.60	7.30	9.40	7.20	8.50	9.30	7.80	7.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.00	12.00	6.00	9.00	5.00	11.00	9.00	3.00	4.00	2.00	10.00	3.00	3.00
53.5	55.9	53.7	54.3	53.4	52.2	53.0	55.1	55.2	57.5	50.7	52.0	53.5
57.9	61.2	56.3	59.5	57.8	60.0	57.9	59.7	62.1	62.0	58.3	53.9	61.1
60.0	64.4	59.3	61.9	60.3	62.5	60.2	62.7	63.4	66.1	61.0	63.2	56.4
332	315	363	370	358	432	380	334	398	445	477	411	439
168	112	299	176	216	156	183	227	223	333	184	298	208
114	82	181	110	141	103	132	117	167	206	140	149	205
77	67	86	80	80	73	73	90	73	88	67	72	91

APPENDIX 3: DEINKING TRAINING DATA

271	272	273	274	275	276	277	278	279	280	281	282	283
09/11/25	09/11/27	09/11/26	09/11/26	09/11/26	09/11/27	09/12/01	09/12/01	09/12/01	09/12/02	09/12/02	09/12/02	09/12/03
HL1MID	HL2MID	OMGHL1H L2.1	OMGHL1H L2.2	OMGHL1H L2.3	OMGHL1H L2.4	OMGHL1H L2.5	OMGHL1H L2.6	OMGHL1H L2.7	OMGHL1H L2.8	OMGHL1H L2.9	OMGHL1H L2.10	OMGHL1H L2.11
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
100.00	0.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
0.00	100.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
0.34	0.34	0.00	1.00	1.22	0.60	1.10	0.50	0.40	0.10	0.40	0.20	1.32
1.00	1.00	1.50	0.50	1.70	1.20	2.00	0.00	2.80	1.20	0.70	1.40	2.80
0.50	0.50	2.00	0.60	1.90	1.30	0.20	0.50	1.20	0.30	0.50	1.80	0.90
0.50	0.50	0.50	0.50	0.70	0.60	1.00	0.30	0.60	0.90	0.70	0.80	0.25
10.00	10.00	14.00	5.00	10.00	6.00	6.00	8.00	9.00	12.00	12.00	11.00	13.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.04	1.04	1.02	1.20	0.83	1.10	1.20	1.30	1.20	1.10	1.20	0.93	1.01
9.10	9.10	7.40	9.70	8.30	9.50	8.00	9.20	8.70	8.20	9.50	7.90	7.00
0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.50	12.50	10.00	12.00	9.00	4.00	5.00	6.00	11.00	4.00	8.00	2.00	10.00
96.6	58.7	56.0	54.6	53.9	60.2	60.4	61.7	59.7	58.9	60.2	59.4	61.7
103.0	59.7	62.8	62.8	62.4	64.4	67.1	62.5	66.0	60.2	65.4	66.4	69.3
99.3	61.0	65.0	64.3	64.5	63.8	68.3	67.0	68.0	62.2	67.5	67.3	70.6
115	61	427	430	464	219	296	283	285	300	295	335	291
54	33	168	176	148	126	112	254	151	258	161	171	131
57	42	128	131	120	130	93	195	118	209	130	141	89
88	73	72	70	60	80	79	79	83	90	79	77	78

APPENDIX 3: DEINKING TRAINING DATA

284	285	286	287	288	289	290	291	292	293	294	295	296
09/12/03	09/12/04	09/12/04	09/12/04	09/12/09	09/12/07	09/12/07	09/12/07	09/12/09	09/12/09	09/12/10	09/12/10	09/12/11
OMGHL1H L2.12	OMGHL1H L2.13	OMGHL1H L2.14	OMGHL1H L2.15	ONPMID	HL1MID	HL2MID	OMGMID	ONPOMGH L1HL2.1	ONPOMGH L1HL2.2	ONPOMGH L1HL2.3	ONPOMGH L1HL2.4	ONPOMGH L1HL2.5
0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	25.00	25.00	25.00	25.00	25.00
33.00	33.00	33.00	33.00	0.00	0.00	0.00	100.00	25.00	25.00	25.00	25.00	25.00
33.00	33.00	33.00	33.00	0.00	100.00	0.00	0.00	25.00	25.00	25.00	25.00	25.00
33.00	33.00	33.00	33.00	0.00	0.00	100.00	0.00	25.00	25.00	25.00	25.00	25.00
0.30	0.80	1.52	0.20	0.34	0.34	0.34	0.34	1.20	1.20	0.40	0.10	1.32
1.40	0.10	2.50	1.50	1.00	1.00	1.00	1.00	2.10	1.90	0.00	1.50	1.40
1.30	0.10	1.60	1.60	0.50	0.50	0.50	0.50	1.20	2.00	0.10	1.10	1.70
0.80	0.80	1.00	0.30	0.50	0.50	0.50	0.50	0.40	0.60	1.00	0.30	0.80
12.00	15.00	12.00	14.00	10.00	10.00	10.00	10.00	10.00	15.00	8.00	13.00	13.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.93	0.84	1.10	0.93	1.04	1.04	1.04	1.04	1.11	1.00	1.20	0.93	0.83
8.30	9.70	9.30	7.70	8.60	9.10	9.10	9.10	7.50	9.00	9.50	7.00	9.00
0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00
5.00	11.00	4.00	7.00	12.50	12.50	12.50	12.50	5.00	9.00	9.00	3.00	11.00
62.6	60.1	57.3	62.1	40.5	92.1	67.8	42.1	51.9	52.2	49.9	51.7	53.5
69.4	71.3	65.9	70.2	50.1	96.7	68.9	62.5	61.6	66.4	58.5	58.2	60.3
68.9	72.2	68.0	71.0	52.2	94.0	70.1	61.2	63.8	67.8	58.9	61.1	63.6
267	317	301	279	1147	154	95	776	554	550	508	548	554
77	101	126	81	393	96	44	129	260	203	213	275	323
72	90	96	76	327	100	52	136	184	142	184	218	213
74	69	77	69	82	80	72	45	71	69	69	76	85

APPENDIX 3: DEINKING TRAINING DATA

297	298	299	300	301	302	303	304	305	306	307	308	309
09/12/11	09/12/11	09/12/14	09/12/14	09/12/14	09/12/15	09/12/15	09/12/15	09/12/15	09/12/17	09/12/18	09/12/17	09/12/18
ONPOMGH L1HL2.6	ONPOMGH L1HL2.7	ONPOMGH L1HL2.8	ONPOMGH L1HL2.9	ONPOMGH L1HL2.10	ONPOMGH L1HL2.11	ONPOMGH L1HL2.12	ONPOMGH L1HL2.13	ONPOMGH L1HL2.14	ONPOMGH L1HL2.15	HL1MID	HL2MID	OMGMID
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	0.00	0.00	0.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	0.00	0.00	100.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	100.00	0.00	0.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	0.00	100.00	0.00
0.60	0.40	0.20	0.40	0.51	1.00	0.61	0.80	0.30	0.10	0.34	0.34	0.34
1.90	1.60	2.50	0.10	2.90	2.70	1.40	0.00	1.80	1.70	1.00	1.00	1.00
1.70	0.30	1.50	0.40	0.60	1.40	1.10	1.20	1.20	0.70	0.50	0.50	0.50
0.90	0.70	0.60	0.70	0.60	0.40	1.00	0.70	0.50	0.90	0.50	0.50	0.50
12.00	14.00	10.00	9.00	6.00	6.00	13.00	13.00	5.00	13.00	10.00	10.00	10.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.92	1.11	1.02	1.12	1.20	1.10	1.28	0.83	0.83	0.93	1.04	1.04	1.04
7.50	7.50	9.50	8.00	9.00	9.50	8.50	9.50	8.00	10.00	9.10	9.10	9.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.25
5.00	7.00	9.00	7.00	12.00	3.00	6.00	3.00	4.00	10.00	12.50	12.50	12.50
54.4	53.6	54.6	50.8	52.6	53.2	50.9	51.9	55.3	48.7	100.7	51.5	42.5
59.7	60.2	63.4	57.4	62.1	59.1	58.6	58.8	62.9	59.7	104.6	53.0	60.9
62.5	63.2	64.1	59.1	64.0	62.5	62.0	61.8	65.1	62.1	100.2	56.3	61.6
505	517	544	575	544	522	563	514	429	613	62	216	770
328	273	251	353	238	345	284	317	227	211	40	176	126
226	186	198	289	201	258	195	215	172	174	41	151	113
76	77	86	80	80	88	78	84	83	79	89	87	58

APPENDIX 3: DEINKING TRAINING DATA

310	311	312	313	314	315	316	317	318	319	320	321	322
10/01/20	10/01/20	10/01/21	10/01/22	10/01/25	10/01/25	10/01/27	10/01/27	10/01/28	10/01/28	10/01/29	10/02/01	10/02/01
ONPMID	OMGMID	ONPOMG7 525.19	ONPOMG7 525.20	ONPOMG7 525.21	ONPOMG7 525.22	ONPOMG7 525.23	ONPOMG7 525.24	ONPOMG7 525.25	ONPOMG7 525.26	ONPOMG7 525.27	ONPOMG7 525.28	ONPOMG7 525.29
100.00	0.00	25.00	75.00	25.00	75.00	25.00	75.00	25.00	75.00	25.00	75.00	25.00
0.00	100.00	75.00	25.00	75.00	25.00	75.00	25.00	75.00	25.00	75.00	25.00	75.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.34	0.34	1.50	1.50	1.30	1.50	1.30	1.10	1.40	1.30	1.40	1.30	1.00
1.00	1.00	2.90	2.60	2.80	2.60	3.00	3.00	2.70	2.70	2.90	2.50	2.60
0.50	0.50	1.80	2.00	1.20	1.80	2.00	1.60	1.80	1.40	2.00	1.50	1.20
0.50	0.50	0.35	0.35	0.35	0.85	0.85	0.85	0.85	0.35	0.35	0.35	0.35
10.00	10.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	12.50	12.50	12.50	12.50
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.04	1.04	0.90	0.90	1.15	0.90	1.15	0.90	1.15	0.90	1.15	0.90	1.15
9.10	9.10	7.30	8.30	8.30	7.30	7.30	8.30	8.30	7.30	7.30	8.30	8.30
0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.50	12.50	6.00	10.00	11.00	9.00	7.00	7.00	9.00	10.00	6.00	7.00	7.00
40.34	43.47	46.56	43.04	45.30	44.39	45.27	45.26	46.89	45.96	47.68	48.47	46.15
43.11	58.85	52.86	55.25	59.81	53.04	56.80	57.04	0.00	0.00	0.00	0.00	0.00
51.51	60.27	57.13	57.69	61.21	57.10	58.70	58.51	64.95	60.71	64.28	59.74	63.72
1156.00	733.50	729.00	943.75	830.25	859.75	707.25	817.50	666.75	839.50	778.00	781.75	762.50
887.50	176.00	525.50	351.75	262.00	458.25	325.75	280.00	0.00	0.00	0.00	0.00	0.00
571.60	136.40	349.90	261.50	199.40	330.20	232.10	216.90	106.39	190.00	180.70	180.40	136.10
94	84	88.59	81.35	71.44	82.04	70.44	79.10	62.01	63.58	66.57	70.75	70.08

APPENDIX 3: DEINKING TRAINING DATA

323	324	325	326	327	328	329	330	331	332	333	334	335
10/02/02	10/02/02	10/02/03	10/02/03	10/02/04	10/02/04	10/02/05	10/02/05	10/02/08	10/02/08	10/02/09	10/02/09	10/02/10
ONPOMG7 525.30	ONPOMG7 525.31	ONPOMG7 525.32	ONPOMG7 525.33	HL1MID	HL2MID	HL1HL2-7525.1	HL1HL2-7525.2	HL1HL2-7525.3	HL1HL2-7525.4	HL1HL2-7525.5	HL1HL2-7525.6	HL1HL2-7525.7
75.00	25.00	75.00	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25.00	75.00	25.00	75.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	100.00	0.00	75.00	25.00	75.00	25.00	75.00	25.00	75.00
0.00	0.00	0.00	0.00	0.00	100.00	25.00	75.00	25.00	75.00	25.00	75.00	25.00
1.30	1.40	1.30	1.30	0.34	0.34	1.50	1.50	1.30	1.52	1.32	1.11	1.40
2.70	2.70	2.80	2.90	1.00	1.00	2.90	2.60	2.80	2.60	3.00	3.00	2.70
1.20	1.40	1.80	1.20	0.50	0.50	1.80	2.00	1.20	1.80	2.00	1.60	1.80
0.85	0.85	0.85	0.85	0.50	0.50	0.35	0.35	0.35	0.85	0.85	0.85	0.85
12.50	12.50	12.50	12.50	10.00	10.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.90	1.15	0.90	1.15	1.04	1.04	0.90	0.90	1.15	0.90	1.14	0.92	1.15
7.30	7.30	8.30	8.30	9.10	9.10	7.30	8.30	8.30	7.30	7.30	8.30	8.30
0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.00	7.00	10.00	6.00	12.50	12.50	6.00	10.00	11.00	9.00	7.00	7.00	9.00
48.70	46.65	47.67	44.79	95.98	52.05	85.32	67.85	87.15	67.65	87.60	66.65	86.67
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61.12	63.91	60.60	62.52	98.50	59.05	90.32	76.21	87.84	73.55	88.29	71.80	90.26
714.00	723.50	801.50	723.75	91.50	226.75	107.75	184.93	103.90	167.75	100.75	155.00	107.25
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
163.30	136.50	173.90	143.50	43.50	132.50	57.80	86.90	50.00	84.23	51.20	88.90	46.08
68.30	64.63	72.46	69.67	86.16	79.82	84.40	72.20	77.19	88.80	79.94	76.57	74.05

APPENDIX 3: DEINKING TRAINING DATA

336	337	338	339	340	341	342	343	344	345	346	347	348
10/02/10	10/02/11	10/02/11	10/02/12	10/02/12	10/02/15	10/02/16	10/02/16	10/02/17	10/02/18	10/02/17	10/02/17	10/02/19
HL1HL2-7525.8	HL1HL2-7525.9	HL1HL2-7525.10	HL1HL2-7525.11	HL1HL2-7525.12	HL1HL2-7525.13	HL1HL2-7525.14	HL1HL2-7525.15	HL1MID	HL2MID	OMGMID	ONPMID	TEST.1
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	70.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	5.00
25.00	75.00	25.00	75.00	25.00	75.00	25.00	75.00	100.00	0.00	0.00	0.00	15.00
75.00	25.00	75.00	25.00	75.00	25.00	75.00	25.00	0.00	100.00	0.00	0.00	10.00
1.30	1.40	1.32	1.00	1.30	1.42	1.30	1.30	0.34	0.34	0.34	0.34	0.80
2.70	2.90	2.50	2.60	2.70	2.70	2.80	2.90	1.00	1.00	1.00	1.00	0.70
1.40	2.00	1.50	1.20	1.20	1.40	1.80	1.20	0.50	0.50	0.50	0.50	2.00
0.35	0.35	0.35	0.35	0.85	0.85	0.85	0.85	0.50	0.50	0.50	0.50	0.30
12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50	10.00	10.00	10.00	10.00	14.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.90	1.15	0.90	1.15	0.90	1.15	0.90	1.15	1.04	1.04	1.04	1.04	1.00
7.30	7.30	8.30	8.30	7.30	7.30	8.30	8.30	9.10	9.10	9.10	9.10	8.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.00
10.00	6.00	7.00	7.00	8.00	7.00	10.00	6.00	12.50	12.50	12.50	12.50	3.00
66.49	89.38	73.20	87.20	71.03	87.15	72.93	83.93	98.88	65.35	44.03	38.60	42.67
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.15
73.44	93.53	79.89	92.73	80.18	91.08	79.42	90.79	100.24	70.03	62.51	51.73	50.66
147.50	86.63	121.75	88.13	122.50	95.75	110.25	150.00	86.25	132.25	718.25	1207.25	993.11
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	951.71
64.09	37.00	63.80	43.70	48.10	43.90	51.60	46.57	42.90	77.89	95.79	334.60	588.76
96.47	70.16	77.60	78.60	64.80	68.04	76.50	42.50	80.28	74.65	42.37	70.10	95.77

APPENDIX 3: DEINKING TRAINING DATA

349	350	351	352	353	354	355	356	357	358	359	360	361
10/02/19	10/02/23	10/02/22	10/02/22	10/02/23	10/02/24	10/02/24	10/02/25	10/02/25	10/02/26	10/02/26	10/03/01	10/03/01
TEST.2	TEST.3	TEST.4	TEST.5	TEST.6	TEST.7	TEST.8	TEST.9	TEST.10	TEST.11	TEST.12	TEST.13	TEST.14
20.00	50.00	15.00	47.00	50.00	70.00	60.00	80.00	20.00	18.00	25.00	27.00	37.00
30.00	5.00	5.00	15.00	0.00	15.00	20.00	10.00	20.00	22.00	8.00	18.00	20.00
23.00	20.00	40.00	28.00	30.00	10.00	10.00	0.00	30.00	52.00	59.00	30.00	25.00
27.00	25.00	40.00	10.00	20.00	5.00	10.00	10.00	30.00	8.00	8.00	25.00	18.00
1.15	0.70	0.90	0.20	0.94	0.10	1.00	0.73	1.56	0.52	0.94	1.25	0.10
0.50	0.50	2.10	1.03	0.40	0.90	2.68	2.58	0.10	2.16	0.40	2.47	0.93
0.80	0.50	0.40	1.44	1.65	1.85	1.23	1.34	1.13	1.03	1.75	1.34	1.13
0.72	0.50	0.40	0.72	0.80	0.82	0.41	0.72	0.31	1.00	0.41	1.00	0.72
10.00	5.00	8.00	6.00	8.00	10.00	5.00	13.00	13.00	7.00	14.00	13.00	9.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.00	0.81	0.90	1.00	1.16	1.08	0.90	1.16	0.80	0.90	1.00	1.00	1.08
8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	9.00	7.00	2.00	12.00	11.00	5.00	5.00	8.00	6.00	5.00	5.00	10.00
53.57	48.15	59.93	47.46	48.98	42.43	46.64	41.64	53.71	59.02	58.60	53.71	48.98
57.78	57.44	65.02	48.92	54.17	45.99	57.62	47.64	67.01	71.11	70.99	62.23	58.17
60.96	59.45	67.51	55.63	59.15	51.38	60.33	52.56	68.23	71.73	72.67	65.86	61.31
545.30	606.29	313.60	737.66	732.50	1074.55	741.54	1032.69	474.28	432.48	474.67	486.92	624.40
392.42	286.32	215.52	698.22	522.06	761.66	313.36	728.86	153.55	171.65	235.75	267.68	283.94
263.61	212.77	160.52	389.31	294.70	500.29	230.44	461.97	112.47	143.96	163.85	173.33	199.43
83.26	74.64	77.77	87.02	77.36	88.07	70.33	88.99	63.74	73.29	74.46	71.50	74.11

APPENDIX 3: DEINKING TRAINING DATA

362	363	364	365	366	367	368	369	370	371	372	373	374
10/03/01	10/03/02	10/03/02	10/03/02	10/03/04	10/03/04	10/03/05	10/03/05	10/03/05	10/03/08	10/03/08	10/03/10	10/03/10
TEST.15	TEST.16	TEST.17	TEST.18	TEST.19	TEST.20	TEST.21	TEST.22	TEST.23	TEST.24	TEST.25	TEST.26	TEST.27
20.00	6.00	20.00	28.00	10.00	20.00	66.00	43.00	63.00	71.00	51.00	47.00	85.00
5.00	12.00	15.00	7.00	5.00	25.00	26.00	9.00	0.00	7.00	8.00	10.00	8.00
70.00	70.00	25.00	38.00	60.00	50.00	8.00	15.00	32.00	22.00	20.00	12.00	0.00
5.00	12.00	40.00	27.00	25.00	5.00	0.00	33.00	5.00	0.00	21.00	31.00	7.00
0.20	0.94	1.36	1.15	1.56	0.63	1.00	0.30	1.36	0.00	1.00	1.25	0.94
1.34	2.26	1.13	0.10	1.85	0.21	2.79	1.00	1.34	1.55	1.55	2.06	2.58
2.10	0.92	1.54	0.60	1.75	0.41	0.82	1.54	0.82	1.75	0.72	0.93	0.20
0.41	0.82	0.30	0.62	0.72	0.93	0.30	0.82	0.93	0.82	0.51	1.00	0.52
10.00	6.00	7.00	8.00	12.00	8.00	13.00	13.00	14.00	11.00	10.00	13.00	8.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.81	1.17	1.16	0.90	1.16	1.26	1.16	1.00	0.90	0.90	0.90	0.80	1.16
8.50	8.50	8.50	8.50	8.50	8.50	9.40	9.30	8.60	8.80	9.10	8.80	9.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.00	9.00	11.00	4.00	5.00	12.00	5.00	10.00	12.00	8.00	5.00	7.00	2.00
64.35	71.11	53.54	53.15	70.14	54.67	41.72	47.73	42.95	42.45	45.80	43.05	40.26
75.70	79.94	59.23	61.74	76.66	68.54	49.29	58.47	57.04	54.98	57.75	59.24	38.98
77.14	81.48	64.60	65.94	80.40	69.72	53.39	60.20	59.21	55.36	58.92	60.41	46.90
360.73	246.71	446.56	511.82	270.89	512.24	1110.33	701.85	972.38	1033.97	766.56	744.25	976.43
160.94	125.40	323.02	263.67	158.88	187.73	609.85	252.58	372.49	336.25	319.56	231.60	1103.53
125.95	99.26	196.85	177.53	107.75	151.98	393.53	201.05	292.90	294.22	250.17	192.82	554.36
63.73	70.40	79.38	67.03	71.41	63.54	71.86	57.92	57.67	54.77	61.64	32.85	84.18

APPENDIX 3: DEINKING TRAINING DATA

375	376	377	378	379	380	381	382	383	384	385	386	387
10/03/11	10/03/11	10/03/11	10/03/12	10/03/12	10/03/12	10/03/15	10/03/15	10/03/15	10/03/16	10/03/16	10/03/16	10/03/17
TEST.28	TEST.29	TEST.30	TEST.31	TEST.32	TEST.33	TEST.34	TEST.35	TEST.36	TEST.37	TEST.38	TEST.39	TEST.40
43.00	34.00	22.00	11.00	8.00	0.00	19.00	26.00	28.00	28.00	10.00	17.00	28.00
17.00	11.00	23.00	4.00	31.00	5.00	22.00	7.00	15.00	15.00	18.00	29.00	15.00
11.00	30.00	22.00	59.00	49.00	69.00	34.00	67.00	43.00	43.00	58.00	22.00	42.00
29.00	25.00	33.00	26.00	12.00	26.00	25.00	0.00	14.00	14.00	14.00	32.00	15.00
1.25	0.10	0.94	0.94	1.25	0.94	1.36	0.83	1.56	0.83	0.31	0.52	0.10
2.10	0.70	2.99	2.16	0.00	1.96	1.54	0.21	1.03	0.62	3.00	1.03	2.99
1.95	0.40	1.85	0.90	1.85	0.62	1.54	0.31	1.64	1.13	0.62	0.21	0.00
0.93	1.00	0.40	0.72	1.00	0.62	0.51	0.31	0.51	0.82	0.31	0.51	0.82
11.00	10.00	10.00	6.00	9.00	9.00	6.00	5.00	7.00	13.00	8.00	7.00	6.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
0.80	1.10	1.16	0.80	1.08	0.90	1.08	0.82	1.10	1.17	1.00	1.10	0.90
9.80	9.90	8.60	9.50	10.00	9.40	10.00	9.40	7.00	7.50	7.50	8.00	7.20
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.00	9.00	9.00	6.00	6.00	4.00	5.00	7.00	11.00	2.00	7.00	11.00	4.00
47.54	50.35	55.03	72.13	61.89	73.08	56.35	60.45	56.19	55.22	65.84	51.69	55.36
61.22	60.60	65.04	77.49	70.03	77.85	65.54	73.15	70.62	61.83	75.31	61.83	59.75
62.91	62.37	68.21	78.86	72.73	79.88	67.65	73.39	72.57	65.85	76.08	63.19	62.03
767.24	646.96	440.76	193.29	348.61	163.61	429.28	391.16	469.68	474.15	287.01	427.99	407.29
206.55	196.20	204.43	123.42	200.36	88.19	229.13	150.18	140.70	309.06	122.80	143.19	232.30
164.29	156.76	140.16	104.86	153.96	77.10	160.52	129.15	108.25	194.92	103.59	119.48	177.23
55.61	61.25	69.97	75.80	75.81	70.53	61.49	54.55	61.97	69.93	70.80	61.90	72.65

APPENDIX 3: DEINKING TRAINING DATA

388	389	390	391	392	393	394	395	396	397	398	399	400
10/03/09	10/03/09	10/03/09	10/03/10	10/03/17	10/03/17	10/03/18	10/03/18	10/03/18	10/03/19	10/03/19	10/03/23	10/03/23
ONPMID	OMGMID	HL1MID	HL2MID	ALL MIDPT	ALL 1	ALL 2	ALL 3	ALL 4	ALL 5	ALL 6	ALL 7	ALL 8
100.00	0.00	0.00	100.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
0.00	100.00	0.00	0.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
0.00	0.00	100.00	0.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
0.00	0.00	0.00	100.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
0.34	0.34	0.34	0.34	0.34	0.67	0.67	0.00	0.67	0.67	0.67	0.00	0.00
1.00	1.00	1.00	1.00	1.00	0.00	2.00	2.00	0.00	2.00	2.00	2.00	0.00
0.50	0.50	0.50	0.50	0.50	1.00	0.00	1.00	1.00	0.00	1.00	1.00	1.00
0.50	0.50	0.50	0.50	0.50	0.25	0.75	0.25	0.75	0.75	0.25	0.75	0.75
10.00	10.00	10.00	10.00	10.00	5.00	5.00	15.00	5.00	15.00	15.00	5.00	15.00
43.00	43.00	43.00	43.00	43.00	35.00	35.00	35.00	50.00	35.00	50.00	50.00	35.00
38.00	38.00	38.00	38.00	38.00	45.00	30.00	30.00	30.00	45.00	30.00	45.00	45.00
1.04	1.04	1.04	1.04	1.04	1.30	1.30	0.80	0.80	0.80	1.30	0.80	1.30
9.10	9.10	9.10	9.10	9.10	10.00	10.00	10.00	8.00	8.00	8.00	10.00	8.00
0.25	0.25	0.25	0.25	0.25	0.00	0.50	0.50	0.50	0.00	0.00	0.00	0.50
12.50	12.50	12.50	12.50	12.50	20.00	5.00	20.00	20.00	20.00	5.00	5.00	5.00
35.56	44.96	93.71	59.42	53.63	53.41	46.57	49.71	49.41	45.13	48.59	48.40	46.72
50.33	65.20	98.02	61.33	62.09	64.92	48.48	57.74	61.34	54.80	55.80	57.28	52.73
51.57	63.63	96.14	64.53	64.02	66.41	51.63	59.27	62.64	55.05	59.78	58.64	56.49
1396.56	809.35	101.02	121.57	492.11	465.98	469.23	481.54	554.43	551.36	521.43	527.53	599.96
371.77	99.98	56.87	93.93	217.11	136.30	311.87	141.03	152.03	148.88	236.86	187.06	307.85
342.36	98.02	57.39	70.67	155.08	114.93	230.19	115.32	128.50	122.35	167.83	157.71	194.86
43.52	70.32	80.44	74.57	59.93	58.22	77.14	60.07	36.74	36.56	65.25	60.74	67.85

APPENDIX 3: DEINKING TRAINING DATA

401	402	403	404	405	406	407	408	409	410	411	412	413
10/03/23	10/03/24	10/03/24	10/03/25	10/04/01	10/03/25	10/03/26	10/03/26	10/03/26	10/03/29	10/03/29	10/03/29	10/03/31
ALL 9	ALL 10	ALL 11	ALL 12	ALL 13	ALL 14	ALL 15	ALL 16	ALL 17	ALL 18	ALL 19	ALL 20	ALL 21
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
0.00	0.67	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.67	0.67	0.67
0.00	0.00	2.00	0.00	2.00	0.00	0.00	2.00	0.00	0.00	0.00	2.00	2.00
0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00
0.75	0.25	0.25	0.25	0.75	0.25	0.75	0.25	0.25	0.75	0.25	0.25	0.25
15.00	15.00	5.00	5.00	15.00	15.00	5.00	15.00	5.00	5.00	15.00	5.00	5.00
50.00	50.00	50.00	35.00	50.00	50.00	50.00	35.00	50.00	35.00	35.00	50.00	35.00
30.00	45.00	45.00	30.00	30.00	45.00	45.00	45.00	30.00	45.00	30.00	30.00	45.00
1.30	0.80	1.30	0.80	0.80	0.80	1.30	1.30	1.30	0.80	1.30	0.80	0.80
10.00	10.00	8.00	8.00	8.00	8.00	8.00	10.00	10.00	10.00	8.00	10.00	8.00
0.00	0.50	0.50	0.00	0.50	0.00	0.00	0.00	0.50	0.50	0.50	0.00	0.50
20.00	5.00	20.00	5.00	5.00	20.00	5.00	5.00	5.00	20.00	20.00	20.00	5.00
46.66	45.24	50.71	50.10	50.75	47.90	47.03	47.48	50.08	49.63	46.03	48.45	51.58
54.98	51.94	58.61	56.14	57.48	59.10	50.13	52.81	53.73	56.82	54.80	55.30	61.72
57.21	54.51	59.92	57.72	58.88	60.57	54.69	53.50	55.84	57.07	56.50	57.64	62.78
665.29	626.06	498.08	501.26	444.25	573.48	570.81	594.58	524.95	487.00	627.50	519.50	487.25
236.98	253.90	137.00	217.10	179.25	163.55	382.32	278.29	301.00	158.75	185.75	179.00	176.50
172.22	177.21	129.28	178.70	135.60	142.14	194.35	260.94	237.22	147.50	147.87	143.90	147.30
59.33	65.85	49.14	59.66	67.52	39.37	75.99	68.07	68.19	35.70	54.87	97.08	57.63

APPENDIX 3: DEINKING TRAINING DATA

414	415	416	417	418	419	420	421	422	423	424	425	426
10/03/31	10/04/01	10/04/06	10/04/06	10/04/06	10/04/07	10/04/07	10/04/08	10/04/08	10/04/09	10/04/09	10/04/12	10/04/13
ALL 22	ALL 23	ALL 24	ALL MIDPT	ALL MIDPT	ALL MIDPT	ALL MIDPT	TEST.41	TEST.42	TEST.43	TEST.44	TEST.45	TEST.46
25.00	25.00	25.00	25.00	25.00	25.00	25.00	40.00	42.00	57.00	51.00	54.00	53.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	18.00	20.00	7.00	29.00	15.00	6.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	22.00	12.00	8.00	12.00	11.00	10.00
25.00	25.00	25.00	25.00	25.00	25.00	25.00	20.00	26.00	28.00	8.00	20.00	31.00
0.00	0.67	0.67	0.34	0.34	0.34	0.34	1.46	0.00	0.20	1.46	0.30	0.40
2.00	0.00	2.00	1.00	1.00	1.00	1.00	1.55	1.55	1.55	1.55	1.50	1.50
1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.13	1.65	0.72	1.65	1.70	1.20
0.75	0.75	0.75	0.50	0.50	0.50	0.50	0.62	0.62	0.62	0.62	0.62	0.62
5.00	15.00	15.00	10.00	10.00	10.00	10.00	8.00	8.00	8.00	8.00	13.00	11.00
35.00	35.00	50.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	50.00	50.00
30.00	30.00	45.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	45.00	45.00
1.30	0.80	1.30	1.04	1.04	1.04	1.04	1.25	0.81	1.10	1.16	1.30	1.10
8.00	10.00	10.00	9.10	9.10	9.10	9.10	9.90	9.30	8.10	9.40	7.00	7.60
0.00	0.00	0.50	0.25	0.25	0.25	0.25	0.10	0.16	0.12	0.11	0.30	0.30
20.00	5.00	20.00	12.50	12.50	12.50	12.50	10.00	2.00	10.00	11.00	4.00	9.00
50.95	53.20	50.23	46.70	43.48	54.35	53.70	51.60	49.33	46.60	48.93	46.11	48.30
61.60	62.13	61.90	59.38	57.35	63.25	65.15	58.60	53.33	61.05	52.65	48.90	54.65
62.29	64.96	64.27	61.23	59.76	64.70	66.14	61.96	56.23	63.21	55.28	53.74	56.90
529.75	449.25	487.25	502.50	522.00	418.50	418.25	446.75	525.75	576.25	593.75	640.00	556.00
190.75	161.00	114.75	157.25	154.75	128.00	113.00	240.25	340.50	182.25	265.00	503.00	280.00
169.70	116.60	94.77	124.90	116.20	108.60	98.31	164.20	251.50	141.30	209.70	333.00	216.00
56.32	65.58	58.64	66.98	67.93	61.44	63.70	77.08	77.85	76.60	76.28	86.70	76.20

APPENDIX 3: DEINKING TRAINING DATA

427	428	429	430	431	432	433	434	435	436	437	438	439
10/04/13	10/04/20	10/04/20	10/04/23	10/04/23	10/04/28	10/04/28	10/04/29	10/04/30	10/04/30	10/05/03	10/05/03	10/05/04
TEST.47	Test 48	Test 49	Test 50	ALLMIDPT	ALLMIDPT	Test 51	Test 52	Test 53	Test 54	Test 55	Test 56	Test 57
74.00	59.00	87.00	76.00	25.00	25.00	53.00	16.00	53.00	36.00	51.00	53.00	70.00
17.00	16.00	1.00	5.00	25.00	25.00	21.00	25.00	7.00	20.00	16.00	8.00	14.00
7.00	12.00	10.00	15.00	25.00	25.00	17.00	31.00	23.00	24.00	14.00	30.00	3.00
2.00	13.00	2.00	4.00	25.00	25.00	9.00	28.00	17.00	20.00	19.00	9.00	13.00
0.80	1.10	1.40	1.30	0.34	0.34	1.20	0.90	1.40	0.50	1.30	0.10	0.00
1.50	1.50	1.50	1.50	1.00	1.00	1.50	1.50	1.50	1.50	1.50	1.50	1.50
0.80	1.20	0.30	0.70	0.50	0.50	0.00	1.80	1.30	1.70	0.40	1.20	0.10
0.62	0.62	0.62	0.62	0.50	0.50	0.62	0.62	0.62	0.62	0.62	0.62	0.62
7.00	13.00	13.00	8.00	10.00	10.00	8.00	13.00	14.00	8.00	7.00	12.00	5.00
50.00	50.00	50.00	50.00	43.00	43.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
45.00	45.00	45.00	45.00	38.00	38.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
0.90	1.10	1.20	1.00	1.04	1.04	0.80	1.20	1.20	0.90	1.30	1.00	1.00
7.50	7.20	8.10	9.60	9.10	9.10	7.20	8.60	9.60	8.70	7.30	7.50	7.10
0.30	0.30	0.30	0.30	0.25	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30
8.00	9.00	5.00	10.00	12.50	12.50	10.00	10.00	4.00	8.00	8.00	8.00	10.00
44.50	47.24	43.26	42.42	51.30	51.03	43.67	55.82	50.38	50.60	46.34	52.12	41.82
54.74	58.08	48.66	52.38	62.79	61.80	52.65	60.29	54.68	60.89	50.89	60.68	52.80
57.23	61.03	53.02	56.44	64.65	63.08	53.82	63.88	60.19	63.23	56.48	62.87	53.81
792.00	703.53	816.29	893.26	467.07	526.66	709.15	384.21	582.23	520.96	639.50	508.11	892.08
327.00	248.63	529.00	369.31	129.99	144.72	197.06	252.44	416.57	209.47	392.40	203.88	229.48
243.00	177.96	327.55	254.15	106.46	112.01	169.56	168.42	249.38	154.90	241.10	150.00	196.69
80.60	72.96	88.44	78.36	62.05	63.98	43.78	82.03	88.38	70.95	80.20	74.27	62.85

APPENDIX 3: DEINKING TRAINING DATA

440	441	442	443	444	445	446	447	448	449	450	451	452
10/05/04	10/05/06	10/05/06	10/05/07	10/05/07	10/08/30	10/08/30	10/08/31	10/09/01	10/08/31	10/09/01	10/09/02	10/09/02
Test 58	Test 59	Test 60	ALLMIDPT	ALLMIDPT	All Midpoint 1	MIX1	MIX2	MIX3	MIX4	MIX5	MIX6	MIX7
55.00	17.00	75.00	25.00	25.00	25.00	42.00	39.00	65.00	65.00	42.00	29.00	63.00
9.00	21.00	14.00	25.00	25.00	25.00	17.00	10.00	9.00	20.00	30.00	27.00	15.00
23.00	30.00	6.00	25.00	25.00	25.00	14.00	25.00	13.00	4.00	12.00	19.00	17.00
13.00	32.00	5.00	25.00	25.00	25.00	27.00	26.00	13.00	11.00	16.00	25.00	5.00
0.80	1.00	0.30	0.34	0.34	0.34	0.10	1.15	0.10	0.50	0.00	0.63	0.30
1.50	1.50	1.50	1.00	1.00	1.00	0.10	0.40	2.68	1.34	0.20	1.24	0.20
1.50	0.30	1.10	0.50	0.50	0.50	0.80	1.10	1.75	1.65	1.95	1.95	0.50
0.62	0.62	0.62	0.50	0.50	0.50	1.00	1.00	0.93	0.52	0.62	1.00	0.52
8.00	12.00	6.00	10.00	10.00	10.00	8.00	6.00	7.00	13.00	5.00	10.00	13.00
50.00	50.00	50.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
45.00	45.00	45.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.10	1.20	0.90	1.04	1.04	1.04	1.50	1.50	1.50	1.50	1.50	1.50	1.50
8.90	8.10	8.80	9.10	9.10	9.00	8.40	9.70	9.40	9.70	9.00	7.50	8.20
0.30	0.30	0.30	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.00	4.00	3.00	12.50	12.50	12.50	4.00	1.00	5.00	1.00	3.00	1.00	1.00
48.38	56.69	43.53	49.60	48.93	47.11	44.49	46.32	41.43	38.40	42.66	46.24	38.89
59.73	62.04	46.12	60.57	61.86	58.23	44.72	46.64	39.55	37.09	40.03	46.63	38.16
62.02	65.41	51.81	63.96	64.14	59.82	50.44	53.54	46.89	46.11	47.39	51.57	45.77
619.79	388.90	879.13	564.68	579.39	613.92	684.66	671.05	988.94	1219.01	828.91	620.74	1189.70
221.19	231.54	741.23	168.70	169.50	175.84	650.76	664.45	1200.89	1394.83	1026.27	657.79	1225.34
164.39	164.33	460.33	126.45	131.56	144.83	367.43	387.89	679.79	732.66	559.57	422.35	710.92
67.50	78.87	88.96	69.31	69.30	61.06	82.87	96.35	98.82	93.97	87.66	96.51	89.90

APPENDIX 3: DEINKING TRAINING DATA

453	454	455	456	457	458	459	460	461	462	463	464	465
10/09/03	10/09/06	10/09/06	10/09/13	10/09/13	10/09/20	10/09/20	10/09/21	10/09/21	10/09/22	10/09/22	10/09/23	10/09/23
All Midpoint 2	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13	Mix 14	All Midpoint 3	Mix 15	Mix 16	Mix 17	Mix 18
25.00	73.00	30.00	35.00	43.00	59.00	44.00	37.00	25.00	36.00	59.00	56.00	47.00
25.00	0.00	24.00	23.00	30.00	23.00	10.00	27.00	25.00	13.00	14.00	0.00	9.00
25.00	19.00	14.00	18.00	14.00	0.00	21.00	24.00	25.00	32.00	27.00	16.00	24.00
25.00	8.00	32.00	24.00	13.00	18.00	25.00	12.00	25.00	19.00	0.00	28.00	20.00
0.34	0.84	0.73	0.63	0.42	1.46	1.15	1.56	0.34	1.15	1.00	0.00	0.20
1.00	1.65	2.27	1.85	0.40	0.93	2.37	0.30	1.00	1.34	1.65	2.47	0.40
0.50	1.96	0.30	1.10	1.75	1.00	0.62	1.65	0.50	0.62	0.30	0.50	1.65
0.50	0.82	0.93	0.41	0.93	0.51	0.72	0.31	0.50	0.41	0.31	0.51	0.62
10.00	12.00	11.00	15.00	8.00	13.00	6.00	9.00	10.00	9.00	10.00	7.00	9.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.04	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.04	1.50	1.50	1.50	1.50
9.00	9.20	7.40	8.10	7.20	8.70	8.00	8.40	9.00	9.80	8.60	8.30	9.20
0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
12.50	3.00	2.00	2.00	5.00	2.00	2.00	3.00	12.50	1.00	3.00	4.00	5.00
48.52	41.09	48.38	46.35	43.36	39.49	45.30	51.32	51.53	48.17	51.08	47.21	46.21
60.06	40.53	50.27	46.42	48.53	41.78	46.04	54.49	62.11	48.75	51.90	47.20	48.42
61.87	47.83	54.70	52.50	54.02	48.03	52.75	60.64	63.52	56.02	57.35	51.67	54.42
596.41	1092.39	559.30	709.66	836.65	989.17	639.67	518.94	464.54	672.16	429.94	576.57	663.19
176.36	1176.49	521.78	748.88	574.93	906.78	661.44	454.79	112.05	717.63	401.43	589.22	515.30
145.51	711.95	325.83	458.05	362.94	580.93	411.77	259.09	96.53	410.84	230.45	366.37	306.64
58.14	94.21	79.10	89.58	77.00	86.61	89.46	86.92	61.15	88.16	92.55	89.79	90.88

APPENDIX 3: DEINKING TRAINING DATA

466	467	468	469	470	471	472	473	474	475	476	477	478
10/09/27	10/09/27	10/09/28	10/09/28	10/09/28	10/09/29	10/09/29	10/09/29	10/09/30	10/09/30	10/10/01	10/10/01	10/10/04
Mix 19	Mix 20	MIX21	All Midpoint 3	MIX22	MIX23	MIX24	MIX25	MIX26	MIX27	MIX28	MIX29	All Midpoint 3
50.00	38.00	19.00	25.00	22.00	26.00	21.00	33.00	9.00	31.00	12.00	14.00	25.00
19.00	22.00	14.00	25.00	18.00	14.00	14.00	0.00	9.00	8.00	1.00	15.00	25.00
5.00	22.00	57.00	25.00	31.00	37.00	60.00	35.00	82.00	33.00	55.00	60.00	25.00
26.00	18.00	10.00	25.00	29.00	23.00	5.00	32.00	0.00	28.00	32.00	11.00	25.00
0.94	1.25	0.00	0.34	0.10	0.73	1.36	0.52	0.83	0.94	0.30	0.42	0.34
1.13	3.00	1.34	1.00	0.62	1.34	2.88	0.52	1.54	2.78	0.10	1.54	1.00
0.41	0.72	1.44	0.50	0.82	0.51	1.64	1.95	1.54	1.75	1.34	1.64	0.50
0.62	1.03	0.62	0.50	0.82	1.00	0.62	0.93	0.51	0.30	1.03	0.82	0.50
14.00	5.00	13.00	10.00	5.00	12.00	9.00	8.00	8.00	12.00	12.00	10.00	10.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.50	1.50	1.50	1.04	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
10.00	7.50	8.00	9.00	8.70	9.80	9.50	7.90	8.10	7.40	8.10	8.90	9.00
0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
4.00	1.00	5.00	12.50	1.00	5.00	3.00	5.00	1.00	2.00	4.00	2.00	12.50
44.40	50.18	63.72	49.93	54.46	50.34	61.13	50.81	72.25	51.78	61.86	60.18	48.87
45.14	50.50	66.96	60.87	54.16	53.78	64.19	55.35	74.92	54.00	64.23	61.72	57.45
51.23	57.12	71.23	62.10	57.75	59.03	70.40	60.86	77.78	60.40	67.75	65.98	59.51
669.90	487.39	313.43	402.96	319.68	565.40	386.20	580.49	263.88	515.24	283.24	354.72	502.67
651.79	556.61	210.61	109.62	313.40	459.90	332.55	432.75	244.01	496.00	215.23	340.03	157.73
357.75	336.51	131.86	92.06	188.46	285.32	209.88	259.06	192.95	278.57	149.12	239.09	124.72
96.03	91.82	87.76	57.18	88.99	79.04	87.64	75.94	91.80	88.78	82.72	93.51	56.72

APPENDIX 3: DEINKING TRAINING DATA

479	480	481	482	483	484	485	486	487	488	489	490
10/10/04	10/10/04	10/10/05	10/10/05	10/10/05	10/10/06	10/10/06	10/10/07	10/10/07	10/10/08	10/10/11	10/10/11
MIX30	MIX31	MIX32	MIX33	MIX34	All Midpoint 3	MIX35	MIX36	MIX37	MIX38	MIX39	MIX40
21.00	14.00	18.00	10.00	26.00	25.00	11.00	27.00	16.00	14.00	5.00	14.00
13.00	6.00	24.00	1.00	15.00	25.00	28.00	6.00	8.00	15.00	18.00	26.00
45.00	77.00	50.00	81.00	51.00	25.00	45.00	42.00	67.00	50.00	63.00	55.00
21.00	3.00	8.00	8.00	8.00	25.00	16.00	25.00	9.00	21.00	14.00	5.00
1.00	1.56	0.73	0.83	0.94	0.34	1.15	1.25	0.20	0.31	0.30	0.73
1.65	1.24	2.37	3.00	1.96	1.00	2.27	2.78	2.37	2.37	1.34	1.96
1.03	1.00	1.44	0.21	1.13	0.50	1.03	0.92	1.85	1.13	0.62	1.44
0.72	0.62	0.93	0.82	0.82	0.50	0.41	0.72	0.31	0.62	0.62	1.03
11.00	9.00	11.00	14.00	9.00	10.00	10.00	12.00	11.00	8.00	11.00	10.00
43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
7.70	8.90	7.80	8.10	8.80	9.00	7.20	8.50	9.00	7.20	8.60	7.40
0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00
4.00	2.00	5.00	4.00	2.00	12.50	1.00	1.00	4.00	2.00	1.00	2.00
55.98	68.76	60.33	71.10	56.52	50.81	59.84	53.98	66.76	65.96	70.45	59.25
58.37	73.42	66.10	69.44	58.30	59.97	60.84	54.71	71.39	68.62	71.03	60.84
62.98	78.78	70.03	76.50	64.25	62.53	67.87	59.82	73.75	71.52	74.48	67.09
390.79	279.02	339.75	272.69	479.33	451.66	359.08	465.51	291.25	296.79	202.26	385.63
349.95	241.67	244.98	303.91	477.91	175.83	348.45	515.56	224.84	269.19	198.63	385.88
201.66	152.03	158.52	176.31	306.05	131.19	225.57	315.88	155.52	186.39	140.79	251.95
82.10	85.06	81.78	88.12	83.52	63.33	88.80	92.15	83.54	84.55	84.57	82.97

APPENDIX 4A – TRAINING RESULTS FOR BRIGHTNESS

		Performance (mse)			Performance - regression				Independent test	
N.Net name	No. Neurons	Training set	Validation set	Test set	Training set	Validation set	Test set	Total R	Regression	mse
'Bright_ALL_5_1'	5	40.374	65.271	43.219	0.936	0.886	0.936	0.926	0.954	17.617
'Bright_ALL_8_4'	8	18.321	31.048	27.218	0.965	0.904	0.891	0.955	0.951	21.088
'Bright_ALL_9_4'	9	11.862	19.816	20.030	0.962	0.938	0.892	0.955	0.950	19.278
'Bright_ALL_5_4'	5	49.793	48.891	50.228	0.953	0.963	0.957	0.955	0.950	20.253
'Bright_ALL_10_3'	10	13.943	18.885	20.234	0.964	0.935	0.954	0.960	0.942	22.482
'Bright_ALL_1_4'	1	18.207	14.334	13.068	0.935	0.965	0.945	0.941	0.942	22.725
'Bright_ALL_4_3'	4	21.558	23.941	23.811	0.957	0.967	0.924	0.957	0.942	22.758
'Bright_ALL_1_1'	1	17.742	20.558	13.105	0.939	0.949	0.943	0.941	0.942	23.003
'Bright_ALL_5_2'	5	248.143	250.895	502.695	0.967	0.961	0.578	0.924	0.941	23.224
'Bright_ALL_2_2'	2	25.536	29.500	26.875	0.946	0.932	0.949	0.943	0.941	23.012
'Bright_ALL_2_4'	2	98.687	96.813	95.641	0.957	0.965	0.940	0.958	0.940	22.987
'Bright_ALL_6_1'	6	144.980	143.286	156.134	0.962	0.960	0.913	0.958	0.940	23.732
'Bright_ALL_8_1'	8	23.677	24.654	22.248	0.963	0.960	0.954	0.962	0.936	24.359
'Bright_ALL_4_2'	4	23.645	21.727	21.362	0.962	0.976	0.976	0.965	0.936	24.284
'Bright_ALL_1_2'	1	16.965	17.765	40.464	0.945	0.933	0.848	0.938	0.936	24.628
'Bright_ALL_9_2'	9	14.007	17.482	33.998	0.970	0.945	0.921	0.964	0.935	26.207
'Bright_ALL_8_3'	8	14.722	21.781	10.289	0.959	0.925	0.948	0.953	0.934	27.501
'Bright_ALL_7_1'	7	34.599	41.132	44.508	0.971	0.949	0.918	0.966	0.933	25.237
'Bright_ALL_6_4'	6	19.816	17.945	17.173	0.958	0.964	0.951	0.959	0.932	26.033
'Bright_ALL_2_1'	2	17.254	24.620	423.081	0.966	0.928	0.499	0.895	0.932	26.280
'Bright_ALL_7_3'	7	104.561	108.287	108.129	0.947	0.937	0.935	0.945	0.931	26.635
'Bright_ALL_4_1'	4	27.293	29.097	34.405	0.947	0.966	0.963	0.950	0.931	26.727
'Bright_ALL_10_2'	10	9.662	20.360	16.778	0.973	0.947	0.927	0.966	0.930	27.538
'Bright_ALL_7_4'	7	31.646	40.753	63.822	0.959	0.924	0.898	0.949	0.929	27.849
'Bright_ALL_3_2'	3	28.935	35.778	38.964	0.946	0.940	0.799	0.941	0.928	27.999
'Bright_ALL_6_3'	6	31.039	27.832	45.952	0.935	0.926	0.902	0.932	0.926	28.737

'Bright_ALL_5_3'	5	9.245	16.404	14.321	0.970	0.942	0.945	0.965	0.924	30.011
'Bright_ALL_2_3'	2	22.724	25.816	216.901	0.956	0.962	0.648	0.926	0.924	29.526
'Bright_ALL_9_3'	9	156.281	161.162	160.788	0.932	0.933	0.940	0.933	0.923	30.499
'Bright_ALL_3_4'	3	1015.092	1009.349	1026.306	0.928	0.946	0.907	0.929	0.920	30.546
'Bright_ALL_9_1'	9	30.152	28.029	39.516	0.949	0.956	0.926	0.949	0.919	31.370
'Bright_ALL_3_1'	3	49.237	44.533	47.920	0.932	0.949	0.963	0.935	0.919	32.369
'Bright_ALL_6_2'	6	49.838	52.822	58.538	0.974	0.938	0.920	0.969	0.918	31.304
'Bright_ALL_8_2'	8	5.638	22.874	20.446	0.983	0.901	0.898	0.971	0.917	33.477
'Bright_ALL_7_2'	7	19.628	30.409	32.737	0.973	0.940	0.935	0.966	0.914	32.447
'Bright_ALL_3_3'	3	20.365	31.030	17.340	0.961	0.920	0.970	0.955	0.909	35.623
'Bright_ALL_1_3'	1	26.363	37.966	31.400	0.932	0.843	0.920	0.920	0.909	36.402
'Bright_ALL_4_4'	4	49.637	55.410	51.156	0.964	0.931	0.958	0.959	0.902	38.392
'Bright_ALL_10_1'	10	12.515	14.282	17.292	0.964	0.952	0.863	0.960	0.901	38.379
'Bright_ALL_10_4'	10	207.905	228.106	216.102	0.979	0.919	0.925	0.967	0.901	39.247

Notes:

1) These networks were trained with all inputs.
2) The MATLAB performance function used was 'msereg’.
3) The training algorithm was ‘trainlm’.

APPENDIX 4B – TRAINING RESULTS FOR ERIC

		Performance (mse)			Performance - regression				Independent test	
N.Net name	**No. Neurons**	**Training set**	**Validation set**	**Test set**	**Training set**	**Validation set**	**Test set**	**Total R**	**Regression**	**mse**
'Eric_ALL_4_4'	4.000	2728	2857	1644	0.873	0.876	0.860	0.874	0.840	3781
'Eric_ALL_3_4'	3.000	3053	5346	4686	0.829	0.811	0.652	0.819	0.815	3965
'Eric_ALL_2_1'	2.000	3378	7279	5121	0.836	0.660	0.403	0.798	0.810	4371
'Eric_ALL_7_4'	7.000	3125	4103	4025	0.838	0.846	0.721	0.829	0.806	4155
'Eric_ALL_1_4'	1.000	5507	2536	2056	0.773	0.821	0.692	0.773	0.804	5235
'Eric_ALL_5_2'	5.000	3530	5096	2441	0.856	0.840	0.832	0.851	0.803	4146
'Eric_ALL_5_1'	5.000	2356	3014	2839	0.898	0.819	0.690	0.882	0.800	4678
'Eric_ALL_1_2'	1.000	2750	3781	3026	0.861	0.791	0.842	0.850	0.798	4289
'Eric_ALL_6_1'	6.000	10155	11424	8771	0.834	0.755	0.893	0.824	0.797	4385
'Eric_ALL_2_4'	2.000	8397	9455	11564	0.887	0.770	0.698	0.864	0.795	4458
'Eric_ALL_2_2'	2.000	3130	2400	9562	0.854	0.731	0.804	0.839	0.781	4736
'Eric_ALL_10_2'	10.000	15526	16503	16242	0.845	0.834	0.800	0.838	0.781	4623
'Eric_ALL_8_4'	8.000	1930	3147	2607	0.900	0.895	0.826	0.894	0.778	4591
'Eric_ALL_5_4'	5.000	5736	5564	4193	0.849	0.700	0.917	0.830	0.777	4643
'Eric_ALL_4_2'	4.000	2739	3665	5151	0.863	0.744	0.901	0.853	0.773	5124
'Eric_ALL_9_4'	9.000	4145	2790	3987	0.835	0.869	0.796	0.837	0.772	4744
'Eric_ALL_1_3'	1.000	3501	2623	6294	0.834	0.832	0.852	0.831	0.770	5034
'Eric_ALL_1_1'	1.000	2707	2805	10174	0.849	0.901	0.785	0.842	0.770	4989
'Eric_ALL_9_3'	9.000	2700	4310	1687	0.883	0.752	0.551	0.861	0.769	4882
'Eric_ALL_2_3'	2.000	3381	8100	1605	0.811	0.789	0.840	0.800	0.769	4787
'Eric_ALL_3_3'	3.000	2875	3588	3196	0.858	0.825	0.831	0.849	0.767	4823
'Eric_ALL_4_3'	4.000	3105	2693	3612	0.854	0.844	0.850	0.851	0.764	4953
'Eric_ALL_6_3'	6.000	3550	2826	2799	0.866	0.871	0.817	0.865	0.760	5085
'Eric_ALL_3_1'	3.000	2495	2600	3021	0.898	0.740	0.931	0.878	0.758	5181
'Eric_ALL_7_3'	7.000	1827	5002	4416	0.919	0.842	0.805	0.896	0.746	5431

'Eric_ALL_3_2'	3.000	3570	5195	3082	0.845	0.798	0.637	0.833	0.740	5295
'Eric_ALL_8_3'	8.000	3088	2177	5213	0.880	0.779	0.639	0.851	0.736	5419
'Eric_ALL_10_4'	10.000	6181	5222	7155	0.877	0.906	0.773	0.873	0.728	5506
'Eric_ALL_6_2'	6.000	2985	3225	3060	0.877	0.863	0.732	0.870	0.722	5732
'Eric_ALL_4_1'	4.000	8122	7920	9830	0.863	0.871	0.790	0.860	0.722	5739
'Eric_ALL_7_1'	7.000	2960	4328	2054	0.873	0.815	0.800	0.856	0.713	5750
'Eric_ALL_9_2'	9.000	5201	2784	3505	0.763	0.814	0.674	0.767	0.702	5949
'Eric_ALL_9_1'	9.000	5299	4767	4176	0.750	0.578	0.674	0.730	0.701	6357
'Eric_ALL_7_2'	7.000	2435	2637	4605	0.881	0.895	0.725	0.877	0.687	6455
'Eric_ALL_8_2'	8.000	2355	3830	6896	0.875	0.824	0.898	0.867	0.687	6470
'Eric_ALL_10_3'	10.000	2282	3872	5452	0.896	0.780	0.702	0.870	0.680	6942
'Eric_ALL_5_3'	5.000	12906	12014	12567	0.826	0.818	0.670	0.818	0.667	6704
'Eric_ALL_8_1'	8.000	4276	6618	4490	0.920	0.881	0.753	0.906	0.624	8295
'Eric_ALL_10_1'	10.000	10149	9473	6396	0.573	0.577	0.511	0.570	0.399	10236
'Eric_ALL_6_4'	6.000	112708	115802	105643	0.175	-0.154	0.659	0.136	0.033	105528

Notes:

1) These networks were trained with all inputs.
2) The MATLAB performance function used was 'msereg '.
3) The training algorithm was ‘trainlm’.

APPENDIX 4C – TRAINING RESULTS FOR YIELD

		Performance (mse)			Performance - regression				Independent test	
N.Net name	**No. Neurons**	**Training set**	**Validation set**	**Test set**	**Training set**	**Validation set**	**Test set**	**Total R**	**Regression**	**mse**
'Yield_all_3_3'	3.000	65.143	97.148	86.368	0.790	0.540	0.577	0.753	0.725	84.375
'Yield_all_5_2'	5.000	198.325	201.706	179.268	0.788	0.748	0.634	0.774	0.707	90.618
'Yield_all_10_4'	10.000	66.605	71.079	75.427	0.772	0.795	0.636	0.769	0.670	98.089
'Yield_all_7_3'	7.000	360.112	388.086	361.714	0.716	0.710	0.803	0.721	0.667	108.762
'Yield_all_1_4'	1.000	93.990	80.146	87.105	0.653	0.743	0.637	0.664	0.662	99.678
'Yield_all_5_3'	5.000	273.846	248.223	252.858	0.686	0.724	0.750	0.692	0.653	103.238
'Yield_all_1_2'	1.000	95.078	91.795	42.668	0.653	0.703	0.770	0.663	0.642	104.246
'Yield_all_1_3'	1.000	96.518	77.721	109.817	0.637	0.779	0.564	0.660	0.618	108.433
'Yield_all_8_3'	8.000	688.020	739.643	727.596	0.726	0.569	0.430	0.689	0.612	113.298
'Yield_all_5_1'	5.000	132.293	142.171	139.715	0.730	0.678	0.663	0.717	0.610	123.201
'Yield_all_2_4'	2.000	77.632	99.454	134.668	0.728	0.660	0.455	0.705	0.600	116.364
'Yield_all_6_1'	6.000	121.325	104.607	82.785	0.667	0.633	0.657	0.656	0.592	116.523
'Yield_all_8_2'	8.000	57.083	66.781	76.382	0.821	0.715	0.341	0.797	0.592	117.234
'Yield_all_3_1'	3.000	83.336	97.380	96.367	0.737	0.680	0.391	0.722	0.582	121.401
'Yield_all_9_3'	9.000	904.403	868.882	951.156	0.741	0.784	-0.129	0.724	0.579	133.865
'Yield_all_2_2'	2.000	129.959	134.592	119.168	0.740	0.716	0.633	0.732	0.573	125.972
'Yield_all_9_1'	9.000	243.550	233.445	212.470	0.609	0.624	0.757	0.619	0.560	121.096
'Yield_all_7_1'	7.000	322.241	374.623	322.287	0.703	0.503	0.460	0.663	0.546	125.619
'Yield_all_6_4'	6.000	111.784	113.214	96.978	0.754	0.748	0.801	0.754	0.546	141.490
'Yield_all_5_4'	5.000	100.589	139.504	129.790	0.720	0.513	0.551	0.680	0.534	125.291
'Yield_all_4_1'	4.000	137.695	126.173	165.527	0.696	0.764	0.607	0.702	0.527	151.019
'Yield_all_10_2'	10.000	413.659	425.551	497.974	0.689	0.498	0.201	0.645	0.526	138.974
'Yield_all_3_4'	3.000	68.905	83.157	61.285	0.761	0.749	0.607	0.753	0.526	146.740
'Yield_all_1_1'	1.000	91.793	94.379	136.564	0.681	0.640	0.133	0.658	0.514	149.990
'Yield_all_2_1'	2.000	113.356	121.969	252.268	0.696	0.626	0.125	0.661	0.510	154.254
'Yield_all_3_2'	3.000	235.511	219.907	214.708	0.644	0.590	0.576	0.638	0.508	138.835
'Yield_all_4_3'	4.000	231.049	288.906	265.286	0.713	0.605	0.684	0.692	0.492	159.236

'Yield_all_10_1'	10.000	134.003	188.829	146.976	0.640	0.522	0.482	0.612	0.486	142.589
'Yield_all_4_4'	4.000	290.906	293.864	277.011	0.468	0.419	0.494	0.462	0.482	145.304
'Yield_all_8_4'	8.000	208.256	210.409	275.212	0.609	0.574	0.060	0.581	0.482	137.286
'Yield_all_9_4'	9.000	78.501	121.025	161.478	0.729	0.474	0.605	0.685	0.476	161.971
'Yield_all_8_1'	8.000	255.334	287.573	260.884	0.782	0.572	0.746	0.753	0.460	170.600
'Yield_all_7_2'	7.000	137.943	165.387	178.800	0.660	0.545	0.395	0.629	0.443	142.696
'Yield_all_6_2'	6.000	91.086	135.170	149.873	0.747	0.587	0.418	0.711	0.418	209.665
'Yield_all_9_2'	9.000	232.227	213.111	263.337	0.545	0.614	0.317	0.542	0.400	154.080
'Yield_all_2_3'	2.000	164.892	156.057	240.515	0.420	0.534	0.190	0.427	0.373	194.730
'Yield_all_10_3'	10.000	2210.503	2246.136	2412.175	0.650	0.390	0.043	0.576	0.356	165.918
'Yield_all_4_2'	4.000	82.267	159.433	84.537	0.772	0.506	0.765	0.726	0.290	428.520
'Yield_all_7_4'	7.000	94.822	153.727	164.360	0.772	0.566	0.364	0.723	0.195	551.227
'Yield_all_6_3'	6.000	485.690	428.305	518.434	0.047	-0.002	-0.011	0.036	0.015	288.742

Notes:

1) These networks were trained with all inputs.
2) The MATLAB performance function used was 'msereg '.
3) The training algorithm was ‘trainlm’.

APPENDIX 5A: NEURAL NETWORK SENSITIVITY ANALYSIS - BRIGHTNESS

	All Grades: ONP:OMG:HL1:HL2::25:25:25:25									ONP:OMG::50:50									HL1:HL2::50:50									ONP 100%								
Neural network	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf
'Bright_ALL_5_1'	+-	O	+	+-	O	O	+-	+	+	-	+	-	-	+	-	O-	-	+	+	+	+-	+-	+	-	+-	+	+	-	+	O	-	+	-	+	-	-
'Bright_ALL_8_4'	-	+	+	+-	-	-	+	-	+	-	+	+	+-	-	O	-	-	+	+	+	+	+	-	-	-	O+	+	-	+	+	+	-	-	-	-	+
'Bright_ALL_9_4'	+	+	+	-	-	+-	-	+-	+-	-	+	+	O	-	-	-	-	+	+	O+	+	-	+	+-	-	+	O+	-	+	+	+	-	-	-	-	+
'Bright_ALL_5_4'	+-	+	+-	+-	-	-	+	+	+	+	+	+	O	-	+	-	-	+	+	+	+	-	-	+	-	+	O+	+-	O	+	+	-	-	-	-	+
'Bright_ALL_10_3'	+	+	+	+-	+	-	+-	+	+	+	+	+-	+-	+	-	+-	-	+	+	+	+	-	-	+	+-	+	+	+	+	+-	+-	+	-	-	-	+
'Bright_ALL_1_4'	+	+	+	-	+	-	-	+	+	+	+	+	-	O	-	-	+	+	+	+	+	-	O+	-	-	+	+	+	+	+	-	O+	-	-	+	+
'Bright_ALL_4_3'	+	O	+	O	O-	-	-	-	+	+	O	+	O	-	-	-	-	+	+	+	+	-	+	-	-	+	+	+	O	+	O	-	-	-	-	+
'Bright_ALL_1_1'	+	+	+	-	+	-	-	+	+	+	+	+	-	+	-	-	+	+	+	+	+	-	+	-	-	+	+	+	+	+	O-	O+	-	-	+	+
'Bright_ALL_2_2'	+	+	+	+-	+-	-	-	+	+	+	+	+-	+-	+-	-	-	+	+	+	+	+	+-	+-	-	-	+	+	+	+	+	O	+	-	O-	+	+
'Bright_ALL_2_4'	+	+	+	O	+	-	-	+	+	+	+	+	+	-	O-	-	O	+	+	+	+	O	+	-	-	+	+	+	+	+	+	-	-	-	O	+
'Bright_ALL_6_1'	+	+	+	-	-	O-	-	+	+	+	+	+	O	-	+-	-	-	+	+	+	+	O	+	-	-	+	+	+	+	+	+-	-	+	-	-	+
'Bright_ALL_8_1'	+	O+	+	+	+-	-	-	-	+	+-	+-	+	+-	-	-	-	+-	+	+	+	+	+	+-	-	+-	+	+	+-	+-	+	+	-	-	-	-	+
'Bright_ALL_4_2'	+	+	+	O	+-	-	+-	+-	+	+-	+	+	+	-	-	+-	+-	+	+-	+	+	-	+-	-	+-	+	O-	+-	+	+	O+	-	-	+-	+-	+
'Bright_ALL_9_2'	+	+-	+	+-	+	-	-	-	+	+	+-	+	+	-	-	-	-	+	+	+	+	+-	+	-	+	-	+-	+-	+-	+	+	-	-	-	-	+
Bright_ALL_7_1'	+	+	+	+	-	+-	-	+-	+	-	+	+	+	+-	+-	+-	+-	+	+	-	+	O	+	-	+-	+	+	+-	+	+	+	-	+-	-	-	+
Bright_ALL_6_4'	+	+-	+	O	+	+	+-	+-	+	+	+	+	+	+	-	-	O-	+	+-	+-	+	-	+-	-	+	+	+	+	+	+-	+-	+	-	-	-	+
Bright_ALL_7_3'	+	+	+-	+-	+	+-	-	+	+	-	+	+	+-	O	-	-	+	+	+	+	+	-	+	+	+	+	+-	-	+	+	+	O	-	+-	+-	+
Bright_ALL_10_2'	+-	-	+	+-	+	-	-	+-	+	+	-	+	+	+	-	-	-	+	-	-	+	+-	+	+-	+-	+-	+	+-	+-	+	+-	+	-	-	-	+
Bright_ALL_3_2'	+	+	+	-	+	-	-	+	+	O	+	+	-	+	-	-	-	+	+	O	+	-	+	-	+	+	+	-	+	+	-	O-	-	-	-	+
Bright_ALL_3_4'	+	+	+	-	+	-	-	+-	+-	+	+	+	-	+	-	O	+-	+	+	+	+	-	+	-	-	+	+	+	+	+	-	O	-	-	+	+
% Response																																				
% +	80	70	90	10	50	5	10	50	90	60	80	85	30	35	5	0	20	100	85	75	95	10	60	15	20	85	75	45	75	85	40	25	5	5	20	95
% -	5	5	0	30	25	70	70	20	0	25	5	5	25	45	75	75	50	0	5	10	0	55	15	75	50	5	0	25	0	0	20	50	90	80	65	5
% other	15	25	10	60	25	25	20	30	10	15	15	10	45	20	20	25	30	0	10	15	5	35	25	10	30	10	25	30	25	15	40	25	5	15	15	0

	OMG 100%									HL1 100%									HL2 100%								
Neural network	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf
'Bright_ALL_5_1'	+-	+	+-	+	+	-	+	-	+	+	+	+-	+	+	+-	+-	+	O	+	+	+-	+	+-	+	+	+	+-
'Bright_ALL_8_4'	-	+	+-	-	+	-	+	+	+	+	+	+	+	+-	-	-	-	+	+	+	+	+-	+	-	-	+	+
'Bright_ALL_9_4'	-	+	+	-	-	-	-	-	+	+	+	+	-	+	+-	-	+	+-	+	O	+	-	+	O	+-	+	+-
'Bright_ALL_5_4'	+	+	+	+	-	+	-	+	+	+	+	+-	+-	O	-	+	+	+	-	+	+-	-	-	+	-	+	+-
'Bright_ALL_10_3'	+-	+	+-	+-	+	-	+-	-	+-	+	+	+-	+-	+	-	+-	+-	+-	-	-	+	-	+	+	+	+	+-
'Bright_ALL_1_4'	+	+	+	-	O+	-	-	+	+	+	+	+	-	O+	-	-	+	+	+	+	+	-	O+	-	-	+	+
'Bright_ALL_4_3'	+	O	-	O+	-	-	-	-	+	+	+	-	-	+	-	-	+	-	+	+	-	-	+	-	-	+	+-
'Bright_ALL_1_1'	+	+	+	-	+	-	-	+	+	+	+	+	-	+	-	-	+	+	+	+	+	-	+	-	-	+	+
'Bright_ALL_2_2'	+	+	+	O+	O+	-	O-	+	+	+	+	+	O	O-	+	O	+	+	+	+	+	O	O+	-	O-	+	+
'Bright_ALL_2_4'	+	+	+	+	-	-	-	+	+	+	+	+	+	+	-	-	O	+	+	+	+	-	+	-	+	+	O-
'Bright_ALL_6_1'	+	+	+	O	-	-	-	-	+	+	+	+	+-	+	-	-	+	+	+	+	-	+-	+-	-	-	+	+
'Bright_ALL_8_1'	+-	+-	+	-	-	+-	-	+-	+	+	-	+	+-	+	+-	+-	+-	+	+	O	+	+	+	-	-	+-	+
'Bright_ALL_4_2'	-	+	+	O	+-	-	+-	+-	+	+	+	+	+	O-	+-	+-	+-	+	+	O+	+	-	+	+-	+-	+	-
'Bright_ALL_9_2'	+	O	+	+-	+	+	+	+	+	+	O	+	-	+	+	+	+	+	-	+	+-	+-	+	-	+-	-	-
Bright_ALL_7_1'	-	+	+	+	+-	+-	+-	+-	+	+	O-	+	O	+	-	+-	+-	+	+	O	+	-	+-	-	+	+-	+-
Bright_ALL_6_4'	+	+	+	+	+-	+-	-	-	+	+	O-	+	O	+	+-	+-	+	+	+	O	+	O	+	O	+	+-	+
Bright_ALL_7_3'	-	+	+	+-	O	-	-	-	+	+	+	+-	+	O	-	+-	+-	+	+	+	+	-	+	+-	+	+	+
Bright_ALL_10_2'	+	-	+	+-	-	-	+-	+-	+	+	+	+	-	+	+	+	+	+	+-	+-	+	-	O+	-	+-	+-	+
Bright_ALL_3_2'	+	+-	+	-	+	-	+-	+	+	+	+	+	-	+	-	+-	+	+	+	-	+	+	-	+	+	+	+-
Bright_ALL_3_4'	+	+	+	-	+	-	-	+-	+-	+	+	+	-	O	-	-	+	+	+	+	+	-	+	-	-	+-	+-
% Response																											
% +	60	75	80	25	35	10	15	40	90	100	80	75	25	65	15	15	65	80	80	60	75	15	60	20	35	70	45
% -	25	5	5	35	35	75	55	35	0	0	5	5	40	0	60	40	5	5	15	10	10	60	10	60	40	5	10
% other	15	20	15	40	30	15	30	25	10	0	15	20	35	35	25	45	30	15	5	30	15	25	30	20	25	25	45

APPENDIX 5B: NEURAL NETWORK SENSITIVITY ANALYSIS - ERIC

	All Grades: ONP:OMG:HL1:HL2::25:25:25:25									ONP:OMG::50:50									HL1:HL2::50:50									ONP 100%								
Neural network	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf
'Eric_ALL_4_4'	+-	-	+	-	-	+	+-	+-	-	-	-	+	-	+	+	+	-	-	+-	-	+	+-	-	+	+-	+	-	-	-	+	-	+	+	O+	-	-
'Eric_ALL_3_4'	-	-	+	-	O	+	+	-	-	-	+	+	-	O	+	+	-	-	-	+	+	-	O	+	+	-	-	-	O	+	-	O	+	+	-	-
'Eric_ALL_2_1'	-	-	+	-	+	+	+	O	-	-	-	+	-	+	+	+	O	-	-	-	+	-	+	+	+	o+	-	-	-	+	-	+	+	+	O	-
'Eric_ALL_7_4'	-	+	+	O+	+	+	+	-	-	-	-	+	-	+	+	+	-	-	-	+-	+	+-	+	+	+	-	-	-	-	+	-	+	+	+	-	-
'Eric_ALL_1_4'	-	-	+	+	+	+	O	-	-	-	-	+	+	+	+	O	-	-	-	-	+	+	+	+	O	-	-	-	-	+	+	+	+	O	-	-
'Eric_ALL_5_2'	-	+-	+	+-	+-	+	+	-	-	-	-	+	-	O	+	+	-	-	-	-	+-	+-	+-	+	+	+-	-	-	-	+	-	+	+	O	-	-
'Eric_ALL_5_1'	+-	+-	-	+	+-	+	+	+-	-	+-	+-	+	+-	+	+	+	+	-	+-	-	+-	+-	+	+	+	+-	-	-	-	+	-	+	+	+	+-	-
'Eric_ALL_1_2'	-	-	+	-	+	+	O+	-	-	-	-	+	-	+	+	+	-	-	-	-	+	-	+	+	O+	-	-	-	-	+	-	+	+	+	-	-
'Eric_ALL_6_1'	-	-	+	-	+	+	+	+	-	-	+	+	-	O+	+	+-	+-	-	+	-	+-	+-	+	+-	+	+	-	-	+	+	-	+	+	+	-	-
'Eric_ALL_2_4'	-	O	+	-	+	+	+	-	-	-	O	+	-	+	+	+	-	-	-	O	+	-	+	+	+	-	-	-	O	+	-	+	+	O	O	O
'Eric_ALL_10_2'	+-	+-	+	+-	+-	+	O	-	-	-	O	+	-	+	+	+	+	-	O	+	+-	+-	+-	+	O	O	+-	-	-	+	+-	+-	+-	+	-	-
Eric_ALL_8_4'	+-	-	+	+	-	+	+	+-	-	+-	-	+	-	-	+	+-	+-	-	-	+	+-	+-	-	+	+-	+-	-	-	-	+	-	+	+	O	-	-
'Eric_ALL_4_2'	-	+	+-	+-	+-	+-	+	O+	+-	-	+	+-	-	+-	+-	O+	O+	-	-	-	+	+	-	+-	-	-	+	+	+	+	-	+	+	O	-	-
'Eric_ALL_9_4'	-	-	+	+	+-	+	-	+-	-	-	-	+	+-	+	+	-	-	-	-	-	+	+	-	+	-	+-	-	-	-	+	+-	-	+	-	+-	-
'Eric_ALL_9_3'	O	+	+	-	+	+	+-	+-	-	-	+-	+	+-	+	+	+-	-	-	+-	+-	+-	-	+	+	+	+-	-	-	-	+	-	+	+	+	-	-
'Eric_ALL_2_3'	-	-	+	-	+	+	+	+	-	-	O	+	O-	+	+	+	+	-	-	O	+	O-	+	+	+	+	-	-	O	+	O-	+	+	+	+	-
Eric_ALL_3_3'	-	-	+	-	+	+	+	-	-	-	-	+	-	+	+	+	-	-	+	-	+	-	+	+	+	-	-	-	O-	+	-	+	+	+	-	-
Eric_ALL_6_3'	-	+	+-	+-	+-	+	+	+-	-	-	+-	+	-	+	+	+	-	-	-	+-	+	+-	+-	+	+	+	-	-	-	+	-	+	+	+	-	-
Eric_ALL_7_3'	-	+-	+	-	+-	+	+-	+-	-	-	+-	+	+-	-	+	+-	+-	-	-	+-	+	+-	-	+	+-	+-	-	-	+-	+	+-	-	+	+-	+-	-
Eric_ALL_8_3'	+-	-	+	+	-	+	+	+-	-	+-	-	+	-	-	+	-	+-	-	-	+	+-	+-	O-	+	-	+	-	-	-	+	-	+	+	O	-	-
% Response																																				
% +	0	20	85	25	45	95	65	10	0	0	15	95	5	65	95	60	15	0	10	20	65	15	50	90	55	25	5	5	10	100	5	80	95	55	5	0
% -	70	55	5	50	15	0	5	40	95	85	50	0	70	15	0	10	55	100	70	50	0	30	25	0	15	35	90	95	65	0	75	10	0	5	70	95
% other	30	25	10	25	40	5	30	50	5	15	35	5	25	20	5	30	30	0	20	30	35	55	25	10	30	40	5	0	25	0	20	10	5	40	25	5

	OMG 100%									HL1 100%									HL2 100%								
Neural network	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf f	tf
'Eric_ALL_4_4'	+	-	+	+-	-	+	+-	+	-	+	+-	+	+-	-	+	+-	+	-	-	-	+	+-	-	+	+-	-	-
'Eric_ALL_3_4'	-	O-	+	-	o	+	+	-	-	-	+	+	-	+	+	+-	-	-	-	o	+	-	o	+	+	-	-
'Eric_ALL_2_1'	-	-	+	-	+	+	+	o	-	-	-	+	-	+	+	+	o	-	-	-	+	-	+	+	+	o+	-
'Eric_ALL_7_4'	-	+	+	+	+	+-	+	-	-	-	+-	+	+	+	+	+	-	+-	-	-	+	-	+	+	+	-	-
'Eric_ALL_1_4'	-	-	+	+	+	+	o	-	-	-	-	+	+	+	+	o	-	-	-	-	+	+	+	+	o	-	-
'Eric_ALL_5_2'	-	+	+-	+	+-	+	o	+	-	-	+	+-	+	-	+	+	+	-	-	-	+	+-	+-	+	+	-	-
'Eric_ALL_5_1'	+	+	-	+	-	+-	+	+	-	+	+	-	-	+	+	+	+	-	+-	-	+-	+-	+-	+-	+	-	-
'Eric_ALL_1_2'	-	-	+	-	+	+	o+	-	-	-	-	+	-	+	+	+	-	-	-	-	+	-	+	+	+	-	-
'Eric_ALL_6_1'	O+	O-	+-	+	+	+-	+-	+-	-	+	-	-	+	+	-	+	+	-	+-	-	+	-	+	+	+-	+-	-
'Eric_ALL_2_4'	-	O	+	-	o+	+	o+	o-	-	-	o	+	-	+	+	o+	-	-	-	o	+	o-	+	+	o+	-	-
'Eric_ALL_10_2'	-	-	+-	-	o+	+-	-	o	-	+	+	+	+	-	+-	-	+	+	-	-	+	+-	+-	-	-	-	-
Eric_ALL_8_4'	-	+	+-	+-	-	+	-	+	-	-	+	+-	+-	-	+	-	o	+-	+-	+-	+	+-	+	+	+-	+-	-
'Eric_ALL_4_2'	-	+	-	-	+-	+-	+	+	-	-	+	-	-	+-	+-	+	+	-	-	o+	-	-	-	-	+	o+	-
'Eric_ALL_9_4'	+-	+	+	+	+-	+	+	+-	-	-	-	+	+	-	o+	-	+	-	-	-	+	+	+-	+	+-	+-	-
'Eric_ALL_9_3'	+-	+	-	o-	+	+-	+-	+-	-	+	+-	+-	-	+-	+-	+	+	-	-	+	+	-	+	+	-	+-	-
'Eric_ALL_2_3'	-	O	+-	+	-	+	+	+-	-	-	o	+	-	+	+	+	+	-	-	o	+	o-	o+	+	+	+	-
Eric_ALL_3_3'	-	-	+	-	+	+	+	-	-	-	-	+	-	+	+	+	-	-	+	o	+	-	-	+	+	+	-
Eric_ALL_6_3'	-	+	+-	+-	-	-	o-	+	-	+	-	+	+-	+	-	-	+	-	-	+-	+	-	+-	+	+-	+-	-
Eric_ALL_7_3'	-	+-	+	+-	-	+	+-	+-	-	-	+-	+	+-	-	+	+-	+-	-	-	+-	+	+-	-	+	+-	+-	-
Eric_ALL_8_3'	-	+	+-	+-	-	+	-	+	-	-	+	+-	+-	o-	+	-	o	+-	+-	+-	+	+-	+-	+	+-	+-	-
% Response																											
% +	10	45	50	35	35	65	40	35	0	30	35	65	30	55	70	50	50	5	5	5	90	10	40	85	45	10	0
% -	75	30	15	35	35	5	15	25	100	70	35	15	45	30	10	25	30	80	75	50	5	45	20	10	10	45	100
% other	15	25	35	30	30	30	45	40	0	0	30	20	25	15	20	25	20	15	20	45	5	45	40	5	45	45	0

APPENDIX 5C: NEURAL NETWORK SENSITIVITY ANALYSIS - YIELD

	All Grades: ONP:OMG:HL1:HL2::25:25:25:25									ONP:OMG::50:50									HL1:HL2::50:50									ONP 100%								
Neural network	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf
Yield_all_3_3	-	+	+	-	o+	+	+	-	-	+	+	+	-	o	+	+	-	-	-	+	o	-	+	+	+	-	-	-	+-	o	-	o	+	+	-	-
Yield_all_5_2	-	+	+	-	o+	+	+	+-	-	-	+	+	o	-	+	-	-	-	-	+-	+	-	+-	+-	+	+	-	-	o	+	+-	+-	+	+	+	-
Yield_all_10_4	+-	+-	+	+	+-	+	+	-	-	+-	+-	+	+	o	+	+-	+-	-	+	+-	+	+	+	+	+	-	-	-	+	+	+-	o	+	+_	-	-
Yield_all_7_3	+	+	+	+-	+-	+	+	-	-	+	+	+	o	o+	+	o+	-	-	-	+-	+-	+-	+	+-	+	+-	-	+	-	+-	o	o	+	+	o-	-
Yield_all_1_4	O-	+	+	-	o+	+	+	o+	-	-	+	+	-	o	+	+	o	-	-	+	+	-	o	+	+	o	-	-	+	+	-	o	+	+	o-	-
Yield_all_5_3	-	+	+	-	-	+-	+-	-	-	-	+	+	-	-	+-	+	-	-	-	o-	+	+-	+	+	+-	+-	-	-	+	+	-	+	+	+	-	-
Yield_all_1_2	-	+	+	-	o+	+	+	+	-	-	+	+	-	o	+	+	+	-	-	+	+	-	o	+	+	+	-	-	+	+	-	o	+	+	+	-
Yield_all_8_3	+-	+-	+-	+-	+-	+-	+-	+-	-	o-	+	+	-	+-	+-	+-	+-	-	+-	+-	+	o-	+	+	o+	+-	-	+	+	+	+-	-	+-	+-	+-	-
Yield_all_2_4	+-	+	+	+-	-	+	+	-	-	+-	+	+	+	+-	+	+	+-	-	+	+	+	-	-	+	+	-	-	o-	+	+	+	o+	+	+	+	+-
Yield_all_6_1	+-	+	+	-	o+	+	+	+-	-	o	+	+	-	o	+	+	+	-	+-	+	o+	o-	o	+	+	-	-	-	+	o+	-	+-	+	+	-	-
Yield_all_8_2	+	+-	+	+	+-	+	+	-	-	+	+-	+	o+	+-	+	+	+-	-	+	+	+	+-	+	+	+	+-	-	+	-	+	+	+	+	+	-	-
Yield_all_3_1	+-	+	+	+	o+	+	+	+-	-	+	+	+	+	o	+	+	-	-	-	+	+	-	-	+-	+	+	-	+	+	+	-	o	+	+	-	-
Yield_all_9_3	+-	+	+	-	+-	+	+	+-	-	+	o	+	+-	-	+	-	-	-	+-	+-	-	+-	-	+	+	+	o-	+	+-	-	-	+-	+	_	-	-
Yield_all_2_2	-	+	+	-	-	+	+	-	-	+-	+	+	-	o+	+	+	-	-	-	+	+	-	-	+	+	-	-	+	+-	+	+-	+	+	+	o-	-
Yield_all_9_1	-	+	+	+	+-	+	+-	+-	-	-	+	o+	+	+-	+	=-	+-	-	-	o+	+	+-	+-	+	+-	+-	-	-	-	+	+	+-	+-	+-	-	-
Yield_all_7_1	-	+	+-	-	+	+	+	+	-	-	+	+-	-	+	+	+	+	-	+-	+	-	-	+	+	+	+	-	-	+	-	-	+	+	+	o-	-
Yield_all_6_4	+-	-	+	+	+	+	+	+	-	+	+	-	+	+	+	+	-	-	+-	+-	+	+	+	+	+-	-	-	+-	+	+	+	+	+	+	-	-
Yield_all_4_1	+-	+	+	+-	+	+	+-	-	-	+	+	+	+	+	+	+	-	-	-	+-	o	-	+	+	+-	+-	-	+-	+-	o	-	+-	+	+	+	-
Yield_all_10_2	+-	+-	+	+	+-	+	+	-	-	+-	+	+	+	-	+	+-	+-	-	+	+-	+	+	+	+	+	-	-	-	+	+	+-	-	+-	+-	-	-
Yield_all_4_3	+	+	+	+-	+-	+	+	+-	-	+	+	+	+-	+	+	+	+-	-	+	+	+	+	+-	+	+-	-	-	-	+	+	+-	+-	+-	+-	-	-
% Response																																				
% +	15	75	90	30	15	90	80	15	0	40	85	85	35	20	90	65	15	0	25	50	70	20	50	85	70	25	0	30	60	70	20	25	80	70	20	0
% -	35	5	0	45	15	0	0	45	100	30	0	5	40	20	0	10	45	100	50	0	10	45	20	0	0	40	95	55	15	10	45	10	0	0	55	95
% other	50	20	10	25	70	10	20	40	0	30	15	10	25	60	10	25	40	0	25	50	20	35	30	15	30	35	5	15	25	20	35	65	20	30	25	5

Neural network	OMG 100%									HL1 100%									HL2 100%								
Yield_all_3_3	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf	NaOH	Ssil	H2O2	Surf p	tp	cons	pH	Surf F	tf
Yield_all_5_2	-	+	+	-	o	+	+	-	-	-	o-	+	-	+	-	+	-	+	-	+	+	-	o	+	+	-	-
Yield_all_10_4	-	+	+	-	0	+	+	-	-	-	o-	-	-	+	+	+	+	-	-	+	+	+-	o	+	+	+-	-
Yield_all_7_3	-	+	+	-	o-	o+	+	+-	-	-	o-	+-	+	o	+	+-	+	-	-	o+	+	+-	o-	+	+-	+	-
Yield_all_1_4	+	+	+-	+-	+	+-	+	-	-	-	+-	+-	+-	+	+	+	+-	-	-	+-	+-	+-	+-	+	+-	+-	-
Yield_all_5_3	-	+	+	-	o	+	+	o	-	-	+	+	-	o	+	+	o	-	-	+	+	-	o	+	+	o	-
Yield_all_1_2	-	+	+	-	-	+	+	-	-	-	o-	+	+-	+	+-	+-	+-	-	-	-	+	+-	o+	+-	+-	+-	-
Yield_all_8_3	-	+	+	-	o	+	+	+	-	-	+	+	-	o	+	+	+	-	-	+	+	-	o	+	+	+	-
Yield_all_2_4	-	+	+	-	+-	+-	+	+-	-	-	+-	+	o	+-	+-	+-	+-	-	-	+	+	-	+	+	+-	-	-
Yield_all_6_1	+	+	+	+-	-	+	+	-	-	o-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	+	-	-
Yield_all_8_2	o	+	+	o-	o	+	+	+	-	-	+-	+	+-	+	+-	+	-	-	o	+	+	-	o	+	+	+-	-
Yield_all_3_1	+-	-	+	o+	o	+	+	+-	-	+	o+	+	+	+	+	+	-	-	+	+-	+	+	+	+	+	-	-
Yield_all_9_3	+	+	+	+	o	+	+	-	-	+-	+-	+	+	o	+	+	+-	-	+-	+	+	-	o	+	+-	=-	-
Yield_all_2_2	+	+-	+-	+-	-	+	+	+-	-	+-	-	-	-	+-	+-	o	-	o-	+-	+-	-	+-	+-	+	+-	o	o-
Yield_all_9_1	-	+	+	-	-	+	o+	-	-	-	+	+	-	-	+	o	-	-	+	-	+	+	+	+	+-	o	-
Yield_all_7_1	-	+	o-	-	o+	+	+	+-	-	+-	+-	+	-	o	o	+	o+	o-	+	+	+-	+-	+-	+	+-	-	-
Yield_all_6_4	-	+	+	-	+	+	+	o	-	-	+	+-	-	+	+	+	+	-	+-	+-	+-	-	+	+-	+-	+	-
Yield_all_4_1	+-	+-	-	+	+	+	+	+-	+-	+-	+-	-	-	+	+	+-	-	-	-	-	+	+-	+-	+	+-	+	-
Yield_all_10_2	+	+	+	+	+	+	+	-	-	-	+	+	-	+	+	+-	-	-	-	+-	o	-	+-	+	+-	+-	-
Yield_all_4_3	-	+	+	-	-	+	+	+-	-	-	o	+-	+	o	+	+-	+	-	-	+	+	+-	-	+	+-	+	-
	+	+	+	-	+	+	+	+-	-	+	+	+	+-	+	+	+	-	-	-	+	+	+-	+-	+	-	-	-
% Response																											
% +																											
% -	30	85	80	15	25	85	95	10	0	10	35	65	25	55	70	60	30	10	20	55	75	10	20	90	35	25	0
% other	55	5	5	60	25	0	0	40	95	65	5	15	50	5	5	0	40	80	60	15	5	45	10	0	5	30	95
	15	10	15	25	50	15	5	50	5	25	60	20	25	40	25	40	30	10	20	30	20	45	70	10	60	45	5

APPENDIX 6A: FLOTATION ALIGNMENT NEWSPRINT

					Ratios		
	Flotation time (min)	%Bright - ness (B)	ERIC (E) ppm	%Flotation Yield (Y)	B/Bo	E/Eo	Y/Yo
Lab run 1	0	42.5	975	100	1.000	1.000	1.000
	2	48.0	655	91	1.129	0.671	0.909
	4	48.9	630	91	1.150	0.646	0.912
	8	57.7	226	69	1.357	0.232	0.686
	12	60.9	126	49	1.432	0.129	0.494
Lab run 2	0	40.1	797	100	1.000	1.000	1.000
	2	46.0	678	83	1.148	0.850	0.831
	4	50.8	409	79	1.267	0.513	0.786
	8	53.6	275	71	1.336	0.345	0.708
	12	55.3	210	70	1.380	0.264	0.701
Lab run 3	0	39.4	954	100	1.000	1.000	1.000
	2	51.4	486	91	1.304	0.510	0.908
	4	50.3	548	87	1.275	0.574	0.867
	8	56.9	252	79	1.443	0.264	0.791
	12	58.9	181	71	1.493	0.190	0.705

								Standard error		
					Average Ratios			B/Bo	E/Eo	Y/Yo
Lab averages	0	40.7	909	100	1.000	1.000	1.000	0.000	0.000	0.000
	2	48.5	606	88	1.194	0.677	0.883	0.055	0.098	0.026
	4	50.0	529	85	1.231	0.578	0.855	0.040	0.039	0.037
	8	56.1	251	73	1.379	0.280	0.728	0.032	0.033	0.032
	12	58.4	173	63	1.435	0.194	0.633	0.033	0.039	0.070

Plant averages	0	42.1	846	100.0	1.000	1.000	1	0	0	0
	3.1	52.7	269	89.0	1.253[1]	0.327[1]	0.89[1]	0.0037	0.0092	0.4900

Notes:

1. Calculated as the average of the ratios, not the ratio of averages.

APPENDIX 6B: FLOTATION ALIGNMENT - DOUBLE LOOP TISSUE

	Flotation time (min)	%Brightness (B)	ERIC (E) ppm	%Flotation Yield (Y)	B/Bo	E/Eo	Y/Yo
Lab run 1	**0**	82.6	105	100	1.000	1.000	1.000
	2	85.4	72	79	1.034	0.690	0.789
	6	85.6	67	82	1.036	0.639	0.819
	12	86.7	61	74	1.050	0.581	0.738
Lab run 2	0	74.6	283	100	1.000	1.000	1.000
	4	75.7	237	83	1.015	0.838	0.831
	12	77.9	139	75	1.045	0.490	0.751
Lab run 3	0	79.1	126	100	1.000	1.000	1.000
	2	82.3	89	91	1.040	0.706	0.908
	4	84.2	91	81	1.064	0.725	0.810
	8	85.2	79	79	1.076	0.625	0.786
	12	86.0	80	82	1.086	0.637	0.821
Lab run 4	0	77.3	154	100	1.000	1.000	1.000
	2	77.4	145	85	1.003	0.941	0.848
	8	80.2	115	74	1.038	0.746	0.735
	12	79.5	127	72	1.029	0.823	0.724
Lab run 5	0	76.6	141	100	1.000	1.000	1.000
	2	81.8	94	83	1.067	0.667	0.831
	4	85.6	69	77	1.117	0.485	0.772
	12	87.4	52	75	1.141	0.370	0.753
Lab run 6	0	82.0	118	100	1.000	1.000	1.000
	2	85.0	70	66	1.037	0.597	0.661
	4	88.0	70	70	1.073	0.591	0.698
	8	88.5	55	66	1.079	0.468	0.656
	12	88.6	52	62	1.080	0.440	0.623

								Standard error		
					Average Ratios			B/Bo	E/Eo	Y/Yo
Laboratory averages	0	78.7	155	100	1.00000	1.000	1.000	0.000	0.000	0.000
	2	82.4	94	81	1.03603	0.720	0.807	0.010	0.058	0.041
	4	83.4	117	78	1.06732	0.660	0.778	0.021	0.077	0.029
	6	85.6	67	82	1.03637	0.639	0.819			
	8	84.6	83	73	1.06464	0.613	0.726	0.013	0.081	0.038
	12	84.4	85	74	1.07194	0.557	0.735	0.016	0.066	0.026
Plant averages										
Medium grade 2	0	71.8	120	100.0	1.000	1.000	1.000	0	0	0
	0.9	79.7	92[2]	80.7	1.045[1]	0.767[2]	0.807[1]	0.0092	0.0614	0.807
High grade 2	0	75.6		100.0	1.000		1.000	0		0
	0.9	81.8		77.2	1.038[1]		0.772[1]	0.0123		0.772

Notes:

1. Calculated as the average of the ratios, not the ratio of averages.
2. Based on limited data.

APPENDIX 6C: FLOTATION ALIGNMENT SINGLE - LOOP TISSUE

	Flotation time (min)	%Brightness (B)	ERIC (E) ppm	%Flotation Yield (Y)	B/Bo	E/Eo	Y/Yo
Lab run 1	0	80.7	78	100	1.000	1.000	1.000
	2	80.5	58	78	0.997	0.743	0.777
	4	81.4	52	76	1.008	0.662	0.763
	8	81.5	47	72	1.009	0.603	0.716
	12	73.2	50	71	0.907	0.642	0.709
Lab run 2	0	83.7	131	100	1.000	1.000	1.000
	2	86.8	114	86	1.038	0.875	0.863
	4	88.4	83	75	1.057	0.632	0.751
	8	89.0	82	72	1.063	0.625	0.722
	12	86.4	86	71	1.032	0.660	0.706
Lab run 3	0	81.0	146	100	1.000	1.000	1.000
	2	80.0	145	83	0.989	0.996	0.827
	4	79.2	143	82	0.978	0.981	0.816
	12	80.0			0.988		
Lab run 4	0	85.3	123	100	1.000	1.000	1.000
	2	85.7	109	85	1.004	0.890	0.848
	12	87.1	74	77	1.021	0.601	0.770
Lab run 5	0	69.2	200	100	1.000	1.000	1.000
	2	74.0	139	80	1.069	0.697	0.802
	4	75.6	101	66	1.092	0.505	0.661
	8	75.6	88	65	1.092	0.439	0.653
	12	72.7	122	71	1.050	0.608	0.714
Lab run 6	0	77.3	132	100	1.000	1.000	1.000
	2	76.3	90	83	0.988	0.683	0.828
	4	81.3	83	80	1.053	0.628	0.800
	8	82.9	69	76	1.073	0.526	0.764
	12	83.8	64	71	1.085	0.488	0.707

								Standard error		
					Average Ratios			B/Bo	E/Eo	Y/Yo
Laboratory averages	0	79.5	135	100	1.000	1.000	1.000	0.000	0.000	0.000
	2	80.6	109	82	1.014	0.814	0.824	0.013	0.051	0.013
	4	81.2	92	76	1.038	0.681	0.758	0.020	0.080	0.027
	8	82.2	72	71	1.059	0.548	0.713	0.018	0.042	0.023
	12	80.5	79	72	1.014	0.600	0.722	0.025	0.030	0.012

Plant average[3]	0	71.1	151	100	1.000	1.000	1.000	0.000	0.000	0.000
	5.8	76.6	144[2]	71.4	1.082[1]	0.954[2]	0.714[1]	0.004	0.115	0.005

Notes:

1. Calculated as the average of the ratios, not the ratio of averages
2. Based on limited data, used ratio of averages.
3. For all grades

APPENDIX 7: PROCESSED PLANT DATA

																		BRIGHTNESS UV-included			ERIC			
Grade	ONP	OMG	HL1	HL2	NaOH (%)	Sodium silicate (%)	Hydrogen peroxide (%)	Surfactant in pulper (%)	Pulping Time(mins)	Pulping T (oC)	Estimated flotation Temp (oC)	Flotation consistency %	Flotation pH	Surfactant in flotation%	Adjusted flotation time (mins), Brightness	Adjusted Flotation time (mins), ERIC	Adjusted flotation time (mins), Yield	Pulper	Floated	Washed, before bleaching	Pulper	Floated	Washed, before bleaching	Estimated Flotation Yield
news	64.0	36.0	0.0	0.0	0.55	0.36	0.50	0.62	10.8	44	44	1.36	7.8	0.00	3.69	6.14	3.10	42.4	54.5	55.9	885	212	221	89
news	64.0	36.0	0.0	0.0	0.55	0.36	0.50	0.62	10.8	44	44	1.41	7.9	0.00	3.69	6.14	3.10	41.0	52.3	53.5	931	244	247	89
news	64.0	36.0	0.0	0.0	0.55	0.36	0.50	0.62	10.8	44	44	1.31	8.3	0.00	3.69	6.14	3.10	41.5	50.2	51.4	792	235	240	90
news	64.0	36.0	0.0	0.0	0.55	0.36	0.50	0.62	10.8	44	44	1.38	7.9	0.00	3.69	6.14	3.10	38.8	50.6	51.8	1034	242	245	84
news	64.0	36.0	0.0	0.0	0.55	0.36	0.50	0.62	10.8	44	44	1.33	8.2	0.00	3.69	6.14	3.10	37.6	48.0	49.1	1034	314	304	93
news	64.0	36.0	0.0	0.0	0.55	0.37	0.55	0.62	10.8	44	44	0.00	0.0	0.00	3.69	6.14	3.10	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.55	0.38	0.55	0.62	10.8	45	44	1.39	7.8	0.00	3.58	5.95	3.01	41.2	51.0	52.3	939	210	219	88
news	64.0	36.0	0.0	0.0	0.55	0.38	0.55	0.62	10.2	45	44	1.34	7.8	0.00	3.59	5.97	3.01	38.0	48.5	49.6	1053	276	273	90
news	64.0	36.0	0.0	0.0	0.54	0.38	0.55	0.62	10.2	45	44	1.42	7.9	0.00	3.75	6.24	3.15	39.9	51.2	52.4	864	215	223	90
news	64.0	36.0	0.0	0.0	0.53	0.38	0.53	0.62	9.8	45	44	1.52	7.9	0.00	3.75	6.25	3.15	38.2	48.8	49.9	1023	270	268	90
news	64.0	36.0	0.0	0.0	0.53	0.38	0.52	0.62	9.3	45	44	1.40	7.8	0.00	3.75	6.23	3.15	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.53	0.37	0.52	0.62	10.6	46	44	1.40	7.8	0.00	3.72	6.19	3.13	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.53	0.36	0.50	0.62	9.9	44	44	1.67	8.0	0.00	3.66	6.10	3.08	41.2	53.1	54.5	873	250	252	90
news	64.0	36.0	0.0	0.0	0.52	0.36	0.50	0.62	9.6	45	44	1.40	7.6	0.00	3.89	6.47	3.27	40.8	53.1	54.4	897	278	275	90
news	64.0	36.0	0.0	0.0	0.52	0.36	0.50	0.62	9.6	45	44	1.40	7.6	0.00	3.89	6.47	3.27	40.8	53.1	54.4	897	278	275	90
news	64.0	36.0	0.0	0.0	0.51	0.36	0.50	0.62	10.3	43	44	1.60	7.8	0.00	4.12	6.86	3.46	40.0	51.9	53.1	993	245	248	90
news	64.0	36.0	0.0	0.0	0.50	0.36	0.50	0.62	10.8	43	44	1.42	8.1	0.00	3.97	6.60	3.33	40.8	53.2	54.6	926	214	223	90
news	64.0	36.0	0.0	0.0	0.50	0.36	0.50	0.62	11.0	46	44	1.55	7.8	0.00	3.93	6.54	3.30	43.8	55.8	57.2	883	204	214	90
news	64.0	36.0	0.0	0.0	0.50	0.36	0.50	0.62	11.4	45	44	1.49	7.9	0.00	3.85	6.41	3.24	44.0	54.1	55.4	828	243	246	87
news	64.0	36.0	0.0	0.0	0.50	0.36	0.50	0.62	10.7	43	44	1.41	8.3	0.00	3.99	6.65	3.36	40.8	52.7	54.0	990	226	232	90
news	64.0	36.0	0.0	0.0	0.50	0.36	0.50	0.62	9.6	42	44	1.53	8.1	0.00	3.95	6.57	3.32	44.1	54.3	55.6	813	231	236	90
news	64.0	36.0	0.0	0.0	0.50	0.36	0.50	0.62	12.5	41	44	1.52	8.0	0.00	3.94	6.56	3.31	41.7	51.8	53.0	914	285	280	90
news	64.0	36.0	0.0	0.0	0.50	0.37	0.53	0.62	11.0	40	44	1.40	7.8	0.00	3.84	6.39	3.23	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.50	0.38	0.54	0.62	10.6	41	44	1.40	7.8	0.00	3.63	6.04	3.05	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.50	0.38	0.55	0.62	11.3	39	44	1.30	8.3	0.00	3.63	6.04	3.05	41.1	50.7	51.9	925	471	432	90
news	64.0	36.0	0.0	0.0	0.50	0.38	0.54	0.62	11.1	45	44	1.34	9.1	0.00	3.52	5.85	2.96	42.1	52.9	54.2	886	221	228	89
news	64.0	36.0	0.0	0.0	0.50	0.36	0.50	0.62	10.8	43	44	1.40	8.0	0.00	3.66	6.09	3.08	44.6	55.0	56.4	790	222	229	91
news	64.0	36.0	0.0	0.0	0.51	0.38	0.54	0.62	11.6	43	44	1.38	8.0	0.00	3.74	6.21	3.14	42.3	54.2	55.6	931	225	231	87
news	64.0	36.0	0.0	0.0	0.49	0.37	0.54	0.62	10.6	45	44	1.41	8.0	0.00	3.86	6.43	3.25	41.7	53.5	54.8	919	254	255	89
news	64.0	36.0	0.0	0.0	0.48	0.37	0.53	0.62	9.4	42	44	1.40	7.8	0.00	3.72	6.19	3.13	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.47	0.37	0.52	0.62	10.8	44	44	1.40	7.8	0.00	3.72	6.19	3.13	41.4	52.6	53.9	920	259	259	90

news	64.0	36.0	0.0	0.0	0.45	0.37	0.51	0.62	11.2	45	44	1.46	8.0	0.00	3.67	6.10	3.08	42.8	54.2	55.6	865	204	214	93
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.2	45	44	1.52	7.8	0.00	3.63	6.04	3.05	38.9	51.6	52.9	1043	247	250	89
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	7.9	44	44	1.46	8.0	0.00	3.74	6.23	3.14	43.5	53.3	54.6	818	240	244	74
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	9.9	42	44	1.45	8.2	0.00	3.74	6.22	3.14	39.4	51.2	52.5	969	291	285	89
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	9.9	44	44	1.38	8.2	0.00	3.63	6.04	3.05	43.0	55.1	56.5	866	225	231	88
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	9.7	43	44	1.40	7.8	0.00	3.64	6.06	3.06	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.6	44	44	1.40	7.8	0.00	3.65	6.08	3.07	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	9.6	45	44	1.44	7.8	0.00	3.69	6.15	3.10	42.4	52.4	53.7	882	302	294	87
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	8.9	45	44	1.48	8.0	0.00	3.56	5.92	2.99	41.6	53.3	54.6	847	229	235	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.0	45	44	1.44	7.7	0.00	3.46	5.76	2.91	42.0	53.2	54.5	911	254	255	95
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.2	45	44	1.40	7.6	0.00	3.60	5.99	3.03	41.0	50.1	51.3	1048	324	312	87
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	11.3	44	44	1.35	8.1	0.00	3.51	5.84	2.95	42.5	52.0	53.3	874	277	274	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	11.8	46	44	1.31	7.5	0.00	3.66	6.08	3.07	41.8	54.3	55.7	934	222	229	89
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.8	45	44	1.44	8.0	0.00	3.56	5.93	2.99	40.9	53.2	54.5	946	228	234	89
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.0	45	44	1.44	7.7	0.00	3.48	5.79	2.92	43.8	54.5	55.9	837	278	275	91
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	9.8	45	44	1.43	8.0	0.00	3.48	5.79	2.92	42.2	54.8	56.2	902	190	203	86
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	9.6	45	44	1.40	7.8	0.00	3.57	5.95	3.00	41.0	54.4	55.8	994	202	213	96
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.4	45	44	1.40	7.8	0.00	3.49	5.80	2.93	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.4	45	44	1.40	7.8	0.00	3.51	5.85	2.95	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.2	45	44	1.39	8.0	0.00	3.51	5.84	2.95	41.6	52.5	53.8	813	222	229	88
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.8	45	44	1.38	7.9	0.00	3.51	5.84	2.95	41.4	53.6	55.0	867	241	244	87
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	10.8	45	44	1.41	7.7	0.00	3.62	6.03	3.04	42.3	52.8	54.1	856	228	234	88
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.60	12.9	45	44	1.47	7.8	0.00	3.68	6.13	3.09	41.0	51.8	53.0	1003	294	288	80
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.59	11.7	45	44	1.53	7.7	0.00	3.90	6.48	3.27	38.8	49.9	51.1	1104	319	308	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.59	11.3	46	44	1.40	7.8	0.00	3.77	6.27	3.16	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.59	12.2	45	44	1.40	7.8	0.00	3.71	6.17	3.12	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	9.6	45	44	1.37	7.8	0.00	3.78	6.29	3.18	42.2	52.2	53.5	936	288	282	96
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	11.2	41	44	1.45	8.0	0.00	3.73	6.20	3.13	42.1	53.2	54.5	925	261	261	87
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.62	11.6	44	44	1.36	8.2	0.00	3.64	6.06	3.06	40.6	50.4	51.6	916	231	236	96
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	11.0	43	44	1.47	7.9	0.00	4.07	6.77	3.42	42.6	55.3	56.7	634	538	487	82
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	10.6	41	44	1.40	8.2	0.00	3.74	6.23	3.15	37.3	50.8	52.0	1168	278	275	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	10.6	45	44	1.40	7.8	0.00	3.62	6.03	3.05	41.4	52.6	53.9	920	259	259	89
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	10.2	45	44	1.45	7.9	0.00	3.59	5.98	3.02	43.7	54.2	55.6	920	259	259	93
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	11.3	45	44	1.46	7.7	0.00	3.69	6.14	3.10	42.8	54.0	55.4	959	280	276	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	11.7	45	44	1.53	7.8	0.00	3.65	6.07	3.06	40.1	51.5	52.7	1076	306	298	40
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	11.6	42	44	1.37	8.0	0.00	3.46	5.76	2.91	41.1	52.8	54.1	963	264	264	87
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	11.3	42	44	1.37	8.0	0.00	3.30	5.48	2.77	43.3	54.2	55.6	770	226	232	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	9.8	42	44	1.40	7.8	0.00	3.51	5.83	2.95	41.4	52.6	53.9	920	259	259	90
news	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	10.2	42	44	1.40	7.8	0.00	3.61	6.01	3.04	41.4	52.6	53.9	920	259	259	90
news trial	64.0	36.0	0.0	0.0	0.45	0.36	0.50	0.61	10.0	44	44	1.42	7.8	0.00	3.95	6.57	3.32	42.2	53.4	54.8	975	268	267	91
news trial	64.0	36.0	0.0	0.0	0.15	0.37	0.58	0.82	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	40.5	50.9	52.1	856	320	309	90
news trial	64.0	36.0	0.0	0.0	0.15	0.37	0.58	0.82	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	41.7	52.0	53.3	742	280	276	90
news trial	64.0	36.0	0.0	0.0	0.15	0.37	0.58	0.82	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	43.3	52.2	53.5	745	322	311	90
news trial	64.0	36.0	0.0	0.0	0.15	0.37	0.58	0.82	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	45.0	53.0	54.3	687	561	506	90
news trial	64.0	36.0	0.0	0.0	0.15	0.37	0.58	0.82	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.5	51.7	52.9	777	276	273	90
news trial	64.0	36.0	0.0	0.0	0.15	0.37	0.58	0.82	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.4	53.7	55.0	732	241	244	90

news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.5	52.3	53.6	794	197	209	90
news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.1	52.8	54.1	757	271	269	90
news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.6	52.5	53.8	647	250	252	90
news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	45.7	53.7	55.0	625	262	262	90
news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	41.5	52.3	53.6	827	285	280	90
news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	43.4	51.9	53.1	754	307	298	90
news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.9	51.9	53.2	661	312	302	90
news trial	64.0	36.0	0.0	0.0	0.16	0.64	0.54	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	43.3	50.2	51.4	734	372	351	90
news trial	64.0	36.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	40.6	52.2	53.5	882	286	281	90
news trial	64.0	36.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	40.1	52.4	53.7	882	281	277	90
news trial	60.0	40.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.0	51.2	52.4	709	334	321	90
news trial	60.0	40.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.0	50.8	52.1	738	313	303	90
news trial	60.0	40.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	41.1	50.2	51.4	902	350	334	90
news trial	60.0	40.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.1	52.2	53.4	646	289	284	90
news trial	60.0	40.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	43.9	52.1	53.4	727	242	245	90
news trial	60.0	40.0	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.7	53.6	54.9	727	255	256	90
news trial	55.6	44.4	0.0	0.0	0.16	0.37	0.56	0.74	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.2	53.3	54.6	592	248	250	90
news trial	55.6	44.4	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	43.7	51.9	53.1	641	309	300	90
news trial	55.6	44.4	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.3	53.2	54.5	741	267	266	90
news trial	55.6	44.4	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.2	53.7	55.0	690	251	252	90
news trial	55.6	44.4	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.6	53.0	54.3	731	255	256	90
news trial	51.0	49.0	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.6	54.9	56.3	677	299	292	90
news trial	51.0	49.0	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	41.9	55.0	56.4	807	269	267	90
news trial	51.0	49.0	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.7	55.0	56.4	747	279	275	90
news trial	51.0	49.0	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.0	55.9	57.4	702	211	220	90
news trial	51.0	49.0	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	45.8	56.5	57.9	681	195	207	90
news trial	51.0	49.0	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.8	54.7	56.1	683	234	239	90
news trial	51.0	49.0	0.0	0.0	0.15	0.38	0.54	0.72	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	43.3	51.9	53.2	773	293	287	90
news trial	46.0	54.0	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.8	54.3	55.7	696	287	282	90
news trial	46.0	54.0	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	45.7	53.6	55.0	608	280	276	90
news trial	46.0	54.0	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	41.4	53.2	54.5	766	291	285	90
news trial	40.2	59.8	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.3	52.0	53.3	769	268	267	90
news trial	40.2	59.8	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	45.4	54.3	55.7	608	261	261	90
news trial	40.2	59.8	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.9	54.0	55.3	716	283	278	90
news trial	40.2	59.8	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.1	53.3	54.6	710	291	285	90
news trial	40.2	59.8	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	44.3	53.0	54.3	679	254	255	90
news trial	40.2	59.8	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	43.4	52.9	54.2	732	265	264	90
news trial	40.2	59.8	0.0	0.0	0.18	0.59	0.56	0.76	11.7	46	46	1.42	7.6	0.00	3.59	5.98	3.02	42.6	53.2	54.5	703	387	364	90
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.9	N/A	80.9	N/A	N/A	79	77
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	71.2	N/A	79.7	N/A	N/A	79	83
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	73.6	N/A	81.7	N/A	N/A	79	76
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	67.2	N/A	76.5	N/A	N/A	79	77
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	69.9	N/A	82.1	N/A	N/A	79	84
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	71.6	N/A	73.7	N/A	N/A	79	72
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	75.6	N/A	79.3	N/A	N/A	79	70
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	80.4	N/A	82.7	N/A	N/A	79	88

MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	79.0	N/A	82.9	N/A	N/A	79	69
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	80.4	N/A	76.7	N/A	N/A	79	60
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	75.3	N/A	78.1	N/A	N/A	79	67
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	76.9	N/A	80.2	N/A	N/A	79	75
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.3	N/A	83.3	N/A	N/A	79	80
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.2	N/A	74.3	N/A	N/A	79	90
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	78.4	N/A	79.9	N/A	N/A	79	78
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	61.6	N/A	77.3	N/A	N/A	79	72
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	77.7	N/A	70.5	N/A	N/A	79	70
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	68.8	N/A	76.4	N/A	N/A	79	78
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	70.1	N/A	76.7	N/A	N/A	79	73
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	76.9	N/A	71.5	N/A	N/A	79	77
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	63.5	N/A	81.7	N/A	N/A	79	77
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	61.0	N/A	75.9	N/A	N/A	79	63
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	65.6	N/A	79.8	N/A	N/A	79	75
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.3	N/A	80.6	N/A	N/A	79	75
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	73.2	N/A	79.8	N/A	N/A	79	61
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	74.5	N/A	80.1	N/A	N/A	79	80
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	76.8	N/A	80.5	N/A	N/A	79	74
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	74.8	N/A	81.5	N/A	N/A	79	91
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	76.0	N/A	79.4	N/A	N/A	79	88
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	63.5	N/A	75.2	N/A	N/A	79	76
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	67.5	N/A	78.8	N/A	N/A	79	75
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	73.0	N/A	75.6	N/A	N/A	79	84
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	67.5	N/A	76.1	N/A	N/A	79	102
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	61.4	N/A	84.6	N/A	N/A	79	75
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	76.1	N/A	84.5	N/A	N/A	79	87
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	75.3	N/A	81.3	N/A	N/A	79	76
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	71.5	N/A	82.1	N/A	N/A	79	71
MG2	0.0	11.0	47.0	42.0	0.00	0.00	0.00	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.0	N/A	79.7	N/A	N/A	79	71
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	37	37	1.20	8.6	0.00	7.25	3.16	4.34	73.7	N/A	81.8	N/A	N/A	79	82
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.0	0.00	7.25	3.16	4.34	73.6	N/A	79.8	N/A	N/A	79	69
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.0	0.00	7.25	3.16	4.34	61.4	N/A	78.0	N/A	N/A	79	85
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	58.2	N/A	79.5	N/A	N/A	79	74
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	32	32	1.20	7.0	0.00	7.25	3.16	4.34	72.3	N/A	76.0	N/A	N/A	79	74
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.0	0.00	7.25	3.16	4.34	72.3	N/A	74.7	N/A	N/A	79	85
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.0	0.00	7.25	3.16	4.34	73.2	N/A	78.1	N/A	N/A	79	74
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.0	0.00	7.25	3.16	4.34	75.3	N/A	81.7	N/A	N/A	79	71
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	32	32	1.20	7.4	0.00	7.25	3.16	4.34	56.2	N/A	76.6	N/A	N/A	79	85
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	31	31	1.20	7.0	0.00	7.25	3.16	4.34	71.9	N/A	79.8	N/A	N/A	79	90
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.3	N/A	86.6	N/A	N/A	79	91
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.3	N/A	72.0	N/A	N/A	79	82
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	72.3	N/A	72.0	N/A	N/A	79	86
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	69.9	N/A	78.6	N/A	N/A	79	91
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	32	32	1.20	8.0	0.00	7.25	3.16	4.34	71.5	N/A	81.2	N/A	N/A	79	88
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	35	35	1.20	7.6	0.00	7.25	3.16	4.34	76.0	N/A	83.0	N/A	N/A	79	96

MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	74.8	N/A	76.1	N/A	N/A	79	74
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	36	36	1.20	8.4	0.00	7.25	3.16	4.34	72.3	N/A	79.8	N/A	N/A	79	103
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	65.1	N/A	81.9	N/A	N/A	79	87
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	72.3	N/A	79.8	N/A	N/A	79	93
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	7.0	0.00	7.25	3.16	4.34	60.5	N/A	84.5	N/A	N/A	79	106
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.8	0.00	7.25	3.16	4.34	79.8	N/A	79.8	N/A	N/A	79	125
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.3	0.00	7.25	3.16	4.34	72.3	N/A	79.8	N/A	N/A	79	89
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.9	0.00	7.25	3.16	4.34	71.9	N/A	85.4	N/A	N/A	79	90
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	7.0	0.00	7.25	3.16	4.34	72.3	N/A	81.2	N/A	N/A	79	101
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.2	0.00	7.25	3.16	4.34	72.3	N/A	79.8	N/A	N/A	79	83
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.4	0.00	7.25	3.16	4.34	71.1	N/A	79.6	N/A	N/A	79	83
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.9	0.00	7.25	3.16	4.34	72.3	N/A	83.5	N/A	N/A	79	88
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	31	31	1.20	7.9	0.00	7.25	3.16	4.34	77.8	N/A	85.8	N/A	N/A	79	79
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	74.9	N/A	80.4	N/A	N/A	79	77
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	8.1	0.00	7.25	3.16	4.34	63.6	N/A	80.0	N/A	N/A	79	68
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	63.1	N/A	79.1	N/A	N/A	79	80
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	8.0	0.00	7.25	3.16	4.34	76.0	N/A	80.1	N/A	N/A	79	71
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	8.0	0.00	7.25	3.16	4.34	72.6	N/A	82.1	N/A	N/A	79	77
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	34	34	1.20	7.7	0.00	7.25	3.16	4.34	72.3	N/A	79.2	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	32	32	1.20	7.8	0.00	7.25	3.16	4.34	69.2	N/A	79.5	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	30	30	1.20	7.0	0.00	7.25	3.16	4.34	76.7	N/A	77.3	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	78.3	N/A	86.7	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	70.3	N/A	79.7	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	33	33	1.20	7.4	0.00	7.25	3.16	4.34	78.2	N/A	82.4	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	35	35	1.75	7.0	0.00	7.25	3.16	4.34	73.3	N/A	82.1	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	37	37	1.00	7.0	0.00	5.86	2.56	3.50	76.6	N/A	87.0	N/A	N/A	79	81
MG2	0.0	11.0	47.0	42.0	0.10	0.00	0.90	0.62	14.0	33	35	1.28	7.0	0.00	5.75	2.51	3.44	77.9	N/A	84.3	N/A	N/A	79	81
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	80.8	N/A	89.6	N/A	N/A	79	77
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	80.9	N/A	78.1	N/A	N/A	79	79
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	77.2	N/A	80.5	N/A	N/A	79	83
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	74.4	N/A	75.2	N/A	N/A	79	71
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	73.2	N/A	79.8	N/A	N/A	79	75
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	71.2	N/A	76.3	N/A	N/A	79	60
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	77.4	N/A	81.8	N/A	N/A	79	85
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	82.1	N/A	83.6	N/A	N/A	79	77
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	63.4	N/A	86.4	N/A	N/A	79	75
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	77.2	N/A	87.0	N/A	N/A	79	79
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	80.9	N/A	85.2	N/A	N/A	79	85
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	73.6	N/A	84.0	N/A	N/A	79	78
HG2	0.0	0.0	67.0	33.0	0.00	0.00	0.00	0.62	16.0	34	34	1.20	7.4	0.00	7.25	3.16	4.34	77.2	N/A	79.8	N/A	N/A	79	72
HG2	0.0	0.0	67.0	33.0	0.10	0.00	0.90	0.62	16.0	30	30	1.20	7.0	0.00	7.25	3.16	4.34	72.3	N/A	79.8	N/A	N/A	79	76
HG2	0.0	0.0	67.0	33.0	0.10	0.00	0.90	0.62	16.0	34	34	1.20	7.8	0.00	7.25	3.16	4.34	72.6	N/A	80.3	N/A	N/A	79	87
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.4	77.7	79.7	N/A	N/A	88	70
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.6	82.2	83.1	N/A	N/A	88	68
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	86.9	89.1	N/A	N/A	88	71
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	79.2	78.7	85.0	N/A	N/A	88	77

VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	79.6	80.7	N/A	N/A	88	71
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	80.1	80.8	N/A	N/A	88	63
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	79.4	78.3	N/A	N/A	88	63
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.8	80.1	80.8	N/A	N/A	88	63
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	80.7	83.1	N/A	N/A	88	74
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	79.3	81.4	N/A	N/A	88	68
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	81.8	82.0	N/A	N/A	88	71
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.5	79.6	80.7	N/A	N/A	88	84
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	80.9	81.4	84.1	N/A	N/A	88	70
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.19	7.6	0.00	8.00	0.61	6.06	77.5	80.1	82.5	N/A	N/A	88	78
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.11	7.8	0.00	8.00	0.61	6.06	74.0	81.0	83.6	N/A	N/A	88	66
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.27	8.0	0.00	6.40	0.48	4.85	71.4	80.3	83.0	N/A	N/A	88	66
VHG1	0.0	0.0	100.0	0.0	0.00	0.00	0.00	0.25	18.0	60	48	1.22	7.4	0.00	6.40	0.48	4.85	77.7	83.9	86.4	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	2.08	8.3	0.00	6.40	0.48	4.85	68.7	75.6	78.5	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	67.4	74.0	76.7	N/A	N/A	88	73
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.8	77.9	81.9	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.4	78.9	80.2	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	71.3	75.4	79.6	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.9	77.9	81.3	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.0	80.4	85.5	N/A	N/A	88	68
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	72.4	77.3	79.0	N/A	N/A	88	63
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	70.0	78.8	81.9	N/A	N/A	88	73
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	66.8	74.2	78.9	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.8	79.0	82.1	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	69.1	75.2	78.2	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	72.0	75.6	78.6	N/A	N/A	88	76
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.3	78.1	81.6	N/A	N/A	88	76
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.4	82.2	82.4	N/A	N/A	88	66
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.0	77.0	79.2	N/A	N/A	88	68
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.4	81.5	82.9	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.6	77.4	77.8	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	79.4	80.5	81.2	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.3	79.9	82.4	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	72.5	77.6	79.0	N/A	N/A	88	65
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.2	73.7	78.0	N/A	N/A	88	65
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	71.1	79.3	81.8	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.2	77.6	84.6	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	69.9	78.5	81.8	N/A	N/A	88	84
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	72.6	79.0	79.5	N/A	N/A	88	84
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	67.6	77.5	81.4	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	65.2	66.9	69.2	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.1	76.8	79.1	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.3	75.6	77.5	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.4	78.3	81.0	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.5	77.1	79.4	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.2	74.7	78.3	N/A	N/A	88	71

MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	78.5	80.4	81.5	N/A	N/A	88	80
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.8	77.7	81.1	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	74.4	79.2	80.0	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	74.3	77.3	81.0	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	74.7	77.8	83.1	N/A	N/A	88	68
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.3	81.3	81.6	N/A	N/A	88	78
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.9	76.9	79.1	N/A	N/A	88	78
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	68.4	76.6	80.6	N/A	N/A	88	78
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	68.9	78.1	79.8	N/A	N/A	88	77
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	69.8	78.0	79.5	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	80.1	80.4	81.6	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	80.4	81.0	81.7	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.3	80.8	82.3	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.3	82.6	83.1	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	74.4	77.8	82.4	N/A	N/A	88	64
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.6	75.1	77.5	N/A	N/A	88	79
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.4	77.2	80.4	N/A	N/A	88	84
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	75.5	80.1	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	84.4	87.1	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	78.1	78.6	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	78.9	81.8	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	78.0	83.9	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	84.3	84.4	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	75.3	79.2	N/A	N/A	88	76
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	78.9	85.7	N/A	N/A	88	76
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	84.2	85.0	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	84.2	85.0	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	85.7	86.4	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	81.3	82.1	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	77.0	81.8	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	80.0	80.2	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	77.8	82.8	N/A	N/A	88	78
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	83.6	85.7	N/A	N/A	88	78
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	69.2	75.1	N/A	N/A	88	78
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	79.2	84.4	N/A	N/A	88	83
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	81.5	81.8	N/A	N/A	88	83
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	79.4	82.7	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	77.6	82.3	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	83.0	83.8	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	81.6	84.2	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	76.0	77.8	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	81.2	82.8	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	78.7	85.5	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	79.2	82.5	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	77.8	84.3	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	75.6	79.9	N/A	N/A	88	70

MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	79.3	81.4	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	77.0	78.0	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	79.8	81.4	85.6	N/A	N/A	88	68
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	81.4	85.7	N/A	N/A	88	68
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	80.2	86.3	N/A	N/A	88	80
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	80.4	82.7	N/A	N/A	88	80
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	78.3	77.8	82.7	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	79.2	84.3	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.7	76.8	83.3	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.3	76.8	83.3	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.1	77.5	80.3	N/A	N/A	88	97
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	80.9	81.4	84.1	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.0	77.4	80.1	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.7	79.7	82.4	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	68.2	77.6	79.1	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.9	79.6	79.8	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	71.2	74.1	76.3	N/A	N/A	88	62
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.52	7.9	0.00	8.00	0.61	6.06	71.2	73.6	76.6	N/A	N/A	88	64
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.28	6.8	0.00	8.00	0.61	6.06	72.1	79.7	82.4	N/A	N/A	88	63
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.78	7.4	0.00	8.00	0.61	6.06	72.5	80.6	83.2	N/A	N/A	88	62
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.10	7.8	0.00	8.00	0.61	6.06	76.1	81.7	84.3	N/A	N/A	88	60
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.99	7.7	0.00	8.00	0.61	6.06	70.9	82.1	84.6	N/A	N/A	88	59
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.95	7.7	0.00	8.00	0.61	6.06	66.6	81.9	84.4	N/A	N/A	88	80
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.18	7.6	0.00	8.00	0.61	6.06	74.0	80.4	83.1	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.90	7.6	0.00	8.00	0.61	6.06	73.0	80.1	82.8	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.42	7.6	0.00	8.00	0.61	6.06	70.7	79.0	81.7	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.24	7.4	0.00	8.00	0.61	6.06	78.1	82.2	84.7	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.61	7.7	0.00	8.00	0.61	6.06	71.5	78.5	81.3	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.01	7.8	0.00	8.00	0.61	6.06	75.8	81.6	84.2	N/A	N/A	88	74
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.93	7.8	0.00	8.00	0.61	6.06	74.5	77.3	80.1	N/A	N/A	88	66
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.28	7.6	0.00	8.00	0.61	6.06	69.1	79.7	82.4	N/A	N/A	88	66
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.53	7.8	0.00	8.00	0.61	6.06	78.7	84.0	86.5	N/A	N/A	88	86
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.95	7.7	0.00	8.00	0.61	6.06	65.8	80.9	83.5	N/A	N/A	88	50
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	71.4	78.7	81.4	N/A	N/A	88	81
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.49	7.6	0.00	8.00	0.61	6.06	72.4	79.2	81.9	N/A	N/A	88	69
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.99	7.7	0.00	8.00	0.61	6.06	72.9	86.9	89.2	N/A	N/A	88	73
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.96	7.5	0.00	8.00	0.61	6.06	70.1	82.3	84.9	N/A	N/A	88	77
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.88	7.3	0.00	8.00	0.61	6.06	73.3	81.9	84.5	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.05	7.5	0.00	8.00	0.61	6.06	71.9	80.5	83.1	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.17	7.6	0.00	8.00	0.61	6.06	74.0	83.5	86.0	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.98	7.8	0.00	8.00	0.61	6.06	72.7	78.9	81.6	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.92	8.2	0.00	8.00	0.61	6.06	74.3	80.1	82.8	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.56	7.6	0.00	8.00	0.61	6.06	73.1	78.0	80.8	N/A	N/A	88	94
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.72	7.6	0.00	6.40	0.49	4.85	71.2	79.7	82.4	N/A	N/A	88	54
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.37	8.0	0.00	6.40	0.49	4.85	73.8	82.7	85.2	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.30	7.5	0.00	6.40	0.49	4.85	68.1	78.6	81.4	N/A	N/A	88	71

MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.97	7.3	0.00	6.40	0.49	4.85	72.3	78.6	81.4	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.13	7.6	0.00	6.40	0.49	4.85	71.7	78.4	81.1	N/A	N/A	88	70
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.20	7.6	0.00	6.40	0.49	4.85	73.8	80.2	82.8	N/A	N/A	88	66
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.08	7.6	0.00	6.40	0.49	4.85	72.4	77.6	80.4	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.34	7.6	0.00	6.40	0.49	4.85	72.8	82.1	84.6	N/A	N/A	88	78
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.22	7.8	0.00	6.40	0.49	4.85	72.3	84.2	86.7	N/A	N/A	88	72
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.29	7.4	0.00	6.40	0.49	4.85	75.4	83.0	85.5	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.05	7.6	0.00	6.40	0.48	4.85	74.6	81.2	83.8	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.16	7.6	0.00	6.40	0.48	4.85	73.2	82.8	85.4	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.06	7.5	0.00	6.40	0.48	4.85	72.2	82.4	85.0	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.25	7.8	0.00	6.40	0.48	4.85	74.4	82.7	85.3	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.35	7.6	0.00	6.40	0.48	4.85	75.1	82.1	84.7	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	0.98	7.4	0.00	6.40	0.48	4.85	70.0	78.8	81.5	N/A	N/A	88	75
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.16	7.4	0.00	6.40	0.48	4.85	71.1	79.6	82.3	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.25	7.5	0.00	6.40	0.48	4.85	67.9	74.4	77.4	N/A	N/A	88	71
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.04	7.2	0.00	6.40	0.48	4.85	77.5	81.5	84.1	N/A	N/A	88	61
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.70	7.9	0.00	6.40	0.48	4.85	70.4	73.8	76.9	N/A	N/A	88	68
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.07	7.6	0.00	6.40	0.48	4.85	74.7	78.6	81.3	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.87	7.4	0.00	6.40	0.48	4.85	67.1	71.1	74.3	N/A	N/A	88	67
MG1	0.0	15.0	42.5	42.5	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	6.40	0.48	4.85	69.8	79.9	82.6	N/A	N/A	88	75
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	52.8	57.7	60.8	N/A	N/A	88	76
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	49.2	53.2	58.5	N/A	N/A	88	71
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	42.2	42.7	58.8	N/A	N/A	88	71
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	51.7	60.3	59.5	N/A	N/A	88	70
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	51.4	53.1	53.7	N/A	N/A	88	82
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	56.2	63.1	64.8	N/A	N/A	88	82
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	60.2	62.2	66.4	N/A	N/A	88	82
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	52.8	50.7	52.5	N/A	N/A	88	70
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	52.8	63.8	65.6	N/A	N/A	88	71
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	48.1	52.6	57.3	N/A	N/A	88	83
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	61.9	63.2	70.3	N/A	N/A	88	77
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	54.6	55.8	60.7	N/A	N/A	88	77
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	0.86	7.7	0.00	8.00	0.61	6.06	50.4	59.5	63.3	N/A	N/A	88	80
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.30	7.5	0.00	6.40	0.48	4.85	49.1	63.7	67.2	N/A	N/A	88	88
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	0.88	8.5	0.00	6.40	0.48	4.85	50.3	54.1	58.2	N/A	N/A	88	75
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	0.85	7.8	0.00	6.40	0.48	4.85	53.9	68.9	72.2	N/A	N/A	88	73
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.65	8.3	0.00	6.40	0.48	4.85	55.0	58.6	62.5	N/A	N/A	88	69
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.9	0.00	6.40	0.48	4.85	49.9	54.1	58.2	N/A	N/A	88	56
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.0	0.00	6.40	0.48	4.85	49.5	53.6	57.7	N/A	N/A	88	57
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.9	0.00	6.40	0.48	4.85	47.1	53.1	57.3	N/A	N/A	88	60
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.94	7.6	0.00	6.40	0.48	4.85	42.8	47.5	52.0	N/A	N/A	88	63
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.10	7.7	0.00	6.40	0.48	4.85	50.9	56.4	60.4	N/A	N/A	88	62
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	0.88	8.3	0.00	6.40	0.48	4.85	43.3	54.1	58.2	N/A	N/A	88	71
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.35	7.8	0.00	6.40	0.48	4.85	37.9	46.6	51.1	N/A	N/A	88	74
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.5	0.00	6.40	0.48	4.85	35.3	45.2	49.7	N/A	N/A	88	41
LG1	30.0	30.0	20.0	20.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.5	0.00	6.40	0.48	4.85	35.3	45.2	49.7	N/A	N/A	88	41

HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.2	84.0	87.9	N/A	N/A	88	76
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	68.2	76.8	81.9	N/A	N/A	88	77
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.2	79.6	84.8	N/A	N/A	88	77
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.4	79.4	81.4	N/A	N/A	88	69
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	82.0	86.0	89.8	N/A	N/A	88	69
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.6	79.7	82.2	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.3	78.8	88.3	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	79.8	85.7	86.1	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.2	80.2	87.0	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	80.3	83.3	84.4	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	77.9	86.4	85.4	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	69.5	77.4	79.4	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.8	80.2	84.2	N/A	N/A	88	81
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.5	76.8	78.2	N/A	N/A	88	74
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.5	81.8	82.0	N/A	N/A	88	68
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.5	80.2	88.7	N/A	N/A	88	70
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.5	77.6	79.8	N/A	N/A	88	74
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.5	77.6	80.8	N/A	N/A	88	74
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	75.5	76.9	80.0	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	74.2	77.8	86.7	N/A	N/A	88	72
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	76.5	82.2	84.7	N/A	N/A	88	76
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.21	7.6	0.00	8.00	0.61	6.06	73.8	78.6	80.0	N/A	N/A	88	69
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.29	7.8	0.00	8.00	0.61	6.06	71.1	80.2	82.9	N/A	N/A	88	67
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.09	7.8	0.00	8.00	0.61	6.06	65.0	80.2	82.9	N/A	N/A	88	66
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.12	7.8	0.00	6.40	0.49	4.85	70.9	79.0	81.8	N/A	N/A	88	72
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.26	7.6	0.00	6.40	0.49	4.85	74.0	79.1	81.8	N/A	N/A	88	67
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.49	7.6	0.00	6.40	0.49	4.85	78.5	86.0	88.3	N/A	N/A	88	75
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.16	7.6	0.00	6.40	0.48	4.85	72.5	79.2	81.9	N/A	N/A	88	63
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	0.98	7.6	0.00	6.40	0.48	4.85	72.2	82.4	84.9	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.18	8.1	0.00	6.40	0.48	4.85	73.6	79.1	81.9	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.54	7.8	0.00	6.40	0.48	4.85	77.8	80.1	82.8	N/A	N/A	88	74
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.50	7.3	0.00	6.40	0.48	4.85	77.2	80.1	82.7	N/A	N/A	88	68
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	0.92	7.3	0.00	6.40	0.48	4.85	76.3	81.0	83.6	N/A	N/A	88	69
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.88	7.4	0.00	6.40	0.48	4.85	72.1	75.5	78.5	N/A	N/A	88	74
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.35	7.8	0.00	6.40	0.48	4.85	70.9	79.3	82.1	N/A	N/A	88	74
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.19	7.7	0.00	6.40	0.48	4.85	67.9	79.3	82.0	N/A	N/A	88	71
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.20	7.2	0.00	6.40	0.48	4.85	72.9	78.5	81.3	N/A	N/A	88	74
HG1	0.0	0.0	50.0	50.0	0.00	0.00	0.00	0.25	18.0	60	48	1.56	7.5	0.00	6.40	0.48	4.85	73.1	80.0	82.7	N/A	N/A	88	68

APPENDIX 8A(i): PERFORMANCE OF NEURAL NETWORKS FOR THE PREDICTION OF BRIGHTNESS

	Name of Neural Net	No. neurons	Training performance	Validation performance	Test performance	Training R	Validation R	Test R	Total R	Correlation with plant data	MSE against plant data
Neural network variables: reduced set of 10 variables	'Bright_FinalA_20_2'	20	5477	1166	1100	0.952	0.954	0.946	0.951	0.922	53.5
	'Bright_FinalA_5_1'	5	5292	1031	833	0.954	0.963	0.928	0.954	0.912	57.2
	'Bright_FinalA_1_3'	1	6933	1428	977	0.942	0.923	0.942	0.939	0.920	59.4
	'Bright_FinalA_1_2'	1	6604	1220	1434	0.946	0.930	0.911	0.939	0.913	64.8
	'Bright_FinalA_1_4'	1	6905	1511	883	0.939	0.944	0.939	0.939	0.917	66.9
	'Bright_FinalA_1_1'	1	6936	997	1386	0.942	0.951	0.904	0.939	0.914	69.9
	'Bright_FinalA_11_3'	11	5191	1044	741	0.956	0.953	0.951	0.955	0.910	72.1
	'Bright_FinalA_14_4'	14	4564	1544	1174	0.960	0.934	0.939	0.954	0.902	74.8
	'Bright_FinalA_3_4'	3	5201	740	739	0.952	0.974	0.961	0.957	0.896	76.7
	'Bright_FinalA_3_3'	3	5046	1018	677	0.955	0.962	0.956	0.957	0.892	76.8
Neural network variables: full set of 15 variables	'Bright_FinalB_16_2'	16	5845	992	601	0.950	0.966	0.957	0.954	0.940	26.0
	'Bright_FinalB_13_2'	13	5282	1243	528	0.954	0.944	0.968	0.954	0.933	33.5
	'Bright_FinalB_9_2'	9	5553	1088	1028	0.953	0.949	0.949	0.952	0.937	34.8
	'Bright_FinalB_3_3'	3	5152	1662	813	0.957	0.930	0.944	0.952	0.933	35.0
	'Bright_FinalB_18_2'	18	4815	1060	1201	0.959	0.948	0.930	0.954	0.920	39.8
	'Bright_FinalB_20_2'	20	5018	1294	1147	0.961	0.944	0.940	0.956	0.929	40.1
	'Bright_FinalB_13_4'	13	6887	2207	859	0.943	0.872	0.953	0.936	0.945	46.1
	'Bright_FinalB_14_3'	14	4439	1351	785	0.961	0.950	0.952	0.958	0.909	46.8
	'Bright_FinalB_3_2'	3	5565	1103	748	0.952	0.949	0.957	0.952	0.924	47.0
	'Bright_FinalB_11_3'	11	4914	1138	693	0.962	0.949	0.896	0.957	0.927	47.5

Notes: 1	Reduced set of 10 variables:	ONP,OMG, HL1, HL2, NaOH, Sodium silicate, hydrogen peroxide, flotation consistency, flotation pH and flotation time
2	Full set of 15 variables:	ONP,OMG, HL1, HL2, NaOH, sodium silicate, hydrogen peroxide, surfactant addition to pulper and float cell, pulping time and pulping temperature, flotation time, flotation consistency, flotation temperature and flotation pH

APPENDIX 8A(ii): MEAN PREDICTED BRIGHTNESS OF NEURAL NETWORKS COMPARED TO PLANT BRIGHTNESS, BY PAPER GRADE

		Newsprint Trial		Newsprint		Double-loop, medium grade		Double-loop, high grade		Single-loop. Very high grade		Single-loop, medium grade		Single-loop, low grade		Single-loop, high grade	
		Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error
	Plant output	54.6	0.291	53.8	0.164	79.7	0.384	81.8	1.054	82.6	0.631	81.8	0.237	59.9	1.152	82.4	0.978
Neural network variables: reduced set of 10 variables	'Bright_FinalA_20_2'	53.8	0.206	52.5	1.015	74.0	0.043	80.4	0.078	89.2	0.057	72.2	0.044	57.8	0.163	75.4	0.479
	'Bright_FinalA_5_1'	53.3	0.203	52.1	0.784	74.1	0.069	81.0	0.121	91.0	0.069	71.7	0.062	56.9	0.170	75.6	0.509
	'Bright_FinalA_1_3'	53.0	0.136	52.1	0.241	73.8	0.087	79.1	0.153	88.9	0.075	71.8	0.063	58.9	0.114	73.6	0.411
	'Bright_FinalA_1_2'	53.0	0.134	52.2	0.185	73.3	0.086	78.8	0.155	89.3	0.074	71.3	0.058	58.6	0.102	73.1	0.404
	'Bright_FinalA_1_4'	52.0	0.130	51.2	0.238	73.1	0.082	78.9	0.136	89.2	0.079	71.2	0.078	58.2	0.147	73.1	0.428
	'Bright_FinalA_1_1'	52.6	0.126	51.8	0.154	72.7	0.073	78.4	0.129	88.8	0.071	70.9	0.054	58.4	0.102	72.9	0.401
	'Bright_FinalA_11_3'	51.9	0.202	50.8	1.037	72.8	0.066	79.3	0.126	90.5	0.062	70.7	0.043	56.7	0.109	73.8	0.464
	'Bright_FinalA_14_4'	53.4	0.203	52.0	0.589	72.4	0.073	79.1	0.111	89.3	0.078	70.1	0.050	57.3	0.182	74.5	0.479
	'Bright_FinalA_3_4'	53.1	0.204	51.9	0.929	72.5	0.079	79.6	0.144	90.5	0.062	69.9	0.043	56.4	0.169	74.1	0.474
	'Bright_FinalA_3_3'	53.2	0.228	51.9	0.956	72.6	0.074	79.9	0.130	91.1	0.066	69.9	0.054	56.7	0.217	74.2	0.469
	Plant output	54.6	0.291	53.8	0.164	79.7	0.384	81.8	1.054	82.6	0.631	81.8	0.237	59.9	1.152	82.4	0.978
Neural network variables: full set of 15 variables	'Bright_FinalB_16_2'	53.0	0.202	51.8	0.924	75.0	0.086	80.6	0.133	93.9	0.064	77.6	0.058	60.3	0.195	80.8	0.552
	'Bright_FinalB_13_2'	52.1	0.204	51.1	1.306	73.4	0.038	80.9	0.053	94.4	0.042	76.8	0.011	58.2	0.127	80.9	0.602
	'Bright_FinalB_9_2'	52.0	0.195	51.0	0.954	74.2	0.079	80.3	0.129	92.2	0.054	75.7	0.033	60.2	0.153	78.7	0.494
	'Bright_FinalB_3_3'	53.7	0.207	52.4	0.858	75.8	0.071	82.2	0.092	91.3	0.058	74.6	0.093	59.0	0.250	78.2	0.546
	'Bright_FinalB_18_2'	53.4	0.210	52.1	0.780	72.3	0.051	80.1	0.037	95.2	0.058	75.7	0.043	58.3	0.178	80.2	0.586
	'Bright_FinalB_20_2'	52.7	0.199	51.7	0.889	71.5	0.057	78.7	0.070	92.1	0.044	75.7	0.035	58.9	0.147	79.8	0.556
	'Bright_FinalB_13_4'	52.2	0.208	51.0	1.164	72.8	0.057	77.2	0.078	87.4	0.058	74.3	0.096	59.6	0.384	75.2	0.450
	'Bright_FinalB_14_3'	53.2	0.197	51.9	0.938	70.1	0.091	77.9	0.127	94.5	0.040	75.6	0.019	59.5	0.117	80.6	0.555
	'Bright_FinalB_3_2'	52.6	0.171	51.7	0.983	73.0	0.064	79.5	0.116	92.6	0.067	73.9	0.056	58.8	0.148	76.7	0.488
	'Bright_FinalB_11_3'	53.8	0.203	52.5	0.767	71.7	0.092	78.0	0.140	90.8	0.062	74.1	0.060	59.1	0.170	77.3	0.488

APPENDIX 8B(i): PERFORMANCE OF NEURAL NETWORKS FOR THE PREDICTION OF ERIC

	Name of Neural Net	No. neurons	Training performance	Validation performance	Test performance	Training R	Validation R	Test R	Total R	Correlation with plant data	MSE against plant data
Neural network variables: full set of 15 variables	'ERIC_FinalB_14_4'	14	1974668	319646	332271	0.867	0.832	0.806	0.853	0.934	1021
	'ERIC_FinalB_19_1'	19	1465832	315638	530372	0.894	0.863	0.674	0.860	0.930	1523
	'ERIC_FinalB_6_3'	6	840299	184242	237098	0.922	0.931	0.884	0.918	0.935	1829
	'ERIC_FinalB_20_2'	20	2779947	220083	493533	0.800	0.838	0.845	0.810	0.936	1856
	'ERIC_FinalB_16_4'	16	1584583	464151	160071	0.887	0.790	0.849	0.869	0.920	2008
	'ERIC_FinalB_5_3'	5	821831	266343	351412	0.923	0.893	0.839	0.906	0.936	2125
	'ERIC_FinalB_8_4'	8	890688	83841	435705	0.921	0.938	0.836	0.908	0.941	2168
	'ERIC_FinalB_19_3'	19	741554	387278	207916	0.936	0.830	0.853	0.913	0.936	2272
	'ERIC_FinalB_10_2'	10	705403	331473	469510	0.939	0.881	0.741	0.901	0.904	2694
	'ERIC_FinalB_9_1'	9	1039210	582879	157508	0.899	0.838	0.876	0.882	0.919	2822
Neural network variables: reduced set of 10 variables	'ERIC_FinalA_4_1'	4	906314	185784	322531	0.911	0.940	0.844	0.907	0.934	1370
	'ERIC_FinalA_11_4'	11	875128	184303	107720	0.934	0.878	0.840	0.924	0.922	1408
	'ERIC_FinalA_10_4'	10	1071051	127152	191441	0.923	0.904	0.804	0.911	0.925	1535
	'ERIC_FinalA_18_4'	18	674602	386724	279475	0.925	0.924	0.854	0.913	0.917	1549
	'ERIC_FinalA_9_2'	9	770143	285339	309375	0.921	0.910	0.874	0.911	0.928	1636
	'ERIC_FinalA_12_2'	12	799381	241831	158268	0.933	0.895	0.875	0.922	0.914	1655
	'ERIC_FinalA_17_1'	17	900853	194978	200701	0.928	0.884	0.874	0.915	0.926	1658
	'ERIC_FinalA_9_4'	9	872563	227309	126958	0.920	0.928	0.907	0.921	0.942	1682
	'ERIC_FinalA_17_3'	17	811992	326751	194279	0.918	0.903	0.939	0.915	0.921	1705
	'ERIC_FinalA_18_2'	18	824360	231545	135497	0.928	0.930	0.867	0.923	0.932	1715
Neural network variables: very reduced set of 6 variables	'ERIC_FinalC_17_3'	17	2800784	335744	235524	0.846	0.828	0.868	0.841	0.937	1341
	'ERIC_FinalC_5_2'	5	1104794	318404	276497	0.899	0.796	0.910	0.889	0.918	2336
	'ERIC_FinalC_17_2'	17	1182248	321966	502893	0.873	0.894	0.807	0.866	0.907	2454
	'ERIC_FinalC_13_1'	13	1310021	105458	83272	0.890	0.942	0.956	0.902	0.884	2531
	'ERIC_FinalC_11_1'	11	1135103	291660	174227	0.904	0.862	0.884	0.894	0.872	2681
	'ERIC_FinalC_11_3'	11	1248304	239538	148458	0.892	0.838	0.938	0.892	0.883	2761
	'ERIC_FinalC_7_1'	7	1326503	190120	115420	0.889	0.880	0.930	0.892	0.902	2779
	'ERIC_FinalC_4_4'	4	1132455	133318	371360	0.898	0.945	0.827	0.892	0.884	2808
	'ERIC_FinalC_1_2'	1	2335186	445193	155008	0.829	0.779	0.776	0.816	0.923	2829
	'ERIC_FinalC_19_4'	19	1300055	206100	136754	0.878	0.928	0.920	0.891	0.907	2894

Notes: 1	Reduced set of 10 variables:	ONP,OMG, HL1, HL2, NaOH, Sodium silicate, hydrogen peroxide, flotation consistency, flotation pH and flotation time
2	Full set of 15 variables:	pulping time and pulping temperature, flotation time, flotation consistency, flotation temperature and flotation pH
3	Very reduced set of 6 variables:	ONP,OMG, HL1, HL2, flotation consistency, flotation time

APPENDIX 8B(ii): MEAN PREDICTED ERIC OF NEURAL NETWORKS COMPARED TO PLANT ERIC, BY PAPER GRADE

		Newsprint Trial		Newsprint		Double-loop, medium grade		Double-loop, high grade		Single-loop. Very high grade		Single-loop, medium grade		Single-loop, low grade		Single-loop, high grade	
		Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error
	Plant output	274	6.120	266	5.183	79		79		88		88				88	
Neural network variables: full set of 15 variables	'ERIC_FinalB_14_4'	234	4.106	276	2.058	88	1.732	69	1.851	63	0.237	74	0.728			72	1.433
	'ERIC_FinalB_19_1'	256	5.136	312	2.292	108	1.299	96	1.151	86	0.092	99	1.053			98	1.982
	'ERIC_FinalB_6_3'	279	7.394	323	2.695	83	0.863	72	0.847	108	0.988	113	1.514			110	2.959
	'ERIC_FinalB_20_2'	241	2.361	261	1.572	123	0.940	108	1.012	110	0.514	127	1.101			124	2.159
	'ERIC_FinalB_16_4'	273	5.861	325	2.808	112	2.073	97	1.342	74	0.147	85	1.934			83	3.384
	'ERIC_FinalB_5_3'	289	7.682	338	3.006	103	1.013	80	0.255	69	0.397	94	1.151			73	2.287
	'ERIC_FinalB_8_4'	285	6.893	337	2.707	68	0.750	51	0.382	52	0.280	72	1.519			80	2.900
	'ERIC_FinalB_19_3'	292	7.582	338	3.509	81	0.990	75	1.784	100	0.647	111	1.430			102	2.607
	'ERIC_FinalB_10_2'	277	7.828	325	3.070	143	1.916	108	1.377	70	0.189	104	1.900			87	3.662
	'ERIC_FinalB_9_1'	298	7.663	342	3.970	91	1.001	70	0.547	66	1.125	101	2.925			88	5.518
Neural network variables: reduced set of 10 variables	'ERIC_FinalA_4_1'	266	6.889	309	2.484	78	0.771	60	0.330	74	0.339	106	1.514			89	3.185
	'ERIC_FinalA_11_4'	259	7.678	296	3.369	74	0.668	51	0.741	80	0.297	117	1.096			87	2.097
	'ERIC_FinalA_10_4'	259	7.874	302	2.655	87	0.889	70	0.788	85	0.464	119	1.556			99	3.134
	'ERIC_FinalA_18_4'	252	5.998	296	2.481	76	0.765	61	1.111	96	0.441	125	1.229			99	2.551
	'ERIC_FinalA_9_2'	257	8.115	320	2.396	87	0.814	74	1.278	89	0.265	107	1.019			72	1.687
	'ERIC_FinalA_12_2'	248	9.056	306	3.664	72	1.260	39	1.464	76	0.189	103	1.543			67	3.085
	'ERIC_FinalA_17_1'	269	7.263	314	3.214	74	0.789	55	0.540	69	0.399	111	1.473			93	3.239
	'ERIC_FinalA_9_4'	266	7.769	318	2.494	59	1.076	43	1.270	70	0.146	74	1.072			60	2.422
	'ERIC_FinalA_17_3'	263	6.925	313	2.877	68	1.137	43	0.811	56	0.551	102	2.065			84	4.080
	'ERIC_FinalA_18_2'	262	7.434	309	2.207	95	0.525	74	0.488	88	0.135	127	0.378			102	0.656
Neural network variables: very reduced set of 6 variables	'ERIC_FinalC_17_3'	259	5.097	306	2.155	66	0.820	58	0.000	61	0.337	81	1.630			80	3.362
	'ERIC_FinalC_5_2'	266	6.704	334	3.333	82	0.560	65	0.000	102	0.227	117	1.559			91	3.520
	'ERIC_FinalC_17_2'	261	5.903	319	2.845	94	0.663	69	0.000	94	0.251	135	1.821			105	3.727
	'ERIC_FinalC_13_1'	245	7.389	321	4.193	90	1.304	52	0.000	81	0.241	108	2.834			55	6.203
	'ERIC_FinalC_11_1'	244	6.568	313	3.351	89	0.777	55	0.000	97	0.269	133	2.955			78	5.346
	'ERIC_FinalC_11_3'	256	5.777	313	3.316	86	0.502	56	0.000	91	0.261	144	2.106			103	4.436
	'ERIC_FinalC_7_1'	269	6.623	333	4.680	87	0.816	63	0.000	101	0.686	126	1.903			95	3.991
	'ERIC_FinalC_4_4'	249	6.981	322	3.386	94	0.466	53	0.000	100	0.347	137	2.141			84	4.743
	'ERIC_FinalC_1_2'	290	4.133	325	2.959	113	1.177	106	0.000	110	0.974	127	2.163			132	4.388
	'ERIC_FinalC_19_4'	271	6.902	340	3.476	90	0.816	64	0.000	99	0.146	125	2.212			91	5.126

APPENDIX 8C(i): PERFORMANCE OF NEURAL NETWORKS FOR THE PREDICTION OF YIELD

	Name of Neural Net	**No. neurons**	**Training performance**	**Validation performance**	**Test performance**	**Training R**	**Validation R**	**Test R**	**Total R**	**Correlation with plant data**	**MSE against plant data**
Neural network variables: reduced set of 10 variables	'Yield_FinalA_11_1'	11	26943	3573	3285	0.783	0.846	0.782	0.791	0.453	87.5
	'Yield_FinalA_14_4'	14	24554	6519	4390	0.797	0.771	0.547	0.779	0.444	90.7
	'Yield_FinalA_3_4'	3	30480	7184	3653	0.744	0.690	0.772	0.739	0.380	94.0
	'Yield_FinalA_9_1'	9	25319	4609	6421	0.792	0.856	0.327	0.774	0.423	94.9
	'Yield_FinalA_5_4'	5	24966	5674	5063	0.799	0.736	0.691	0.777	0.371	95.7
	'Yield_FinalA_6_2'	6	26203	6088	3670	0.782	0.772	0.749	0.775	0.428	95.9
	'Yield_FinalA_3_1'	3	30137	6655	3919	0.734	0.813	0.723	0.743	0.319	96.4
	'Yield_FinalA_12_1'	12	27022	5712	6167	0.782	0.743	0.466	0.754	0.329	96.5
	'Yield_FinalA_2_2'	2	25293	5975	6053	0.768	0.814	0.704	0.767	0.360	100.6
	'Yield_FinalA_6_4'	6	24405	6095	4742	0.810	0.664	0.648	0.780	0.264	104.8
Neural network variables: full set of 15 variables	'Yield_FinalB_4_3'	4	21063	10013	2786	0.825	0.598	0.816	0.790	0.425	101.2
	'Yield_FinalB_13_3'	13	48607	7649	5085	0.702	0.358	0.753	0.678	0.069	110.8
	'Yield_FinalB_19_3'	19	22223	6233	6470	0.804	0.785	0.705	0.782	0.176	111.1
	'Yield_FinalB_10_3'	10	26201	3706	6708	0.783	0.851	0.545	0.770	0.137	117.8
	'Yield_FinalB_9_3'	9	22060	4581	5142	0.813	0.839	0.724	0.806	0.094	118.2
	'Yield_FinalB_5_3'	5	21572	4681	7077	0.823	0.814	0.585	0.794	0.171	119.4
	'Yield_FinalB_3_4'	3	26578	4435	4418	0.777	0.837	0.697	0.779	-0.018	120.3
	'Yield_FinalB_1_3'	1	55637	6198	7558	0.608	0.505	0.695	0.604	-0.109	121.8
	'Yield_FinalB_7_4'	7	46277	9557	7444	0.647	0.473	0.776	0.642	-0.020	124.4
	'Yield_FinalB_6_3'	6	22726	5532	5133	0.813	0.783	0.692	0.795	0.058	129.6
Neural network variables: very reduced set of 6 variables	'Yield_FinalC_8_4'	8	25803	4523	6905	0.789	0.756	0.668	0.767	0.534	83.6
	'Yield_FinalC_13_3'	13	27413	5106	5571	0.752	0.799	0.771	0.761	0.502	89.4
	'Yield_FinalC_10_1'	10	29143	7695	2148	0.763	0.702	0.819	0.755	0.472	90.1
	'Yield_FinalC_3_4'	3	29548	4624	2803	0.756	0.808	0.809	0.768	0.479	90.7
	'Yield_FinalC_11_4'	11	28326	6167	2727	0.754	0.756	0.879	0.766	0.525	92.3
	'Yield_FinalC_17_4'	17	28553	5014	3890	0.748	0.854	0.753	0.767	0.475	93.1
	'Yield_FinalC_13_4'	13	26724	5973	3746	0.772	0.780	0.775	0.772	0.510	93.8
	'Yield_FinalC_10_4'	10	27960	4694	3555	0.779	0.728	0.777	0.773	0.544	94.4
	'Yield_FinalC_6_3'	6	23878	6189	5439	0.798	0.776	0.621	0.778	0.519	95.0
	'Yield_FinalC_10_3'	10	25910	5723	6669	0.774	0.824	0.549	0.758	0.387	96.9

Notes: 1	Reduced set of 10 variables:	ONP,OMG, HL1, HL2, NaOH, Sodium silicate, hydrogen peroxide, flotation consistency, flotation pH and flotation time
2	Full set of 15 variables:	ONP,OMG, HL1, HL2, NaOH, sodium silicate, hydrogen peroxide, surfactant addition to pulper and float cell, pulping time and pulping temperature, flotation time, flotation consistency, flotation temperature and flotation pH
3	Very reduced set of 6 variables:	ONP,OMG, HL1, HL2, flotation consistency, flotation time

APPENDIX 8C(ii): MEAN PREDICTED YIELD OF NEURAL NETWORKS COMPARED TO PLANT YIELD, BY PAPER GRADE

		Newsprint Trial		Newsprint		Double-loop, medium grade		Double-loop, high grade		Single-loop. Very high grade		Single-loop, medium grade		Single-loop, low grade		Single-loop, high grade	
		Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error
	Plant output	90		89	0.645	81	1.143	77	1.761	70	1.385	72	0.503	71	2.079	71	0.960
Neural network variables: reduced set of 10 variables	'Yield_FinalA_11_1'	83	0.341	85	0.217	80	0.157	82	0.115	85	0.111	76	0.139	65	0.805	81	0.452
	'Yield_FinalA_14_4'	81	0.244	82	0.392	75	0.204	77	0.190	86	0.093	72	0.241	73	1.144	75	0.463
	'Yield_FinalA_3_4'	78	0.310	81	0.322	76	0.169	78	0.128	82	0.034	74	0.266	72	0.998	77	0.549
	'Yield_FinalA_9_1'	83	0.386	86	0.407	81	0.171	84	0.172	87	0.090	77	0.117	70	0.901	82	0.370
	'Yield_FinalA_5_4'	81	0.339	84	0.427	80	0.135	83	0.109	86	0.076	77	0.115	69	0.945	82	0.380
	'Yield_FinalA_6_2'	79	0.297	82	0.509	74	0.195	78	0.280	88	0.068	71	0.139	70	0.892	74	0.233
	'Yield_FinalA_3_1'	79	0.209	81	0.105	79	0.136	81	0.124	84	0.086	76	0.121	68	0.699	80	0.367
	'Yield_FinalA_12_1'	80	0.322	82	0.411	78	0.141	81	0.109	87	0.098	75	0.185	71	0.757	79	0.379
	'Yield_FinalA_2_2'	77	0.288	80	0.369	75	0.151	79	0.118	87	0.040	72	0.196	70	0.810	75	0.406
	'Yield_FinalA_6_4'	79	0.331	82	0.281	80	0.140	83	0.078	87	0.089	78	0.150	68	0.821	82	0.446
Neural network variables: full set of 15 variables	'Yield_FinalB_4_3'	77	0.410	81	0.417	82	0.141	87	0.135	90	0.133	69	0.184	68	0.938	70	0.340
	'Yield_FinalB_13_3'	75	0.110	76	0.190	80	0.072	80	0.046	78	0.077	76	0.122	74	0.414	77	0.245
	'Yield_FinalB_19_3'	75	0.287	78	0.478	80	0.107	84	0.056	83	0.102	75	0.194	69	0.870	79	0.471
	'Yield_FinalB_10_3'	75	0.407	79	0.393	78	0.178	81	0.161	89	0.153	74	0.302	72	1.032	78	0.619
	'Yield_FinalB_9_3'	77	0.319	80	0.459	82	0.077	87	0.071	84	0.077	78	0.138	71	0.834	82	0.401
	'Yield_FinalB_5_3'	78	0.356	82	0.384	83	0.107	84	0.049	87	0.097	79	0.176	66	0.846	83	0.542
	'Yield_FinalB_3_4'	76	0.254	80	0.365	77	0.181	80	0.179	84	0.079	78	0.271	76	0.812	81	0.553
	'Yield_FinalB_1_3'	73	0.128	75	0.076	79	0.040	80	0.029	79	0.063	75	0.105	73	0.313	78	0.210
	'Yield_FinalB_7_4'	75	0.247	78	0.331	84	0.101	86	0.111	80	0.115	78	0.141	75	0.457	81	0.294
	'Yield_FinalB_6_3'	72	0.210	75	0.394	79	0.101	84	0.059	82	0.062	73	0.127	68	0.903	78	0.360
Neural network variables: very reduced set of 6 variables	'Yield_FinalC_8_4'	87	0.246	89	0.369	78	0.048	76	0.000	85	0.016	78	0.098	75	1.045	77	0.131
	'Yield_FinalC_13_3'	86	0.283	88	0.351	79	0.066	80	0.000	87	0.030	78	0.130	77	0.877	79	0.229
	'Yield_FinalC_10_1'	85	0.246	87	0.345	79	0.069	81	0.000	86	0.028	77	0.145	77	0.916	80	0.239
	'Yield_FinalC_3_4'	87	0.217	88	0.372	78	0.065	79	0.000	89	0.043	77	0.129	76	1.058	79	0.201
	'Yield_FinalC_11_4'	87	0.310	90	0.439	80	0.043	81	0.000	86	0.012	78	0.096	76	0.974	80	0.139
	'Yield_FinalC_17_4'	86	0.286	88	0.342	79	0.091	80	0.000	88	0.070	78	0.170	76	0.974	81	0.339
	'Yield_FinalC_13_4'	88	0.257	90	0.373	79	0.017	79	0.000	90	0.055	78	0.043	76	0.812	79	0.134
	'Yield_FinalC_10_4'	90	0.298	91	0.449	80	0.039	80	0.000	88	0.028	79	0.083	75	0.938	79	0.133
	'Yield_FinalC_6_3'	87	0.276	89	0.294	80	0.053	81	0.000	88	0.082	79	0.125	76	0.922	80	0.209
	'Yield_FinalC_10_3'	83	0.289	86	0.338	79	0.111	81	0.000	89	0.037	77	0.218	77	0.820	80	0.444

APPENDIX 9: MATLAB CODE

```
%A GENERAL PROGRAM FOR TRAINING NETWORKS AND SIMULTANEOUS PLANT
VALIDATION
load DATA %load training data
%create training data files
inputs = [DATA(1:4,:);  DATA(12,:) ;  DATA(15,:)];
%create training target file
targets = DATA(21,:);%brightness


%load Plantdata %load plant data files
PlantInput = [Plantdata(:,1:4)  Plantdata(:,12)
Plantdata(:,16)]';%inputs for brightness
PlantOutput = Plantdata(:,23)';% brightness


n = 1  %order number in data base
Headings = {'n', 'date', 'filename',
'Neurons','Train_perf','Val_perf','Test_perf','Train R', 'Validation
R', 'Test R', 'Total R','Plant R','Plant mse','Comments'};
%DEFINE THE NETWORK
comments = 'input: traininputs:1-4, 12, 15; using DATA 22x490 , BTF =
trainbr, msereg ';
for Si   = 11:20;           %size of ith layer, number of hidden
neurons
for m = 1:4;              %number of iterations for Si

filename = 'ERIC_FinalC'; %File name to save
Filename = [filename '_' int2str(Si) '_' int2str(m)];


TF1 = 'tansig';    %Transfer function of ith layer, default tansig
TF2 = 'purelin';    % default purelin
%BTF = 'trainlm';  %Training function, default trainlm
BTF = 'trainbr';
BLF = 'learngdm';  %Learning function, default learngdm
%PF   = 'mse';  %Performance function
PF = 'trainbr';
%PF = 'msereg';
%net.performParam.ratio = 0.5;
IPF = {'fixunknowns', 'removeconstantrows', 'mapminmax'}; %input
processing functions
OPF = {'mapminmax'};  %Output processing functions
DDF = 'dividerand' ;  %Data division function


%NETWORK
net = newff(inputs,targets,[Si],{TF1,TF2},BTF, BLF,PF,IPF,OPF, DDF);

%SET TRAINING PARAMETERS
net.divideParam.trainRatio = 75/100;  % Adjust as desired
net.divideParam.valRatio = 15/100;  % Adjust as desired
net.divideParam.testRatio = 10/100;  % Adjust as desired
net.trainParam.epochs = 100;
```

```
net.trainparam.max_fail = 7
% Train and Apply Network
%net = init(net)
[net,tr] = train(net, inputs, targets);
outputs = sim(net,inputs);

save(Filename,'net','Si','tr');

%Create data base
a = 1 + getfield(tr,'best_epoch');
A = getfield(tr, 'perf');
B = getfield(tr, 'vperf');
C = getfield(tr,'tperf');
Train_perf = A(1,a);
Val_perf = B(1,a);
Test_perf = C(1,a);

ti = getfield(tr,'trainInd');
vi = getfield(tr,'valInd');
testi = getfield(tr,'testInd');

tr_cor = corrcoef(outputs(ti),targets(1,ti));
val_cor = corrcoef(outputs(vi),targets(1,vi));
test_cor = corrcoef(outputs(testi),targets(1,testi));
tot_cor = corrcoef(outputs, targets);
TrainR = tr_cor(1,2);
ValidationR = val_cor(1,2);
TestR = test_cor(1,2);
TotalR = tot_cor(1,2);

% Test network against Plant data set
val = sim(net, PlantInput);
PredictValues(n,:) = val;
mse = mean((val-PlantOutput).^2);
R = corrcoef(val, PlantOutput);
correlation = R(1,2);
%ResultsNetwork(n,:) = {Filename};
%ResultNumbers(n,:) = {correlation  mse};
plotregression(PlantOutput ,val,'o')
xlabel('Plant values')
ylabel('Output predictions')

%Save data to data base
Training_Data(n,:) = {n, date, Filename,
Si,Train_perf,Val_perf,Test_perf,TrainR, ValidationR, TestR, TotalR,
correlation, mse,comments };
n = n+1
end
end
save Training_Data
save PredictValues
```

```
%Function to input and create a 3D plot of Brightness vs. two
variables
% load the required network
load Yield_FinalB_6_3
upperlimit = [100;100;100;100;1.5;3;2;1.0;15;50;45;1.5;10;0.5;12];
lowerlimit = [0;0;0;0;0;0;0;0.25;5;35;30;0.8;7;0;2];
lables = {'ONP'; 'OMG'; 'HL1' ;'HL2'; '%NaOH'; '%Sod Silicate'
;'%H2O2'; '%Surf-p'; 'tp (min)' ;'Tp (deg C)';' Tf (deg C)'; '%cons';
'pH'; '%Surf-f' ;' tf (min)'};
for n=1:7
Scenario = SCENARIO(:,n);

row_m =  5;%Define 1st parameter to be varied
row_n = 7;%Define 2nd parameter to be varied
[new, X, Y] = geninput(Scenario, row_m, lowerlimit(row_m),
upperlimit(row_m), row_n, lowerlimit(row_n), upperlimit(row_n));
outputs = sim(net, new);
    subplot(2,2,1); bivariate_mesh(reshape(outputs(1,:), 10, 10)',X,Y)
    xlabel(lables(row_m))
    ylabel(lables(row_n))
    title('Yield','FontSize',16)

row_m =  6;%Define 3rd parameter to be varied
row_n = 13;%Define 4th parameter to be varied
[new, X, Y] = geninput(Scenario, row_m, lowerlimit(row_m),
upperlimit(row_m), row_n, lowerlimit(row_n), upperlimit(row_n));
outputs = sim(net, new);
subplot(2,2,2); bivariate_mesh(reshape(outputs(1,:), 10, 10)',X,Y)
xlabel(lables(row_m))
ylabel(lables(row_n))
title('Yield','FontSize',16)

row_m =  12;%Define 5th parameter to be varied
row_n = 15;%Define 6th parameter to be varied
[new, X, Y] = geninput(Scenario, row_m, lowerlimit(row_m),
upperlimit(row_m), row_n, lowerlimit(row_n), upperlimit(row_n));
outputs = sim(net, new);
subplot(2,2,3); bivariate_mesh(reshape(outputs(1,:), 10, 10)',X,Y)
xlabel(lables(row_m))
ylabel(lables(row_n))
title('Yield','FontSize',16)

subplot(2,2,4); bar(Scenario(1:4))
title('Grade mix', 'Fontsize', 16)
set(gca,'xTickLabel',{'ONP';'OMG';'HL1';'HL2'})
xlabel('Grade')
ylabel('%')
pause
end
```

```
function [new_input, row_m_input, row_n_input] = geninput(nom, row_m,
min_m, max_m, row_n, min_n, max_n)
%generate new input
num_steps       = 10;
row_m_input      = linspace(min_m, max_m, num_steps);
row_n_input      = linspace(min_n, max_n, num_steps);
new_input       = nom*ones(1, num_steps^2);

for c_m = 1:num_steps
    for c_n = 1:num_steps
        new_input(row_m, c_m +num_steps*(c_n-1))     =
row_m_input(c_m);
        new_input(row_n, num_steps*(c_n-1)+c_m)      =
row_n_input(c_n);
    end
end
```

APPENDIX 10: NEURAL NETWORK STRUCTURES

'Bright_FinalA_20_2'

```
Neural Network object:
  architecture:

       numInputs: 1
       numLayers: 2
     biasConnect: [1; 1]
    inputConnect: [1; 0]
    layerConnect: [0 0; 1 0]
   outputConnect: [0 1]

      numOutputs: 1  (read-only)
  numInputDelays: 0  (read-only)
  numLayerDelays: 0  (read-only)

  subobject structures:

          inputs: {1x1 cell} of inputs
          layers: {2x1 cell} of layers
         outputs: {1x2 cell} containing 1 output
          biases: {2x1 cell} containing 2 biases
    inputWeights: {2x1 cell} containing 1 input weight
    layerWeights: {2x2 cell} containing 1 layer weight

  functions:

        adaptFcn: 'trains'
       divideFcn: 'dividerand'
     gradientFcn: 'calcjx'
         initFcn: 'initlay'
      performFcn: 'sse'
        plotFcns: {'plotperform','plottrainstate','plotregression'}
        trainFcn: 'trainbr'

  parameters:

      adaptParam: .passes
     divideParam: .trainRatio, .valRatio, .testRatio
   gradientParam: (none)
       initParam: (none)
    performParam: .show, .showWindow, .showCommandLine, .epochs,
                  .time, .goal, .max_fail, .mem_reduc,
                  .min_grad, .mu, .mu_dec, .mu_inc,
                  .mu_max
      trainParam: .show, .showWindow, .showCommandLine, .epochs,
```

```
                .time, .goal, .max_fail, .mem_reduc,
                .min_grad, .mu, .mu_dec, .mu_inc,
                .mu_max

    weight and bias values:

              IW: {2x1 cell} containing 1 input weight matrix

Columns 1 through 9

   -0.0250    0.0488   -0.0038   -0.0900   -0.0019    0.0224   -0.0053   -0.0494   -0.0075
    0.0021    0.1598    0.0613   -0.2002    0.0377    0.0308    0.0802   -0.0404   -0.0442
    0.0162   -0.0143   -0.0109    0.0280   -0.0011   -0.0062    0.0009    0.0118    0.0024
   -0.0188    0.0183    0.0116   -0.0347    0.0012    0.0078   -0.0010   -0.0149   -0.0030
    0.0205   -0.0192   -0.0138    0.0356   -0.0016   -0.0083    0.0007    0.0158    0.0031
   -0.0294    0.0890    0.0510   -0.0933    0.0187    0.0216    0.0346   -0.0249   -0.0153
   -0.0255    0.0611   -0.0014   -0.1025    0.0006    0.0272    0.0026   -0.0565   -0.0102
   -0.0246    0.0520   -0.0101   -0.1006   -0.0042    0.0256   -0.0087   -0.0596   -0.0079
   -0.0246    0.0469   -0.0028   -0.0865   -0.0016    0.0212   -0.0053   -0.0463   -0.0072
   -0.0108    0.1412    0.0751   -0.1631    0.0346    0.0231    0.0662   -0.0241   -0.0349
   -0.0117   -0.0068    0.0214    0.0089    0.0013   -0.0006    0.0018    0.0006    0.0004
    0.0186   -0.0193   -0.0106    0.0364   -0.0011   -0.0081    0.0013    0.0155    0.0031
   -0.1652    0.0415    0.6690    0.2176    0.0834   -0.0325    0.0769   -0.0230   -0.0466
    0.0297   -0.0770   -0.0374    0.0859   -0.0145   -0.0233   -0.0266    0.0307    0.0127
   -0.0270    0.1545    0.2070   -0.1600    0.0418   -0.0169    0.0569    0.0121   -0.0299
   -0.3455   -0.1715    0.5286    0.7436   -0.0793    0.0713   -0.0940    0.0369    0.0915
   -0.0105    0.0015    0.0132   -0.0049    0.0010    0.0017    0.0005   -0.0034   -0.0006
    0.0266   -0.0588   -0.0052    0.0935   -0.0026   -0.0248   -0.0049    0.0485    0.0098
   -0.0563    0.1875    0.4289   -0.1783    0.0578   -0.0736    0.0494    0.0085   -0.0327
   -0.0060    0.0031    0.0057   -0.0068    0.0004    0.0016   -0.0001   -0.0031   -0.0006

  Column 10

    0.0393
    0.0346
   -0.0104
    0.0129
   -0.0141
    0.0300
    0.0467
    0.0472
    0.0368
    0.0271
    0.0037
   -0.0132
    0.0596
   -0.0322
    0.0299
    0.0247
    0.0049
   -0.0410
```

```
    0.0696
    0.0031

            LW: {2x2 cell} containing 1 layer weight matrix
Columns 1 through 9

    0.1066    0.1946   -0.0312    0.0390   -0.0402    0.0988    0.1200    0.1212    0.1022

  Columns 10 through 18

    0.1582   -0.0101   -0.0410    0.4521   -0.0934    0.1353    0.5689    0.0054   -0.1085

  Columns 19 through 20

    0.2206    0.0075

             b: {2x1 cell} containing 2 bias vectors
0.0379
   -0.0060
   -0.0104
    0.0129
   -0.0127
   -0.0051
    0.0376
    0.0450
    0.0364
   -0.0163
   -0.0062
   -0.0138
   -0.3707
   -0.0040
   -0.0819
   -0.3662
    0.0005
   -0.0312
   -0.1831
    0.0023
```

'Bright_FinalB_16_2'

```
Neural Network object:

   architecture:

         numInputs: 1
         numLayers: 2
       biasConnect: [1; 1]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]

        numOutputs: 1  (read-only)
    numInputDelays: 0  (read-only)
    numLayerDelays: 0  (read-only)

   subobject structures:

            inputs: {1x1 cell} of inputs
            layers: {2x1 cell} of layers
           outputs: {1x2 cell} containing 1 output
            biases: {2x1 cell} containing 2 biases
      inputWeights: {2x1 cell} containing 1 input weight
      layerWeights: {2x2 cell} containing 1 layer weight

   functions:

          adaptFcn: 'trains'
         divideFcn: 'dividerand'
       gradientFcn: 'calcjx'
           initFcn: 'initlay'
        performFcn: 'sse'
          plotFcns: {'plotperform','plottrainstate','plotregression'}
          trainFcn: 'trainbr'

   parameters:

        adaptParam: .passes
       divideParam: .trainRatio, .valRatio, .testRatio
     gradientParam: (none)
         initParam: (none)
      performParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
        trainParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
```

```
    weight and bias values:

              IW: {2x1 cell} containing 1 input weight matrix

  Columns 1 through 9

   -0.0058   -0.0311   -0.0079    0.0070    0.0003   -0.0080   -0.0029   -0.0024    0.0083
    0.0047    0.0212    0.0047   -0.0046   -0.0002    0.0054    0.0019    0.0018   -0.0056
    0.0067    0.0537    0.0185   -0.0145   -0.0003    0.0139    0.0066    0.0033   -0.0162
    0.0052    0.0257    0.0061   -0.0057   -0.0002    0.0066    0.0023    0.0021   -0.0068
    0.0140    0.0958    0.0132   -0.0560   -0.0111    0.0343   -0.0105   -0.0123   -0.0438
    0.2158    0.1677   -0.6162   -0.5592    0.0601   -0.0046   -0.0087    0.0468   -0.0949
   -0.0070   -0.0526   -0.0171    0.0142    0.0004   -0.0138   -0.0059   -0.0031    0.0157
    0.1778   -0.0206   -0.5384   -0.5647   -0.0106    0.0811   -0.0513    0.0918   -0.0098
    0.0430    0.1507    0.0553   -0.1191   -0.0034    0.0454   -0.0085   -0.0038   -0.0615
   -0.0761   -0.2005   -0.1958    0.1641   -0.0256   -0.0198   -0.0095   -0.0289    0.0257
   -0.0063   -0.0205   -0.0024    0.0046    0.0006   -0.0049   -0.0011   -0.0018    0.0054
   -0.1209   -0.3335   -0.4685    0.1696   -0.1364   -0.0079   -0.0981   -0.0378   -0.0200
    0.0999    0.2314    0.1596   -0.1940    0.0335    0.0273    0.0283    0.0509   -0.0112
   -0.0137   -0.0875   -0.0194    0.0404    0.0058   -0.0263   -0.0001    0.0025    0.0325
    0.0073    0.0288    0.0051   -0.0066   -0.0006    0.0071    0.0018    0.0023   -0.0075
    0.0505    0.1585    0.0825   -0.1095    0.0078    0.0299    0.0160    0.0196   -0.0336

  Columns 10 through 15

   -0.0102    0.0009    0.0133    0.0049    0.0107   -0.0049
    0.0072   -0.0007   -0.0088   -0.0032   -0.0077    0.0026
    0.0161   -0.0019   -0.0220   -0.0088   -0.0144    0.0112
    0.0086   -0.0008   -0.0108   -0.0040   -0.0091    0.0036
    0.0386   -0.0101   -0.0735   -0.0100   -0.0534    0.0533
    0.0115    0.0575   -0.0469    0.0199   -0.0062    0.0247
   -0.0160    0.0018    0.0222    0.0086    0.0150   -0.0111
   -0.0642   -0.0346    0.0146    0.0257   -0.0428   -0.0597
    0.0259   -0.0069   -0.0900   -0.0163   -0.0380    0.0798
    0.0170   -0.0480    0.0065    0.0080   -0.0300   -0.0467
   -0.0073    0.0007    0.0087    0.0029    0.0089   -0.0016
    0.0323    0.0069    0.0138   -0.0516   -0.0242   -0.0276
   -0.0426    0.0411   -0.0321   -0.0346    0.0269    0.0465
   -0.0283    0.0050    0.0501    0.0119    0.0358   -0.0326
    0.0098   -0.0008   -0.0124   -0.0043   -0.0114    0.0036
    0.0034    0.0132   -0.0434   -0.0239   -0.0065    0.0378

              LW: {2x2 cell} containing 1 layer weight matrix

  Columns 1 through 9

   -0.0408    0.0278    0.0697    0.0337    0.1551   -0.5549   -0.0687   -0.5343    0.2191

  Columns 10 through 16

   -0.2291   -0.0273   -0.3250    0.2564   -0.1258    0.0380    0.1930
```

b: {2x1 cell} containing 2 bias vectors

```
0.0212
    0.0146
    0.0347
    0.0176
    0.0992
    0.1171
   -0.0347
    0.1832
    0.1137
   -0.0085
   -0.0149
    0.1599
    0.0314
   -0.0735
    0.0204
    0.0711
```

'ERIC_FinalB_14_4'

```
Neural Network object:

 architecture:

      numInputs: 1
      numLayers: 2
    biasConnect: [1; 1]
   inputConnect: [1; 0]
   layerConnect: [0 0; 1 0]
  outputConnect: [0 1]

     numOutputs: 1  (read-only)
 numInputDelays: 0  (read-only)
 numLayerDelays: 0  (read-only)

 subobject structures:

         inputs: {1x1 cell} of inputs
         layers: {2x1 cell} of layers
        outputs: {1x2 cell} containing 1 output
         biases: {2x1 cell} containing 2 biases
   inputWeights: {2x1 cell} containing 1 input weight
   layerWeights: {2x2 cell} containing 1 layer weight

 functions:

       adaptFcn: 'trains'
      divideFcn: 'dividerand'
    gradientFcn: 'calcjx'
        initFcn: 'initlay'
     performFcn: 'sse'
       plotFcns: {'plotperform','plottrainstate','plotregression'}
       trainFcn: 'trainbr'

 parameters:

     adaptParam: .passes
    divideParam: .trainRatio, .valRatio, .testRatio
  gradientParam: (none)
      initParam: (none)
   performParam: .show, .showWindow, .showCommandLine, .epochs,
                 .time, .goal, .max_fail, .mem_reduc,
                 .min_grad, .mu, .mu_dec, .mu_inc,
                 .mu_max
     trainParam: .show, .showWindow, .showCommandLine, .epochs,
                 .time, .goal, .max_fail, .mem_reduc,
                 .min_grad, .mu, .mu_dec, .mu_inc,
                 .mu_max
```

```
    weight and bias values:

              IW: {2x1 cell} containing 1 input weight matrix

  Columns 1 through 9

    0.0039    0.0840    0.0450    0.0819    0.0527    0.0504    0.0187    0.0009   -0.0475
   -0.0174    0.0280    0.0319    0.0346    0.0154    0.0128    0.0091    0.0012   -0.0114
   -0.0435    0.0603    0.0740    0.0811    0.0118   -0.0042    0.0123   -0.0211    0.0074
    0.0467   -0.0627   -0.0751   -0.0821   -0.0140    0.0024   -0.0119    0.0208   -0.0057
    0.0661    0.0629    0.1031    0.1037    0.0513    0.0413    0.0362    0.0670   -0.0474
   -0.3991   -0.0806    0.0482   -0.1819   -0.0530   -0.0772   -0.2759    0.0985    0.0805
    0.0614   -0.0909   -0.1015   -0.1084   -0.0438   -0.0317   -0.0228    0.0040    0.0274
   -0.0318    0.0601    0.0772    0.0853    0.0192    0.0089    0.0187   -0.0103   -0.0067
    0.0431   -0.0596   -0.0734   -0.0804   -0.0119    0.0033   -0.0126    0.0206   -0.0065
   -0.0306    0.0541    0.0658    0.0711    0.0241    0.0182    0.0170   -0.0031   -0.0165
   -0.0377    0.0303    0.0209    0.0563    0.0286    0.0567    0.0100   -0.0110   -0.0271
   -0.0661    0.0996    0.1066    0.1135    0.0551    0.0446    0.0266    0.0023   -0.0397
    0.0403   -0.0683   -0.0846   -0.0918   -0.0250   -0.0143   -0.0196    0.0094    0.0117
   -0.0545    0.0839    0.0936    0.0993    0.0463    0.0391    0.0246    0.0014   -0.0360

  Columns 10 through 15

   -0.0381    0.0275   -0.0072    0.0016    0.0073   -0.0354
   -0.0071    0.0005    0.0001   -0.0087    0.0107   -0.0043
   -0.0137    0.0075    0.0180   -0.0093    0.0254   -0.0219
    0.0135   -0.0077   -0.0157    0.0110   -0.0229    0.0217
   -0.0004   -0.0351    0.0139    0.0122    0.1121    0.0567
    0.1828   -0.0672   -0.2669    0.0423   -0.0744    0.6227
    0.0197   -0.0056   -0.0004    0.0247   -0.0237    0.0165
   -0.0168    0.0047    0.0167   -0.0102    0.0352   -0.0179
    0.0140   -0.0074   -0.0177    0.0092   -0.0255    0.0214
   -0.0152    0.0034    0.0062   -0.0128    0.0258   -0.0123
   -0.0235    0.0178    0.0073    0.0030   -0.0414   -0.0152
   -0.0227    0.0066   -0.0061   -0.0294    0.0207   -0.0164
    0.0177   -0.0052   -0.0128    0.0138   -0.0325    0.0180
   -0.0216    0.0069   -0.0034   -0.0248    0.0223   -0.0160

              LW: {2x2 cell} containing 1 layer weight matrix

  Columns 1 through 9

   -0.0370   -0.0764   -0.2288    0.2324    0.2708   -0.7232    0.1976   -0.1864    0.2260

  Columns 10 through 14

   -0.1449   -0.0149   -0.1684    0.1917   -0.1391
```

b: {2x1 cell} containing 2 bias vectors

```
0.1307
    0.0047
    0.1182
   -0.1226
   -0.4445
    0.7752
   -0.0686
    0.0513
   -0.1153
    0.0256
    0.1185
    0.0582
   -0.0579
    0.0444
```

'ERIC_FinalA_4_1'

```
Neural Network object:

    architecture:

         numInputs: 1
         numLayers: 2
       biasConnect: [1; 1]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]

        numOutputs: 1  (read-only)
    numInputDelays: 0  (read-only)
    numLayerDelays: 0  (read-only)

    subobject structures:

            inputs: {1x1 cell} of inputs
            layers: {2x1 cell} of layers
           outputs: {1x2 cell} containing 1 output
            biases: {2x1 cell} containing 2 biases
      inputWeights: {2x1 cell} containing 1 input weight
      layerWeights: {2x2 cell} containing 1 layer weight

    functions:

          adaptFcn: 'trains'
         divideFcn: 'dividerand'
       gradientFcn: 'calcjx'
           initFcn: 'initlay'
        performFcn: 'sse'
          plotFcns: {'plotperform','plottrainstate','plotregression'}
          trainFcn: 'trainbr'

    parameters:

        adaptParam: .passes
       divideParam: .trainRatio, .valRatio, .testRatio
     gradientParam: (none)
         initParam: (none)
      performParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
        trainParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
```

```
   weight and bias values:

              IW: {2x1 cell} containing 1 input weight matrix

Columns 1 through 9

   0.2497    0.2771    0.2173    0.0967    0.0102   -0.1094   -0.0321   -0.0195    0.1303
   0.0897   -0.0900    0.4865    0.8039   -0.2196   -0.0958    0.1313    0.0442    0.0226
   0.8783    0.0195   -0.0404    0.2472   -0.1842    0.0048    0.2854    0.3217   -0.0486
  -0.1342    0.3925   -0.0319   -0.3051    0.2308    0.2135   -0.0692   -0.0104   -0.1973

 Column 10

   0.1087
   0.0228
  -1.0689
  -0.1635

              LW: {2x2 cell} containing 1 layer weight matrix

-0.4833   -0.7142    1.1648   -0.5553

               b: {2x1 cell} containing 2 bias vectors

0.1145
  -0.1195
  -1.6169
   0.4884
```

'ERIC_FinalC_17_3'

```
Neural Network object:

    architecture:

         numInputs: 1
         numLayers: 2
       biasConnect: [1; 1]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]

        numOutputs: 1  (read-only)
    numInputDelays: 0  (read-only)
    numLayerDelays: 0  (read-only)

    subobject structures:

            inputs: {1x1 cell} of inputs
            layers: {2x1 cell} of layers
           outputs: {1x2 cell} containing 1 output
            biases: {2x1 cell} containing 2 biases
      inputWeights: {2x1 cell} containing 1 input weight
      layerWeights: {2x2 cell} containing 1 layer weight

    functions:

          adaptFcn: 'trains'
         divideFcn: 'dividerand'
       gradientFcn: 'calcjx'
           initFcn: 'initlay'
        performFcn: 'sse'
          plotFcns: {'plotperform','plottrainstate','plotregression'}
          trainFcn: 'trainbr'

    parameters:

        adaptParam: .passes
       divideParam: .trainRatio, .valRatio, .testRatio
     gradientParam: (none)
         initParam: (none)
      performParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
        trainParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
```

```
  weight and bias values:

            IW: {2x1 cell} containing 1 input weight matrix

-0.0374    0.0171    0.0448    0.0593    0.0096    0.0065
   0.0758   -0.0239   -0.0830   -0.1091   -0.0064   -0.0161
   0.0469   -0.0096   -0.0476   -0.0620    0.0023   -0.0113
  -0.0631    0.0801    0.0870    0.1093    0.0730   -0.0279
   0.0412   -0.0295   -0.0568   -0.0755   -0.0227   -0.0039
   0.0173    0.0131   -0.0077   -0.0070    0.0182   -0.0081
  -0.0114   -0.0181   -0.0003   -0.0040   -0.0215    0.0076
   0.0419    0.0019   -0.0346   -0.0428    0.0166   -0.0130
  -0.0264    0.0234    0.0384    0.0520    0.0183    0.0016
   0.0149   -0.0397   -0.0370   -0.0518   -0.0338    0.0049
  -0.0152    0.0304    0.0318    0.0448    0.0269   -0.0034
  -0.0316    0.0020    0.0296    0.0377   -0.0060    0.0087
  -0.0245    0.0056    0.0257    0.0334    0.0001    0.0057
  -0.0076    0.0127    0.0143    0.0203    0.0109   -0.0009
   0.0239   -0.1110   -0.0772   -0.1085   -0.1019    0.0425
  -0.5831   -0.0448    0.0843   -0.1174   -0.3470    0.3439
   0.0470   -0.0084   -0.0466   -0.0605    0.0044   -0.0119

            LW: {2x2 cell} containing 1 layer weight matrix

Columns 1 through 9
  -0.0798    0.1396    0.0816   -0.1801    0.1033    0.0100    0.0047    0.0569   -0.0712

 Columns 10 through 17
   0.0722   -0.0618   -0.0504   -0.0450   -0.0276    0.1856   -0.6564    0.0794

             b: {2x1 cell} containing 2 bias vectors
0.0416
  -0.0851
  -0.0533
   0.1731
  -0.0451
  -0.0233
   0.0176
  -0.0491
   0.0274
  -0.0095
   0.0124
   0.0369
   0.0280
   0.0065
  -0.0974
   0.7180
  -0.0534
```

'Yield_FinalA_11_1'

```
Neural Network object:

    architecture:

         numInputs: 1
         numLayers: 2
       biasConnect: [1; 1]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]

        numOutputs: 1  (read-only)
    numInputDelays: 0  (read-only)
    numLayerDelays: 0  (read-only)

    subobject structures:

            inputs: {1x1 cell} of inputs
            layers: {2x1 cell} of layers
           outputs: {1x2 cell} containing 1 output
            biases: {2x1 cell} containing 2 biases
      inputWeights: {2x1 cell} containing 1 input weight
      layerWeights: {2x2 cell} containing 1 layer weight

    functions:

          adaptFcn: 'trains'
         divideFcn: 'dividerand'
       gradientFcn: 'calcjx'
           initFcn: 'initlay'
        performFcn: 'sse'
          plotFcns: {'plotperform','plottrainstate','plotregression'}
          trainFcn: 'trainbr'

    parameters:

        adaptParam: .passes
       divideParam: .trainRatio, .valRatio, .testRatio
     gradientParam: (none)
         initParam: (none)
      performParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
        trainParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
```

```
    weight and bias values:

              IW: {2x1 cell} containing 1 input weight matrix

Columns 1 through 9
   -0.0582   -0.0799   -0.0315    0.0267   -0.0241   -0.0012   -0.0153    0.1022   -0.0157
   -0.0596   -0.1203   -0.0604    0.0314   -0.0303   -0.0039    0.0128    0.1620   -0.0172
   -0.9807   -0.1439    0.3436   -0.0428   -0.0840    0.0278   -0.1158   -0.1761    0.0827
    0.0587    0.0824    0.0328   -0.0274    0.0245    0.0009    0.0144   -0.1055    0.0158
   -0.2950    0.2282   -0.6254   -0.3317   -0.1442   -0.0050    0.1590   -0.1163   -0.1653
    0.3261   -0.5544   -0.1209    0.0542    0.1787    0.0570   -0.0464    0.3635    0.1368
   -0.0565   -0.1304   -0.0735    0.0275   -0.0292   -0.0089    0.0339    0.1834   -0.0189
   -0.1018   -0.0341   -0.1845   -0.0951   -0.1869   -0.0519   -0.1268   -0.0532   -0.0304
   -0.0500   -0.1502   -0.1055    0.0160   -0.0255   -0.0255    0.0950    0.2448   -0.0286
   -0.5439   -0.3465    0.3772    0.2257    0.1954    0.2210    0.1178    0.0183    0.2559
    0.1156    0.0171    0.2358    0.1203    0.2312    0.0654    0.1505    0.0993    0.0447

  Column 10
    0.0017
   -0.0075
    0.3667
   -0.0017
   -0.2917
    0.2852
   -0.0178
    0.1133
   -0.0496
   -0.1484
   -0.1509

              LW: {2x2 cell} containing 1 layer weight matrix
Columns 1 through 9
    0.1606    0.2421   -0.9673   -0.1653   -0.5965   -0.4603    0.2691    0.2928    0.3360
  Columns 10 through 11
    0.8000   -0.3565

               b: {2x1 cell} containing 2 bias vectors
0.0721
    0.1056
    0.4108
   -0.0740
    0.5121
    0.1466
    0.1177
    0.2090
    0.1462
    0.1454
   -0.2457
```

'Yield_FinalB_4_3'

```
Neural Network object:

    architecture:

         numInputs: 1
         numLayers: 2
       biasConnect: [1; 1]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]

        numOutputs: 1  (read-only)
    numInputDelays: 0  (read-only)
    numLayerDelays: 0  (read-only)

    subobject structures:

            inputs: {1x1 cell} of inputs
            layers: {2x1 cell} of layers
           outputs: {1x2 cell} containing 1 output
            biases: {2x1 cell} containing 2 biases
      inputWeights: {2x1 cell} containing 1 input weight
      layerWeights: {2x2 cell} containing 1 layer weight

    functions:

          adaptFcn: 'trains'
         divideFcn: 'dividerand'
       gradientFcn: 'calcjx'
           initFcn: 'initlay'
        performFcn: 'sse'
          plotFcns: {'plotperform','plottrainstate','plotregression'}
          trainFcn: 'trainbr'

    parameters:

        adaptParam: .passes
       divideParam: .trainRatio, .valRatio, .testRatio
     gradientParam: (none)
         initParam: (none)
      performParam: .show, .showWindow, .showCommandLine, .epochs,
                .time, .goal, .max_fail, .mem_reduc,
                .min_grad, .mu, .mu_dec, .mu_inc,
                .mu_max
        trainParam: .show, .showWindow, .showCommandLine, .epochs,
                .time, .goal, .max_fail, .mem_reduc,
                .min_grad, .mu, .mu_dec, .mu_inc,
                .mu_max
```

```
  weight and bias values:

            IW: {2x1 cell} containing 1 input weight matrix

Columns 1 through 9

  0.6509  -0.0755  -0.8161   0.6953   0.2249  -0.0567  -0.0110   0.0374  -0.1010
  0.3205  -0.3754  -0.3956   0.3032   0.2333  -0.2098  -0.1001   0.1490   0.0670
  0.3801   0.5514  -0.0720   0.0219   0.0732  -0.2240   0.0054   0.1467   0.0323
  0.1990  -0.1735   0.1862  -0.0897   0.0736  -0.3204  -0.0323   0.3248   0.2343

 Columns 10 through 15

  0.0614   0.0198   0.0920  -0.0892  -0.0223  -0.1286
 -0.0143   0.3412   0.1748  -0.0020   0.2645   0.2142
 -0.0144  -0.0490  -0.2254  -0.1658  -0.0215   0.0857
 -0.1208   0.2963   0.2220   0.0882   0.2359  -0.0505

            LW: {2x2 cell} containing 1 layer weight matrix

0.7807  -0.8271  -0.7423   0.6609

             b: {2x1 cell} containing 2 bias vectors

 -0.2604
  0.1332
 -0.1827
 -0.2807
```

'Yield_FinalC_8_4'

```
Neural Network object:

    architecture:

         numInputs: 1
         numLayers: 2
       biasConnect: [1; 1]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]

        numOutputs: 1  (read-only)
    numInputDelays: 0  (read-only)
    numLayerDelays: 0  (read-only)

    subobject structures:

            inputs: {1x1 cell} of inputs
            layers: {2x1 cell} of layers
           outputs: {1x2 cell} containing 1 output
            biases: {2x1 cell} containing 2 biases
      inputWeights: {2x1 cell} containing 1 input weight
      layerWeights: {2x2 cell} containing 1 layer weight

    functions:

          adaptFcn: 'trains'
         divideFcn: 'dividerand'
       gradientFcn: 'calcjx'
           initFcn: 'initlay'
        performFcn: 'sse'
          plotFcns: {'plotperform','plottrainstate','plotregression'}
          trainFcn: 'trainbr'

    parameters:

        adaptParam: .passes
       divideParam: .trainRatio, .valRatio, .testRatio
     gradientParam: (none)
         initParam: (none)
      performParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
        trainParam: .show, .showWindow, .showCommandLine, .epochs,
                    .time, .goal, .max_fail, .mem_reduc,
                    .min_grad, .mu, .mu_dec, .mu_inc,
                    .mu_max
```

```
   weight and bias values:

              IW: {2x1 cell} containing 1 input weight matrix

0.6650    0.5515   -0.5316   -0.4863   -0.0580    0.2901
   -0.1443    0.0157   -0.0381   -0.0166    0.0524    0.0716
    0.1911    0.0697    0.0305    0.0739   -0.1327    0.0226
    0.2285   -0.2666    0.1579    0.0750    0.1740   -0.1777
   -0.8297   -0.2673    0.4995   -0.1549   -0.1887    0.4259
    0.1518   -0.0380    0.0383    0.0132   -0.0414   -0.0867
   -0.1665    0.1463   -0.1224   -0.0616   -0.0931    0.1367
   -0.7295   -0.3607   -0.5015    0.7976   -0.0751    0.0045

              LW: {2x2 cell} containing 1 layer weight matrix

  -0.9141    0.1812   -0.2359   -0.3270   -0.9511   -0.1815    0.2522   -0.5112

               b: {2x1 cell} containing 2 bias vectors

-0.0818
    0.0838
   -0.1740
   -0.0886
    0.3897
   -0.0747
    0.0947
    0.4049
```