The Adoption of the Taguchi Design of Experiments Theory for the Optimisation of a Cosmetic Manufacturers Effluent Treatment Plant

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Abstract

This thesis describes experimentation undertaken with a chemical precipitation effluent treatment plant based at the cosmetic manufacturer L'Oreal, South Wales. The main aims of the research are to identify methods to achieve greater automatic control of the process and to eliminate consent breaches. In addition recommendations are formulated for the improvement of effluent discharge and treatment costs through the Taguchi Design of Experiments theory.

The characteristics of the effluent are detailed and discussed including estimations of future hydraulic and concentration loadings. The performance of the plant for 1995-1997 is determined and presented.

The Taguchi Design of Experiments theory is applied to determine the optimum plant settings to achieve minimum chemical and discharge costs and maximum percentage COD reduction which are found at Alum pH setting 4.4, Caustic pH setting 6.5, Polymer flow 333ml/min and effluent volume flow 1800 gph. Several confirmation runs prove that these settings provide minimum costs although maximum COD% reduction is not always achieved. Relationships between untreated and treated effluent concentrations are investigated and presented.

Recommendations are formulated and detailed for running cost minimisation and efficiency optimisation. The total implementation costs are £65k yielding savings of £48.75k p.a. A specification of design parameters for a new effluent treatment facility has been formulated and included in the recommendations.

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Nomenclature

Symbols	*Description*	*Unit*
t	Temperature	°K
M	Mass	kg
Cp	Specific heat capacity	kJ/kgK
ϱ	Density	kg/m^3
D	Distortion data	Unit of specific parameter
D1	Mean average of distortion data	Unit of specific parameter
Y1	Predicted value of quality characteristic	Unit of specific parameter
Y_1, Y_2, etc	Value of quality characteristic after Taguchi experimentation	Unit of specific parameter
P	Power	W or kW
T	Turbidity	FTU
TSS	Total suspended solids	mg / l
TDS	Total dissolved solids	mg / l
COD	Chemical oxygen demand	mg / l
BOD	Biological oxygen demand	mg / l
pH	pH value	No Units
L	Financial loss	£
m	Target value	Unit of specific parameter
K	Taguchi loss function constant	No Units
r	Particle radius	m
s	Particle density	kg / m^3
s1	Liquid density	kg / m^3
μ	Liquid viscosity	kg / ms
g	Particle velocity	m / s
Rt	Residence time	Seconds
PL	Production level	Production units
TV	Treatment volume	m^3
S	Cost of treatment and disposal of primary sludge	pence / m^3
R	Cost of conveying waste to sewage works	pence / m^3
V	Average cost of primary treatment at sewerage works	pence / m^3
Ot	COD of discharge	mg / l
Os	Average COD of all effluent received at the treatment works	mg / l
B	Cost of biological oxidation treatment of settled sewage	pence / m^3
C	Total cost of trade effluent	pence / m^3

Abbreviations

ASP	-	Activated Sludge Process
EPA	-	Environmental Protection Act
PPS	-	Prescribed Processes & Substances
EA	-	Environmental Agency - England & Wales
SEPA	-	Scottish Environmental Agency
DOE	-	Design of Experiments
MBR	-	Membrane Biological Reactor
OFG	-	Oils, Fats & Greases

NB 'Unit of specific parameter' denotes that this symbol may represent a number of differing parameters.

1 Introduction

1.1 Company Background

L'Oréal Golden Ltd at Llantrisant South Wales was opened in November 1973 and is a subsidiary of the French cosmetics company whose head office is based in Paris. The organisation has over 150 manufacturing and logistic facilities in 150 countries, employing over 40,000 people worldwide.

The Llantrisant factory (Figure 1(a)) manufactures facial cosmetics and hair care products mainly for the UK and Japanese markets and occupies a 46,000 square metre site. The facility operates 16 hours per day, 6 days per week and during very heavy production periods 24 hour/day operation has been implemented. In 1997 the highest level of production was celebrated by the factory generating over 120 million units.

The company is subdivided into three main production centres PC1, 2, and 3. PC1 produces all facial cosmetics, lotions, creams and certain shampoos, whereas PC2 manufactures all hair colorants, dyes, perms and shampoos. Production centre 3 is responsible for hair sprays and mousses. Products associated with L'Oréal include Ambre Solaire, Nutralia, Elvive Shampoo and Elnett Hair spray.

The factory utilises over 800 raw materials for its products and all are variable in chemical nature and form. Over 670 products are manufactured in various quantities and it is predicted that production is set to increase in the future from the 1997 level of 120 million units to the 150 million target in 1998.

The company is market driven developing new products as and when the market dictates with a very rapid "conception to launch" time. Production is based upon the "Just In Time" philosophy in order to minimise unnecessary storage. The London based marketing department provides the production requirements to the factory and, once manufactured, the units are transported to the Manchester storage facility where distribution to the retailers is coordinated.

1.2 Effluent Treatment Plant

Effluent is generated by cleaning operations in the production centres and any accidental spillages of product or raw materials. The treatment plant is of the chemical precipitation type with a Dissolved Air Flotation unit for floc removal. The treated effluent is sewer discharged and the sludge is land filled after centrifuge dewatering.

1.3 Definition of the Problem

The Llantrisant factory manufactures many different products each with varying raw material types and quantities. The constant development of new products, their extreme variability and the unpredictable levels of production have resulted in the generation of complex and extensively variable effluent concentrations which has proved to be problematical to treat. Unforeseen accidental spillages have further accentuated effluent instability.

The effluent plant is manual in its operation sometimes necessitating manual control of dosing pumps to bring the process under control when highly concentrated effluent is being treated. The plant is coming to the end of its useful life and its replacement will be required in 2-3 years. The operator undertakes many jar tests to determine plant settings using only pH and visual assessments to establish treatment quality. This process may consume 2-3 hours entailing the re-treating of large quantities of effluent if, after the final plant settings have been inputted, the operator deems treatment unacceptable. This results in the excessive consumption of chemicals, electrical energy and inefficient use of human resources.

The effluent, when finally discharged to sewer, is checked using only pH and a visual assessment for quality. Although composite samples are issued to Hyder Environmental for analysis the results are provided up to one week later, therefore consent breaches will only be known long after discharge.

1.4 Legislation and Market Pressures

During the last ten years considerable developments have been undertaken in the field of Environmental Protection and Management. In the UK the Government is the policy maker which is greatly affected by the European Union, United Nations and International developments. Drivers for policies include scientific research findings, public concern, media attention, pressure groups, think tank inputs etc. International debates result in commitments / principles for governments to adopt and such debates are a two way process enabling all member States to influence final agreements.

The main UK Environmental statutes are:

- Environmental Protection Act 1990
- Water Resources Act 1991
- Water Industry Act 1991
- Clean Air Act 1993
- Radioactive Substances Act 1993
- Environment Act 1995

The Environmental Protection Act 1990 Part 1 covering Integrated Pollution Control (IPC) / Air Pollution Control, Part 2 detailing Waste and Part 3 covering Torts of Nuisance are all potentially relevant to L'Oréal's effluent plant. Sewer discharges are regulated primarily by the Local Water Authority and discussions with Welsh Water suggest that the COD and Suspended Solid discharge consents will be reduced by up to 50% within ten years. Such reductions will not be imposed abruptly but measures must be taken now to accommodate and prepare for these changes. The EPA 1990 Part 2 covering waste affects L'Oréal with regard to sludge land filling. The introduction of the landfill tax promotes the minimisation of effluent production and recycling of sludge for agricultural / incineration purposes priority projects. Although the Llantrisant factory handles comparatively small volumes of effluent and IPC is not applicable, responsibility and control must be taken of the aggregate effect of small installations discharging effluents. The European Commission has recognised this and issued a working paper accordingly.

As previously stated L'Oréal is a market driven company and market image and status is crucial. Environmental issues are vital to the prosperity of such an organisation as a 'dirty polluting' image would be damaging in such a sensitive market. Cosmetics and toiletries are personal products applied directly to the body therefore consumers will wish to use such items with the knowledge that Environmental responsibility has been taken during their production.

Environmental projects are also major business issues as Environmental Management Systems, Waste Minimisation, Energy Management and ECO Labelling schemes are excellent opportunities for cost reductions and are powerful advertising tools. In addition, violation of discharge consent levels will result in fines and adverse publicity.

Therefore, in summary, legislative and market pressures will ensure that L'Oréal's effluent plant performance must be addressed in line with all the company's environmental issues.

1.5 Definition of the Project

The project commenced in October 1995 and formed part of a teaching company scheme between the University of Glamorgan and the host company L'Oréal.

The main aims of the project were as follows:

- To identify methods to achieve a greater level of automated control of the effluent treatment process.
- To identify methods / systems to ensure L'Oréal does not breach consent limits
- To formulate suitable recommendations for the improvement of effluent discharge quality and treatment costs through the application of the Taguchi Design of Experiments theory.

The project aims were categorised into a series of objectives:

- To identify and assess the process and associated operations.
- To identify the existing and assess the future effluent loadings, flows and concentrations.
- To identify and assess the process performance and efficiency.
- To apply a Taguchi Design of Experiments approach to plant optimisation.
- To formulate suitable recommendations for L'Oréal for improved plant efficiency.

1.6 Structure of the Thesis

Chapter 2 identifies the process and any problems / limitations associated with the operation. A description of effluent generation is also provided in addition to a summary of alternative treatment methods.

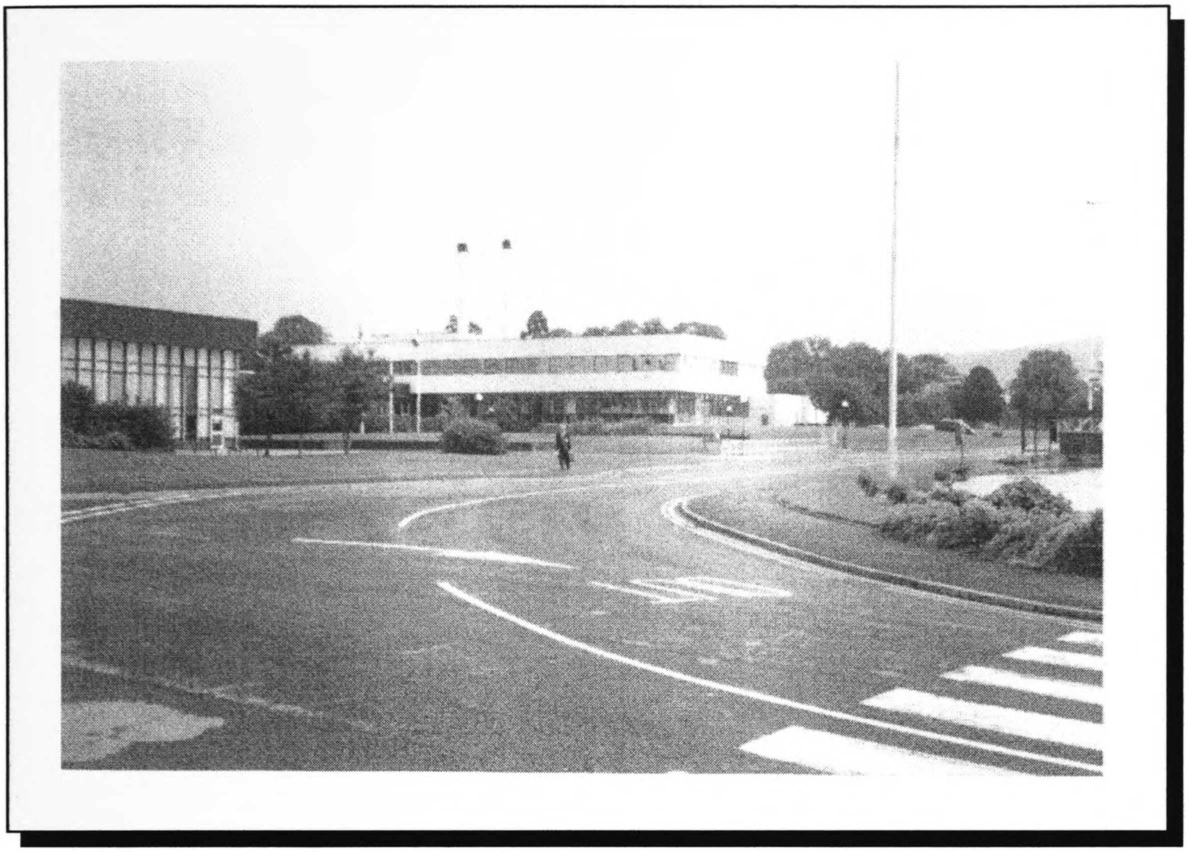
Chapter 3 discusses the influent characteristics and concentrations for 1995 - 1997 including selected raw material details.

Chapter 4 details the performance of the treatment plant concentrating on 1995 - 1997 including all associated treatment costs. Performance indicators have been provided and the future effluent loading predictions discussed.

Chapter 5 details and discusses the application of the Taguchi Design of Experiments theory to L'Oréal's effluent plant for optimisation including all results, implementation costs and cost savings. Interrelationships between certain parameters are also provided and discussed.

Chapter 6 identifies the main conclusions drawn from the project and details recommendations for implementation including all costs and estimated savings / payback period.

Figure 1(a) **L'Oréal Llantrisant Factory**



2 Identification of the Process

2.1 Production Techniques

The Llantrisant factory has eight manufacturing sections each assigned to a specific production centre which house process and storage vessels for the production of the toiletries. All the raw material ingredients, e.g. powders, liquids, crystals, are added to a process vessel and are mixed with a base solution which forms the majority of the product, e.g. alcohol, demineralised / sterile water. The product is thoroughly mixed via mechanical agitation followed by steam heating and finally cooling with refrigeration coils. Figures 2(a) and 2(b) show a 12 Tonne shampoo vessel and storage vessel respectively. All the ingredients and manufacturing methods / thermal requirements are specific to each product and are confidential.

After manufacture the product is transferred into portable vessels for transportation to the production line or, if the product is of low viscosity, pumped through compressed air operated diaphragm pumps directly to the lines. Each Production Centre manufactures different products and an abbreviated summary is provided below:

PC1 manufactures general cosmetics / toiletries such as facial creams, sun block creams, gels, lotions, shampoos.

PC2 manufactures hair products such as dyes, perms, colorants, shampoos.

PC3 manufactures hair care products such as hair sprays and mousses.

Production is on a batch basis with a Just In Time manufacturing policy and minimal finished stock is held in storage. Many products are seasonal e.g. Ambre Solaire and up to fifty differing ingredients can used in a product 'recipe'.

2.2 Effluent Generation and Origination

2.2.1 Cleaning Operations

After the manufacture of a product all the associated equipment is cleansed / sterilised and effluent is generated by the following operations:

- Cleaning and sterilisation of process and storage vessels.
- Cleaning and sterilisation of production lines and utensils.
- Washbay floor cleaning.
- Accidental spillages.
- Tank farm bunded area rainfall.

The majority of the effluent is generated through process vessel cleaning / sterilisation which is categorised into the following main methods:

- The flushing of vessels with 80°C demineralised water followed by steam sterilisation at 1 bar dry saturated condition. Compressed air blow cooling is used for drying.
- The mixing of incoming mains water with steam at 4 bar dry saturated condition and the resultant 80°C water is fed via a rotating sprayball mechanism into the vessel. Blow cooling is again provided.
- The Kewash System is employed in manufacturing sections 1, 4, 6 and 7 for the cleaning of certain vessels. Water is pressurised to 150 bar with two 6.9 kW pump sets and cleaning is achieved by the cutting action of the water. The water flowrate is 1150 litres per hour. The cleaning cycle is approximately 20 minutes, depending on the vessel size, requiring approximately 400 litres of cold water per cycle.
- The cold water flushing of vessels by a hand held mobile hose or via a spray connection located inside the vessel.

Secondary cleansing operations include the cleaning of production lines with demineralised water/steam sterilisation to prevent cross contamination of products and utensil washing with hot water. In order to maximise the efficiency of cleaning, a detergent containing Sodium Hydrochloride and Disodium Matasilicate is sometimes employed. Hobart units fitted in certain manufacturing areas are utensil washing machines fed with steam at 4 bar dry saturated condition and mixed with mains water providing 60 - 90°C water.

Except for large accidental spillages, minimal communication is provided between the Production Centres and the effluent plant.

2.2.2 Effluent Drainage System

The factory has three main drainage systems: the domestic drains convey water and sewerage from the sanitary and kitchen appliances to the domestic sump prior to Welsh Water sewer discharge. The surface water / rain water flows directly into the river via gravity and the effluent discharges into a dedicated trade waste system located under the factory. The trade waste pipework is of stainless steel construction above ground level and ceramic earthenware below.

No segregation of waste streams is provided nor is it practically / economically possible, therefore the effluent streams combine to form one flow. Manholes are provided at various locations to facilitate inspection, cleaning and maintenance.

2.2.3 50,000 Gallon Buffer Storage Tank

The effluent flows to a trade sump and is pumped into a 50,000 gallon buffer storage tank Figure 2(c) which is of steel construction and approximately 15 years old. High level alarms are fitted, linked to an alarm panel in the engineering workshop.

2.3 Current Effluent Treatment Process

2.3.1 Building

The treatment plant (see Figure 2(d) for schematic detail) is located in a dedicated building adjacent to the electricity incoming substations and opposite the boiler plant room. The building is a steel structure with profiled aluminium cladding having an age of 15-20 years and is in fair condition (Figure 2(e)). A full condition appraisal for the plant is provided in Appendix 1.

2.3.2 Chemical Contact Chamber

From the 50,000 gallon buffer tank the effluent passes into the chemical contact chamber (Figure 2(f)) via a 2.2kW submersible pump set with a standby unit. Flow is controlled by a manually operated valve linked to a flow meter. The chamber is of stainless steel construction having a volume of $3m^3$ and consists of 4 separate chambers into which the treatment chemicals are introduced separately. The maximum flow through the unit is 11.4 m^3/h based upon a retention time of 15 minutes. Aluminium sulphate is added in the first chamber depressing the pH value followed by violent mechanical agitation to initiate coagulation. A probe records the pH value after alum introduction, which is fed to the main control panel (Figure 2(g)). The required pH is selected manually and a pulsating dosing pump is automatically controlled via a closed loop system. The pump is powered by a 0.15kW motor and the chemical is delivered through 6mm diameter flexible polyethylene piping.

The second section of the chamber is where the caustic soda is introduced, to raise the pH value, followed by gentle mechanical agitation. Chemical introduction and control is the same as the alum system.

Polyelectrolyte to complete coagulation / flocculation is added in the third section via a 0.15kW centrifugal pump. The flow is continuous and is manually adjusted with a calibrated hand dial. Gentle mechanical agitation is provided.

The effluent then passes into the final section where it is discharged into a funnel exit and flows by gravity to the dissolved air flotation unit. The contact chamber and associated controls were installed in 1993 by Environmental Engineering Ltd of Lincolnshire and are in good general condition.

The alum and caustic pH control settings are generally in the range 4.0 - 4.6 and 6.0 - 6.8 respectively and these values are determined on a trial and error basis. The dosing pump maximum flowrates are $0.05m^3/hr$, $0.025m^3/hr$ and $0.06m^3/hr$ for the alum, caustic and polymer respectively. The pumps generally operate at 40 - 60% of their capacity.

2.3.3 Dissolved Air Flotation Unit

The DAF unit (Figure 2(h)) was supplied by Aquatec of Warrington. The unit is in poor condition and approaching the end of its working life. The effluent and flocs pass into the side of the unit at the base via stainless steel pipework and a proportion of the treated water is passed into the pressure vessel where air is introduced at 5.5 bar gauge. The oxygen rich water is then transferred into the DAF through a sparge pipe arrangement in the base of the unit. A chain scraper mechanism removes the sludge from the water surface discharging it into a 18m^3 collection pit. The treated water passes over a weir in the DAF unit into a discharge pipe and flows under gravity to the domestic sump. There it is combined with domestic sewerage and pumped to the Welsh Water sump via 2.2kW submersible pumps. Alternatively the effluent can be transferred to the rear of the site to be finally 'polished' through a silo trickling filter or stored in an aeration tank, via transfer pumps located in the effluent plant building.

2.3.4 Sludge Collection Pit and Centrifuge

The sludge is removed from the pit with a pump set and passed into a centrifuge manufactured by Centriquip of Derbyshire. The centrate is recycled back to the DAF unit and the sludge transferred to skips for landfill organised by the site based waste contractor. The centrifuge (Figure 2(I)) is in fair condition, however maintenance costs of over £7000 for 1996 have proved that the unit is becoming unreliable and replacement may be necessary. The unit has an 11kW motor operating at 1500rpm and can process 1 m^3/hr of sludge [Centriquip 1997]. The water content of the treated sludge is generally 28%. Polymer is added to the untreated sludge prior to centrifuge entry which is stored and mechanically agitated in a tank adjacent to the centrifuge.

2.3.5 Silo Trickling Filter

The unit is of concrete construction and was the result of extensive experimentation in conjunction with Cardiff University in 1982/1983. Small perforated plastic discs of 100mm diameter are the media used for bacteria growth. No biological nutrients are provided to the filter however, historically, reductions in COD concentrations have been found. The design flowrate is 7.5 m^3/h. After treatment the effluent passes to the Welsh Water sump for sewer discharge. An antifoam agent is introduced to the filter to minimise the undesirable effects of foaming. The agent is delivered in 50 litre drums and is positioned over the filter intake buffer tank and the discharge tap opened and manually adjusted to effect a gradual flow into the effluent.

The Welsh Water discharge sump has run/standby submersible 3.7kW pumps transferring the effluent through 100mm diameter polyethylene pipework to the sewer entrance located in the garden of a private residence.

2.3.6 Aeration Tank

A redundant 795 m^3 aeration facility is provided at the rear of the site adjacent to the trickling filter. It was originally part of an electro flocculation plant which was decommissioned in the late 1970's. It is presently employed as an emergency storage facility for times when effluent concentrations have rendered treatment unacceptable for discharge and the effluent is pumped via the transfer pumps to this tank. It is then blended with effluent of a less concentrated nature in the buffer storage tank for re-treatment. The HSE guidance note [HMSO 1992] recommends the avoidance of water stagnation and materials in water that harbour or provide nutrients for microbial growth, therefore the aeration facility could be a source of such problems at L'Oréal if large quantities of effluent are stored for long periods.

2.3.7 Chemical Storage and Handling

All the chemicals used are provided by Aquatreat of Bridgend and details are presented in Table 2(I). The aluminium sulphate is stored in a 9 tonne vessel and the caustic soda in two 2050 litre stainless steel vessels. The alum is transferred from the 9 tonne tank to a 4050 litre stainless steel vessel prior to contact chamber introduction.

The polyelectrolyte is delivered in powder form to be mixed with water prior to use in a combined mixing and storage vessel.

Dedicated off loading stainless steel lines are provided for chemical deliveries located external to the effluent plant building.

2.3.8 Methods of Sampling

Hyder Environmental of Bridgend take treated samples every Tuesday and Thursday to ensure that the effluent does not exceed the Welsh Water consent limits. All results are tabulated and issued monthly to L'Oréal, France. Welsh Water take samples for compliance assessment and charging purposes at regular intervals and their visits are undertaken with no prior warning to L'Oréal.

2.3.9 Preventative Planned Maintenance

General plant maintenance is undertaken 'in house' or by site based sub-contractors under a Preventative Planned Maintenance (PPM) scheme, however specialist repairs/maintenance is undertaken by equipment manufacturers. The buffer storage tank is drained, flushed and visually inspected annually. Painting and corrosion protection is applied every 4-5 years and Magnetic Particle Inspection (MPI) / X Ray testing every 10 years. The domestic and trade effluent sump pumps are all interchangeable and spare units are provided in the Engineering Workshop.

2.4 Operational Difficulties and Plant Limitations

During the initial research operational difficulties and plant limitations were highlighted with the treatment facility and are detailed below:

The plant exhibits design limitations particularly in flexibility and quality of treatment:

- $225m^3$ buffer storage tank does not have mechanical agitators reducing effluent homogeneity.
- No automated influent control valve is fitted necessitating manual flow adjustment.
- No monitoring equipment is provided for influent/treated effluent streams relying on visual inspection for plant set up and discharge quality assessment.
- Pipework route from contact chamber to DAF unit is tortuous incurring high velocities and turbulence shearing flocs.
- DAF unit 'beach' gradient too high resulting in the backflow of floc into the DAF unit.
- The domestic sump pump after the DAF unit cannot accommodate an effluent flowrate duty of over 1800 gallons per hour, ($8.2m^3/hr$).

The plant exhibits operational limitations resulting in reduced flexibility and quality of treatment:

- The plant is operated under the control and jurisdiction of the engineering department with minimal liaison from production and industrial chemistry departments.
- No detailed operational procedures are provided therefore treatment is dependent on the experience of one operator.
- Polymer dosing pump and storage / mixing tank is corroded and inefficient resulting in inconsistent polymer concentration and dosing quality.
- Polymer is introduced in the third section of contact chamber reducing contact time between aluminium sulphate and caustic soda chemicals resulting in limited coagulation and therefore particle removal.
- Despite an upgrade in 1993 for automation, the plant is manually intensive in its operation requiring an operator in attendance throughout treatment.

2.5 Alternative Methods of Treatment

2.5.1 Physical Treatments

Physical treatments include coarse and fine filtering of particles via sand filters and settling tanks, etc. Such methods are suitable for when insoluble colloidal particles and larger matter are to be removed. Many physical plants are employed as pre-treatments for biological and chemical systems e.g. reservoirs act as large settling tanks for the Water Authorities.

Filter apertures must be quite small for effective filtration and therefore impose a fairly high fluid pressure loss, also a cake of particles builds onto the screen further increasing pressure loss. The increase in cake size will improve filterability however a point will be reached whereby the unit only permits a trickle of very clear water.

True Screens are whereby meshes, sieves, cloths, etc. are located in housings which permit removal / access for cleaning and disposable screens are those which are replaced after each filter cycle (e.g. paper / cartridge filters). Micro strainers are true screens whereby a rotating drum houses a fine wire mesh filter media. Raw water enters the drum centre and passes through the mesh via gravity. Cleaning is achieved via high pressure water jetting of the drum as it rotates. Mesh apertures are usually 25 + microns in diameter [Solt and Shirley 1991].

Pre-coat Filters are semi-disposable whereby a coarse filter is provided, onto which a layer of pre-coat media is sprayed, which collects around the pores of the mesh reducing their diameter and providing finer filtering. When dirty, the filter is cleansed by back washing off the pre-coat prior to the application of a new coat.

Deep Bed Filters consist of vessels which contain a bed of very fine granules. Raw water flows through the vessel and particles are trapped via a number of differing methods. The pores between granules may be too small retaining the particle or a cake of matter may form between granules reducing the filter pore diameter increasing the filterability of the unit. Back washing is performed upwards to allow bed expansion to release the suspended solids and agitation is provided to enhance / accelerate the process. The sand beds are arranged with the coarsest granules at the bottom. Multi media filters utilising differing grades of materials arranged in layers are employed, however care must be taken to ensure the differing materials are retained in their respective layers. Typical advantages of deep bed filters include [Solt and Shirley 1991]:

- Filtration of fine particles 2 - 3μm
- As particles collect in one location coagulation is promoted.
- Deeper beds generally improve filtration quality.
- Running costs are reduced as no chemical or nutrients, etc, have to be provided.
- Minimum moving parts improve reliability and reduce maintenance requirements.

2.5.2 Biological Systems

Biological systems are widely employed in applications such as minute colloidal and dissolved organism removal e.g. sewage, food and drink production, textile production etc. Such treatments are sometimes employed as final 'polishing' mechanisms to physical / chemical systems in addition to acting as complete treatments.

2.5.2.1 Aerobic Digestion

Aerobic biological treatment plants employ bacteria to oxidise organic substrate present in the effluent resulting in bacteria growth and the generation of nitrogen. The major pollution removal mechanism is the conversion of organic matter to more aerobic organisms resulting in a high rate of sludge growth, which requires thickening or de-watering prior to disposal [Tebbutt 1998].

Aerobic or activated sludge plants are based on the principle of effecting the input of air and hence oxygen into the sludge for maximum bacteria growth for wastewater treatment. Large aeration tanks with mechanical agitators promoting air input may be provided. Recent developments include the injection of air via compressors providing far greater control of oxygen input and hence bacteria growth. Injection is via sparge pipes giving excellent and uniform air distribution. Oxidation rates are affected by the effluent's pH level and must be considered during plant design [Pontius 1990].

The Vitox system injects pure oxygen requiring less volume flow than the air system and such a plant will be able to respond to 'shock' loading which is due to the rapid growth in bacteria. The injection system will have to be carefully considered at the design stage and regular maintenance will be required. The system design must include non return mechanisms to eliminate the possibility of effluent back flow into the injection system.

Trickling Filters (Figure 2(j)) are where the effluent cascades over layers of packing onto which bacteria grows digesting the waste. Air passes naturally from the base of the unit through the packing media and is counter current to the effluent flow. The first unit was commissioned in 1893 at Salford. Trickling filters are categorised by BOD and hydraulic loading.

The packing may be slag, clinker, stone, rock, etc. having a depth of 3-8 metres. BS 1438 details the main properties to consider when selecting the media e.g. weight, roughness, size and area. The introduction of plastic discs for media in 1963 enabled high rate filters to be developed. Such discs provide a very efficient treatment/m^2 of area. Grooves / slots may be provided maximising surface area and 'bug traps' ensuring excellent bacteria growth.

The main housing may be cylindrical or rectangular in shape and is generally concrete/brick in construction. The effluent is introduced to the unit via a distributor ensuring uniform dispersion. In order to reduce the BOD and ensure uniform hydraulic loadings a small proportion of treated effluent is re-circulated from the clarifier.

Trickling filters provide excellent treatment of shock / unpredictable loads and are employed in applications for the removal of heavy metals, phenols and cyanide. Regular inspection and maintenance must be undertaken and generally operational difficulties are associated with overloading. The fly species Psychoda and Sylvicola may cause problems, especially in hot climates. Pesticides and treatments may minimise colony growth but care must be taken when treating waters for drinking use. There are several hand books which describe the operation, maintenance and other associated issues with such treatment facilities, such as Ciaccio (1973).

2.5.2.2 Anaerobic Treatment

Anaerobic biological treatment is where oxygen is excluded from the process and the bacteria employed must have an oxygen free environment to survive. The process results in the generation of carbon dioxide and methane and the latter can be used for combustion applications.

Large organic molecules e.g. protein, starch, etc. convert into simpler molecules which are used as the substrate by the methane generating bacteria known as methogens. In order to maximise operating efficiency the temperature must exceed 25°C with the optimum achieved at 37°C. Process activity ceases below 10°C and excessive temperature variation results in poor performance. The optimum pH value is 6.8 - 7.5 [Deakin 1996].

The bacteria responsible for such a process are generally found in small quantities at the base of lakes, animal intestines, soil etc. and can be purchased from companies which are dedicated suppliers of chemicals and bacteria for effluent treatment plants. These companies generally provide a full consultation and research service to ensure the correct chemical/bacteria strain are selected for the application.

Anaerobic process designs are infinitely variable and are almost always custom built systems. Usually digestors are of the high rate type as shown in Figure 2(k) whereby agitation is employed to reduce surface scum from forming and to promote greater mixing between the bacteria and wastes. The methane that develops exits the top of the digester and is stored in holding tanks. The retention time for wastes varies, depending on the application and is 20 - 25 days for a typical sewerage plant [Solt and Shirley 1991].

2.5.3 Membrane Process

Membrane processes are becoming increasingly popular for effluent treatment. All treatments employ a membrane of a certain design allowing particular substances to flow through while retaining others. Membranes have two passages through which the untreated and treated waters must flow without cross contamination. In addition, a driving force must be applied to allow effluent passage through the membrane. Systems are categorised into three types:

- Reversed osmosis, where the membrane permits the passage of water and dissolved molecules, but retains suspended solids/colloidal particles, ionised salts etc. Hydraulic pressure is applied for effluent flow.

- The ultrafiltration technique has membrane pore sizes to suit the matter to be filtered. Water and particles with a diameter less than the membrane pore size will pass through the unit and hydraulic pressure provides the driving force.

- Two membranes of cation and anion exchange material are provided in the electrodialysis filtration system. The membranes permit the passage of small cations and anions but retain all water, suspended matter, non ionic dissolved materials etc. Electromotive force is the transfer method.

In order to protect the membranes, pre-filters are employed removing coarse matter. High turbulence resulting in a 'scrubbing' action removes matter trapped in the membrane.

2.5.4 Alternative Treatments Applied to L'Oreal

Physical treatment alone cannot process L'Oréal's effluent to within consent levels. Sedimentation and / or deep bed filters will reduce the suspended solids, oils, fats and greases, anionic detergents and COD concentrations, however, certain colloidal particles and dissolved materials will pass through these filtration mechanisms. In addition, chemical introduction may be required to ensure that the pH is within consent limits.

Biological systems are employed in selected cosmetic manufacturers where [ETC 1996]:

- BOD / COD loading can be accurately assessed for current and future effluents.
- 'Shock loads' both hydraulically and from effluent concentrations are minimised, resulting in a stable BOD / COD loading.
- The effluent contains specific constituents but minimal / no materials which are inhibiting to micro-organisms.

Such treatment methods have been considered for the Llantrisant plant, however the following disadvantages have rendered such systems impractical:

- The aforementioned factors cannot be satisfied / guaranteed.
- The installation costs are prohibitive, at greater than £1 million.
- The limited success of the silo trickling filter has not generated satisfactory confidence in the application of aerobic processes to such effluents, even though 'shock loads' should not present problems with such systems.
- Parfit and Cooke [Parfit and Cooke 1997] recommended that such treatment methods are not suitable for L'Oréal's application.

Membrane processes are not suitable for the reduction of anionic detergents to the L'Oréal consent limits due to their molecular form. As with physical systems, pH correction may be required after treatment.

Figure 2(a) 12 Tonne Manufacturing Vessel

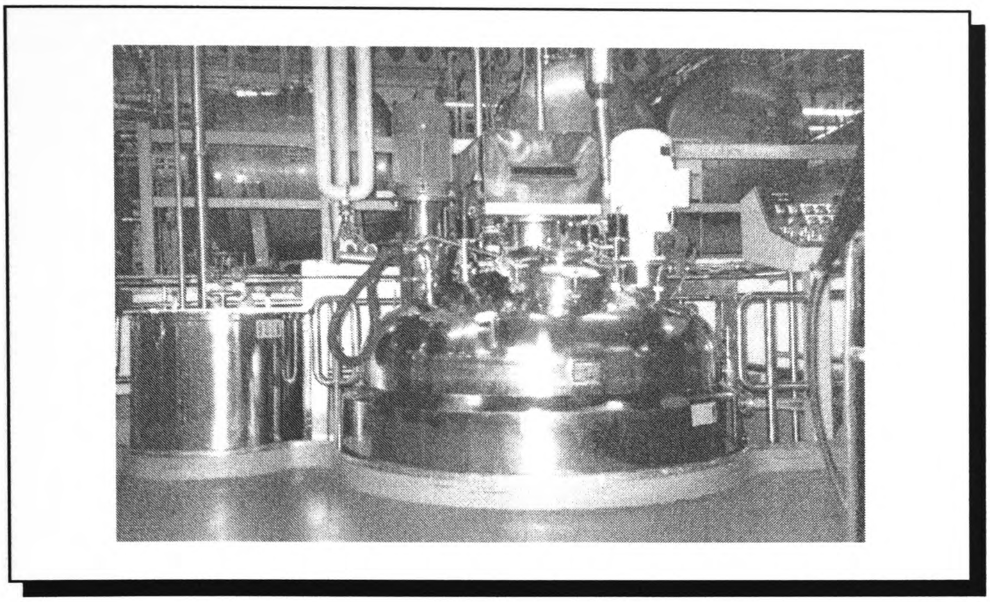


Figure 2(b) 12 Tonne Storage Vessels

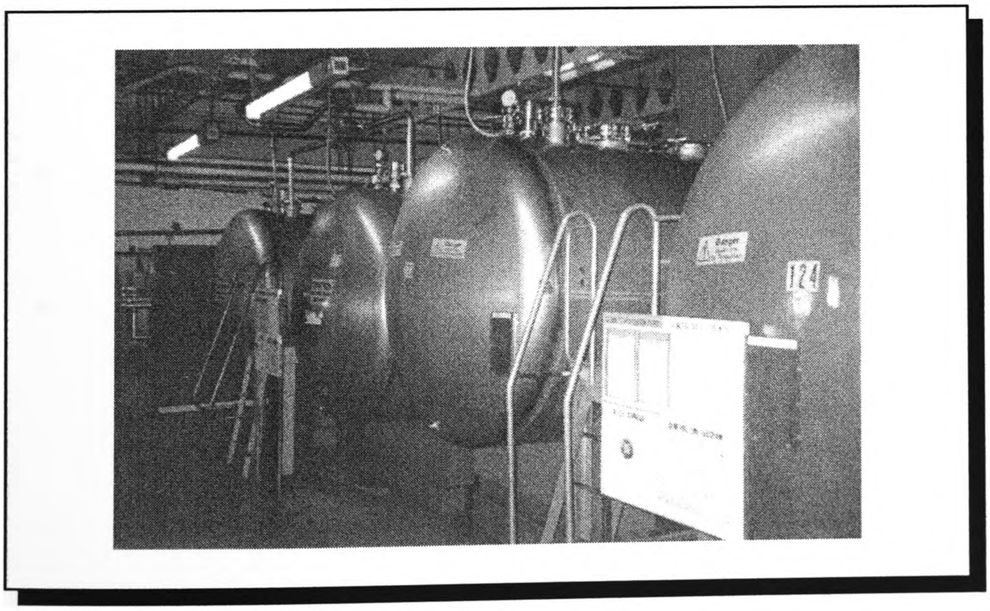


Figure 2(c) **50,000 Gallon Buffer Storage Tank**

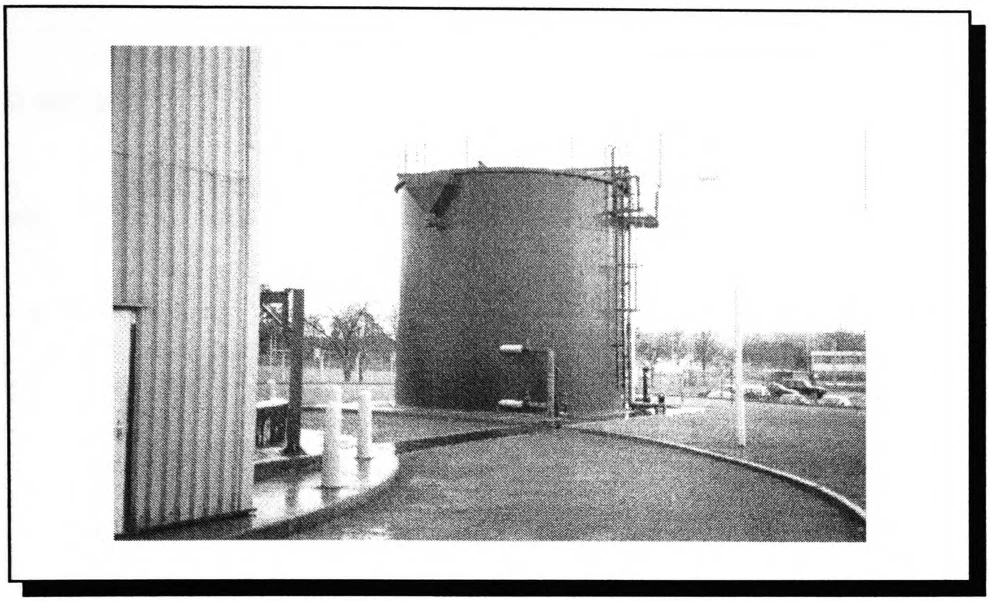


Figure 2(d) Schematic Diagram of Effluent Treatment Plant

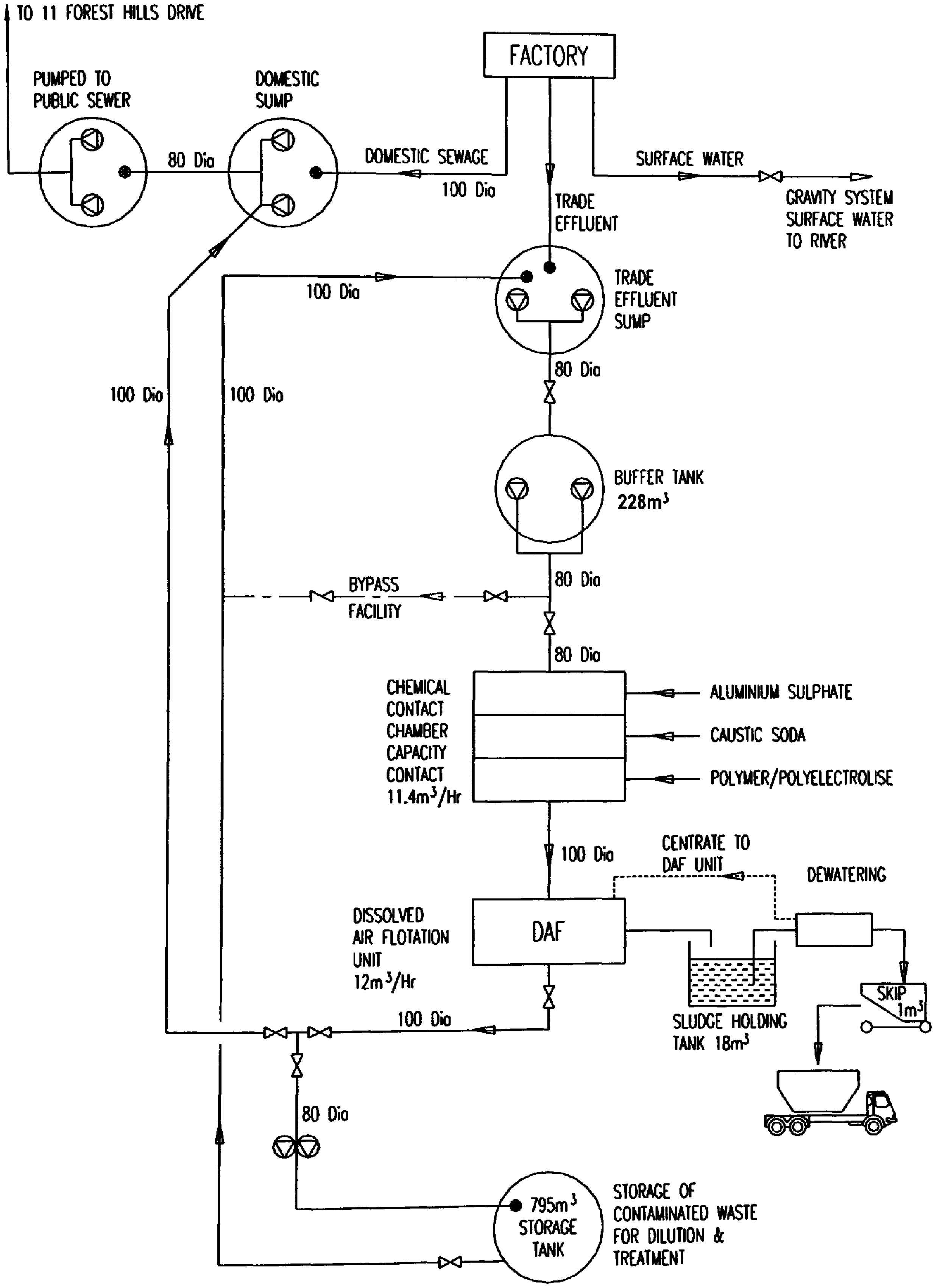


Figure 2(e) **Effluent Plant Building**

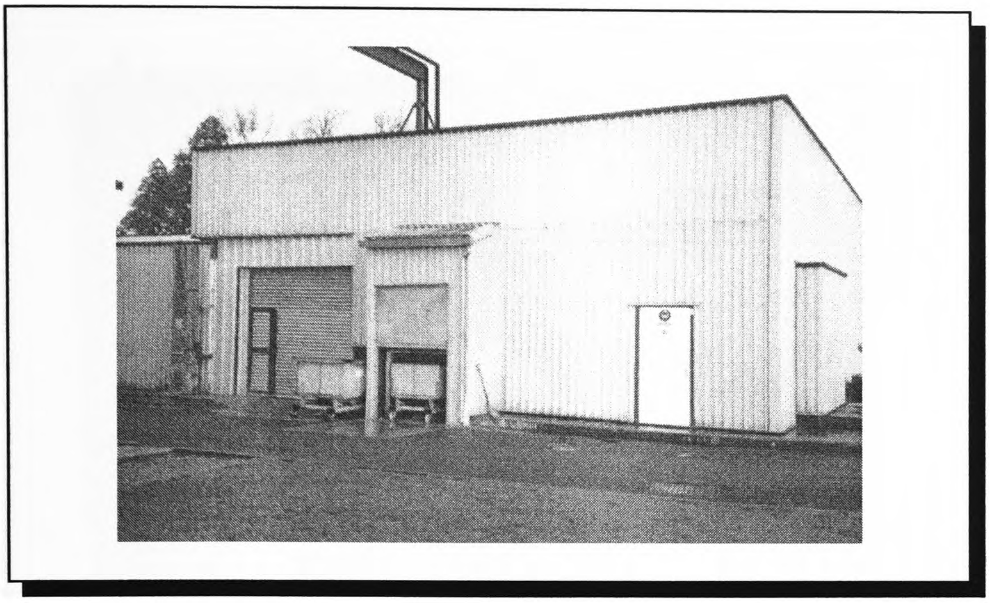


Figure 2(f) **Chemical Contact Chamber**

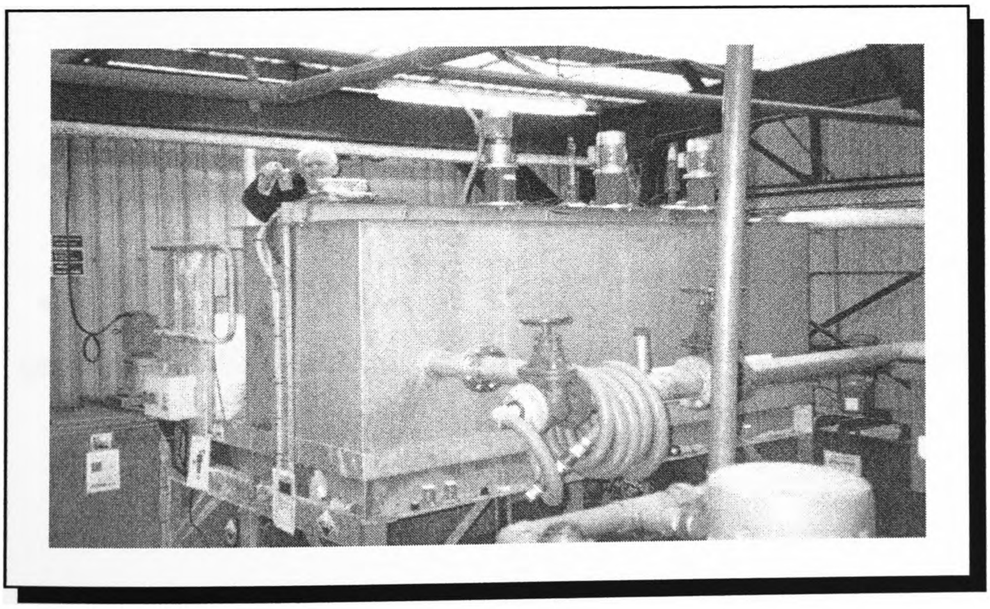


Figure 2(g) Chemical Dosing Control Panel

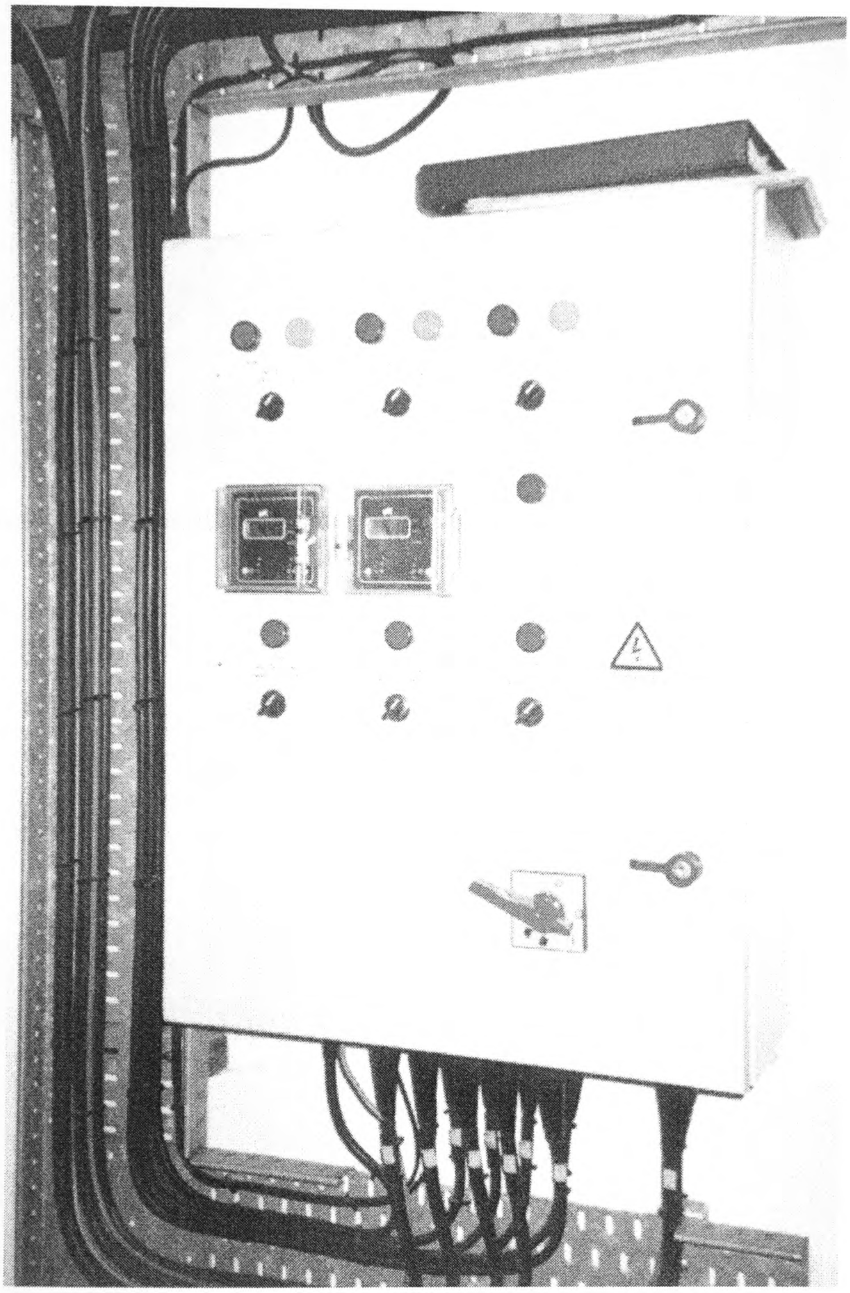


Figure 2(h) Dissolved Air Flotation Unit

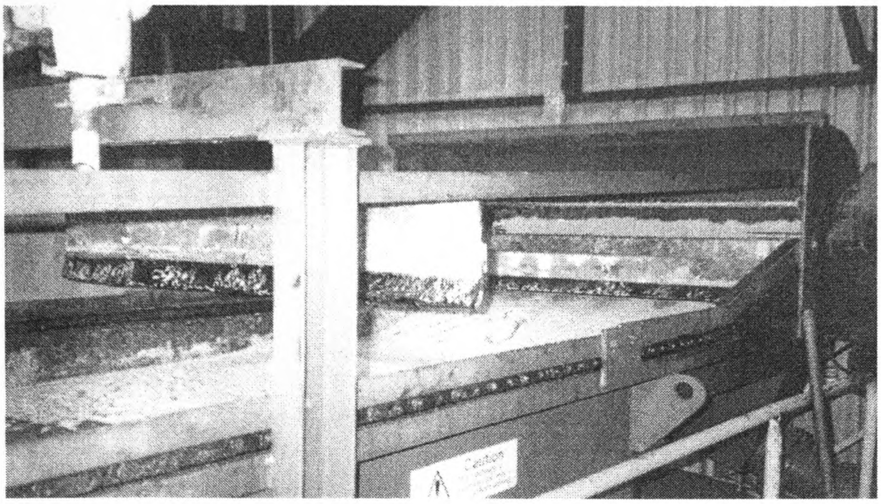


Figure 2(I) Centrifuge

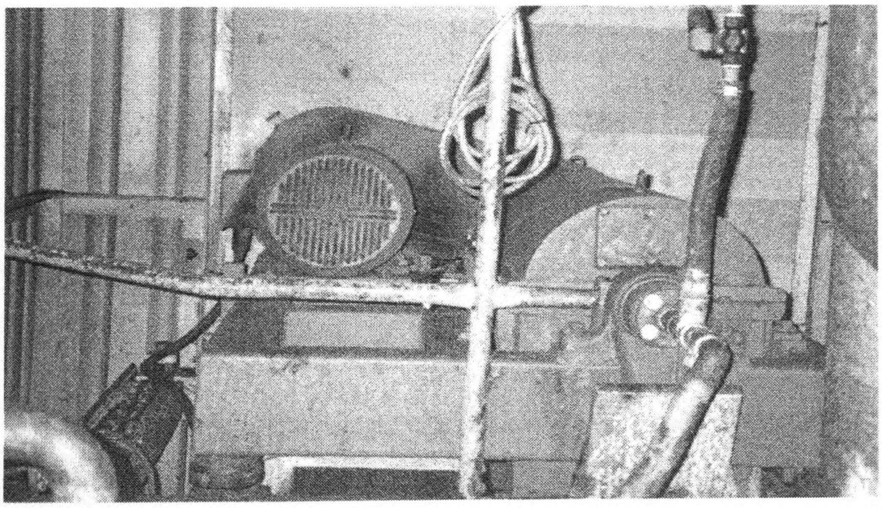


Figure 2(j) Trickling Filter System

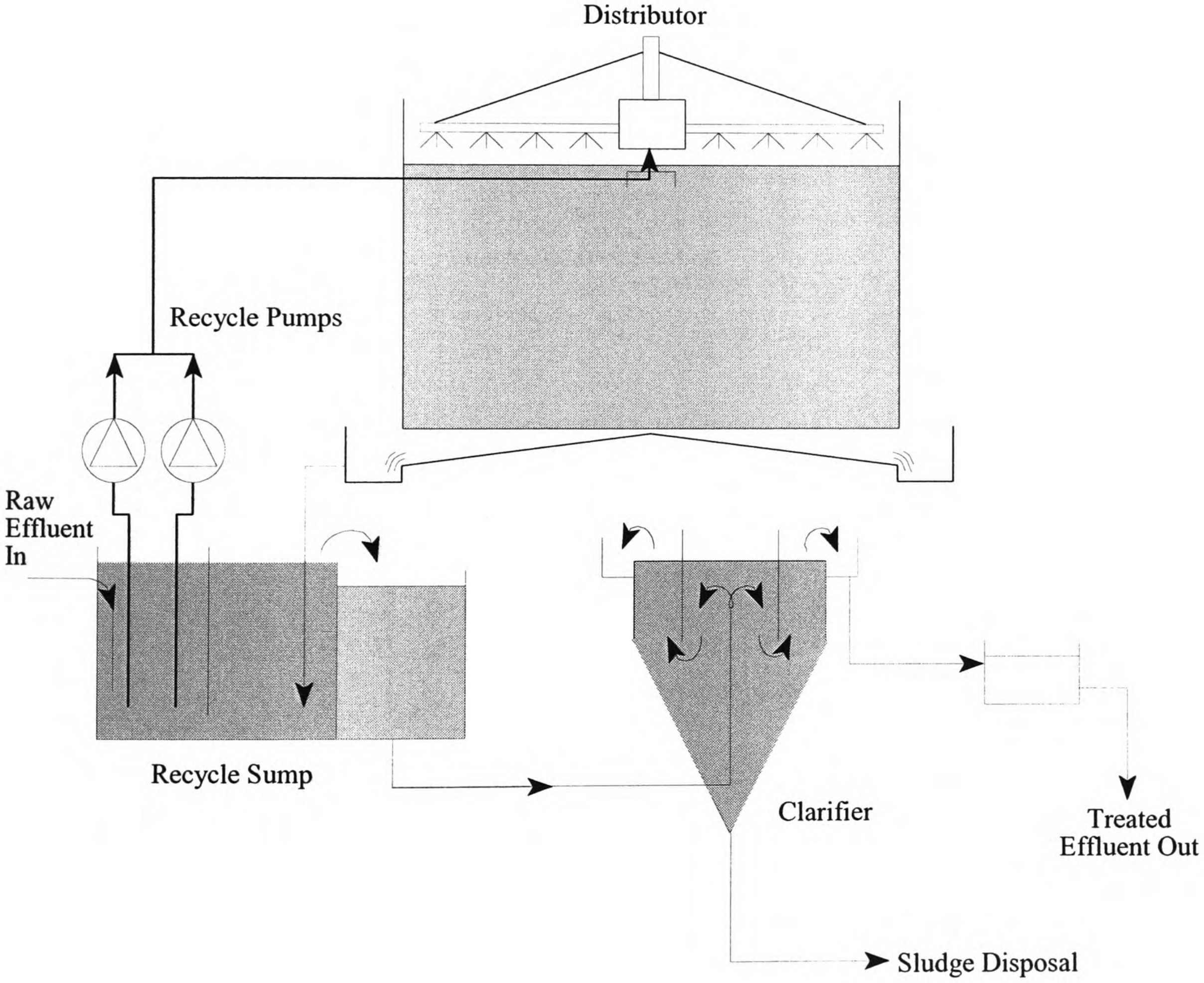


Figure 2(k)   High Rate Digester

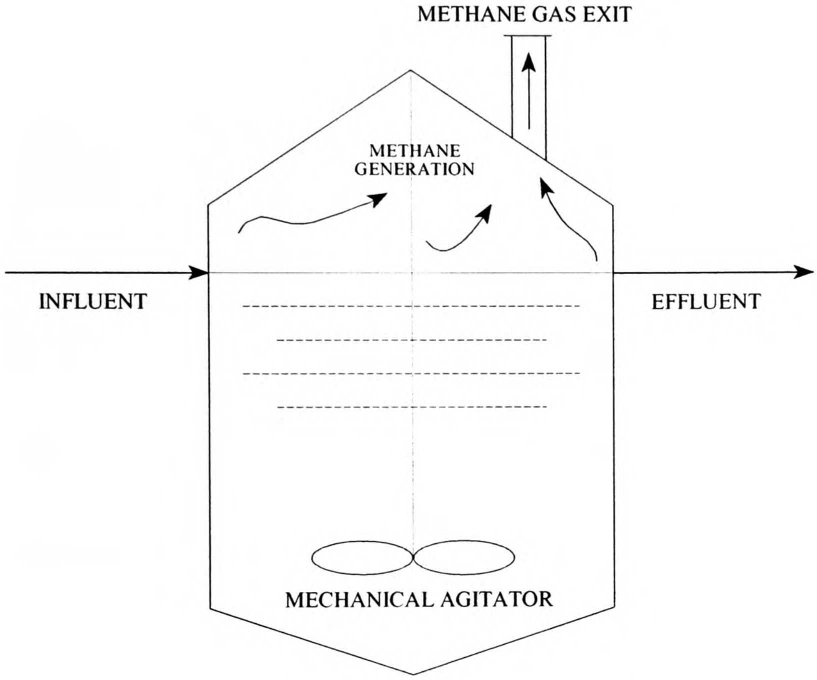


Table 2(I) Table of Treatment Chemical Details

Chemical Description / Aquatreat Reference	Chemical Composition	L'Oréal Utilisation
Aluminium Sulphate 701	8% Al_2O_3 + 1.6% Cationic Polyamine in Acidic Water Solution	Chemical Contact Chamber
Caustic Soda	28% Sodium Hydroxide in water	Chemical Contact Chamber
Polyelectrolyte 515	Granular Anionic Poly-acrylamide	Chemical Contact Chamber
Polyelectrolyte 78	Cationic Poly-acrylamide Dispersed in Mineral Oil	Centrifuge

3 Incoming Untreated Effluent Analysis

3.1 Basic Water Theory

Impurities generally found in water exist in suspended, colloidal and dissolved states. Suspended matter is non dissolvable material which may settle out when the fluid is at rest for certain periods. Suspended matter may be swept into a natural water coarse dependent on the water velocity e.g. sand at a minimum of 0.15m/s, gravel at 0.75m/s [Smethurst 1979].

Colloids are much finer than suspended matter but are also non dissolvable. They are not always visible but may still have an optical effect on the liquid by imparting colour and remain in suspension at rest.

Dissolved solids such as calcium, magnesium, sodium and potassium may combine with sulphates, bicarbonates, chlorides and nitrates which may also be present, in addition to the absorption of gases e.g. carbon dioxide and ammonia. Excessive carbon dioxide concentrations and acidic waters promote corrosion of surfaces.

Algae and certain chemicals e.g. phenols, iron and manganese may impart taste, whilst bicarbonates, sulphates and chlorides of calcium and magnesium promote hardness.

Pollution of waters may take many forms and effluents must be treated to remove / minimise the harmful constituents to ensure that they do not enter into or effect the Eco systems. Measurable parameters exist to identify the level of pollutants present in a water course:

pH is a measurement of a liquids acidity or alkalinity. 7 is the pH value for pure water with acids ranging from 0 - 7 and alkalis 7 - 15. Generally pH probes measure the quantity of positive hydrogen ions on a logarithmic scale.

Turbidity measures the optical clarity of a liquid and has the units Nephelometric Turbidity Unit (NTU) although others are employed e.g. Formazin Turbidity Unit (FTU), Jackson Turbidity Units (JTU) [Endress and Hauser 1997].

Chemical Oxygen Demand (COD) provides information relating to the quantity of organic matter present in the liquid. It is generally used for analysing industrial waste waters / effluent.

Biological Oxygen Demand (BOD) is a measure of the oxygen utilised by the bacteria in consuming organic impurities present in the effluent and indicates the degree in which the impurities would deplete the oxygen content of a water course.

Many other measurements are widely employed detailing the level of pollution / impurities present, e.g. oils, fats greases, detergents, total organic carbon, hydrocarbon content, nitrogen content.

3.2 Product Effluent Analysis

3.2.1 Product Raw Materials

In order to assess / estimate the existing effluent loading, a raw material investigation was initiated. Unfortunately, as over 800 materials in various forms are utilised, it was not possible to undertake a full analysis, therefore it was decided to determine the most common ten constituents. Confidentiality is a major issue and the chemistry department would only release broad details of information and not exact constituent quantities. The most common ten constituents are detailed in Table 3(I). Water is the dominant component at 99%, with oils / fats at 0.08% - 0.35% second.

Stearic Acid is used in cosmetic facial creams, Ambre Solaire and selected shampoo's, etc. These products will be the dominant contributor to the effluents oils, fats & greases content. Stearic acid is white, odourless and pelleted in form, having a density of 0.54 kg/m^3.

Sodium Lauryl Ethoxy Sulphate is a detergent generally found in shampoo's, body washes and selected facial cleansing lotions. At an effluent concentration of 0.06% this represents a 600 mg/l average anionic detergent level. The pH value is 7 at 20°C however, if this falls, an exothermic reaction is possible, releasing gaseous sulphuric acid, therefore care should be taken when acid rich waste streams (e.g. from facial creams / lotions) combine with detergent streams from shampoo vessel washing. Sodium lauryl ethoxy sulphate is a colourless liquid with only a faint odour and is biodegradable, with only shock loads posing a threat to aquatic life.

Tri Sodium Citrate is an organic salt which is white, odourless and solid in form, with a high solubility in water, therefore it will not increase the effluents suspended solids levels. The average effluent percentage content is 0.05%. From the manufacturers data sheet there are no carcinogenic properties or environmental hazards.

Ethonolomine is found in perm products and is a colourless liquid with a faint odour. Its density is 1.020 kg/m^3 and from the data sheets no environmental hazard exists.

Resorcinol is an organic solid, white in colour with a weak odour. Its density is 3.790 kg/m^3 and is very soluble and therefore will not increase the effluents suspended solids levels. It is very harmful to animals, causing cancer in aquatic life. Its average concentrations in effluent are 0.05%.

1351 FD+C Yellow No. 6 chemical formula $C_{16}H_{10}N_2O_7S_2Na_2$ is a disodium salt, having a red odourless, powderous form and is soluble in water.

Ethanol is highly flammable with a pH of 7, an ignition temperature of 425 °C and 13 °C flash point. It is utilised in selected perms / hair colourants but mainly in hair spray products. This constituent will increase the effluents hydrocarbon level.

Ammonium Thioglycolliate Solution S9010 is found in perm products with an effluent percentage concentration of 0.05%. It is white and solid in form with no odour. However, when decomposition commences hydrogen sulphide and sulphur oxides are released. Similar concentrations of the alkali ammonia is also found in similar products which will increase the pH value.

Synperonic PEL44 is a polymer of ethylene oxide and propylene oxide of low toxicity. It is liquid in form with a mild odour, having a high water solubility. The data sheet warns of a hazardous reaction with alkali's.

From the ten most common L'Oréal chemicals the majority are fairly stable products with only resorcinol posing a direct threat to aquatic life. However, certain chemicals (e.g. ammonium thioglycolliate releasing hydrogen sulphide when decomposed, sulphuric acid released with pH depression of sodium lauryl ethoxy sulphate and synperonic PEL44 having a hazardous reaction with alkali's) are unstable in certain conditions and as no waste stream segregation is undertaken the above undesirable reactions are possible. From inspection of The Prescribed Processes & Substances Regulations Red List (a summary is provided in Appendix 2), none of the L'Oréal chemicals are listed.

3.2.2 Product Effluent Analysis

As previously discussed, the incoming effluent to the 50,000 gallon buffer storage tank and treatment plant is a combination of product effluents. An insight into the individual products was required to establish their effect on the measured parameters of COD, oils / greases, suspended solids, pH and anionic detergents. Therefore, through liaison with the production departments, samples of product effluents after various cleaning operations were analysed. Ambre Solaire Factor 30 cream and Factor 15 milk, Nutralia hair shampoo, Argeno Professional salon hair perm and Nutralia body wash were all investigated. The samples were taken from the manufacturing vessel discharge pipework. As the Ambre Solaire cream is viscous prior to sprayball cleaning, the 3,000 litre vessel is filled with 300 - 400 litres of 60°C hot water and the agitators operated to remove any residue. This prewash reduces sprayball cleaning but produces very concentrated effluent. Samples of the prewash and sprayball cleaning effluents were taken and analysed. Table 3(ii) details the results of the analysis and from inspection, the Ambre Solaire Factor 30 prewash has the highest COD and Suspended Solids content at 94,864 mg/l and 15,600 mg/l respectively. This is due to a water to product volume ratio of 4:1 compared to the other product ratios of greater than 50:1. The Factor 30 prewash will impose a shock loading to the effluent plant if there is insufficient effluent volume in the buffer storage tank for dilution.

The Nutralia body wash and shampoo have high anionic detergent levels of 1,505 mg/l and 4,295 mg/l respectively as these products are for face / hair cleaning. The Ambre Solaire Factor 30 cream is far richer in suspended solids and fats, oils and greases than the Ambre Solaire Factor 15 milk which is not demonstrated in the results Table 3(ii) for sprayball cleaning. This is attributed to the prewash removing the majority of the residue from the process vessel for the cream. The high COD / oils and greases / suspended solids levels will still however impose a shock loading to the effluent plant for milk products. The Argeno perm has comparatively low levels of such constituents, but has high quantities of alkalis such as ammonia as shown by the pH value of 9.0. This will result in increased alum consumption required to depress the pH value.

A bench test was undertaken to identify the effect a combination of Ambre Solaire and Nutralia shampoo would have on treatment. It was expected that as the natural action of a detergent is to retain the oils / greases in suspension the alum percentage to depress the pH value to commence coagulation would increase with the Ambre Solaire / Nutralia shampoo effluent. 1 litre of mains water at 15°C was taken and 100ml of Ambre Solaire milk was added and the pH value was depressed to 4.5. The experiment was repeated except 50ml of the sun cream and 50ml of Nutralia shampoo were added, again the pH was depressed to 4.5. It was observed that 0.95%

alum was required with the Ambre Solaire effluent, however 3.6% was required with Ambre Solaire / Nutralia combination, thus proving that waste streams rich in oils and suspended solids are problematical to treat when combined with shampoo waste streams high in detergents. Thomas concluded that the L'Oreal products Belle Colour Colorease Gel, Movida Colourants and Excellence Creme colourant should not be processed through L'Oreal's plant as bench tests revealed that chemical treatment is adversely affected [Thomas 1996].

3.3 Effluent Hydraulic Loading

3.3.1 General

The incoming mains water supply enters the site from Lanelay Road at a mains pressure of 8-9 bar gauge and serves all of the factory's water requirements. Underground tanks are located below the compressor / sprinkler pump house supplying the factory with drinking and domestic water.

During recent years, water meters have been installed at various locations interlinked to the Trend Energy Management System to identify patterns of water consumption on a monthly basis.

3.3.2 Site Water Consumption 1996 Vs 1997

From Figure 3(a) the average monthly incoming water volume was 6586m^3 for 1996 resulting in an effluent flow of 3323m^3, equating to 50.5% and a sanitary loading of 1046m^3 (15.9%). Approximately 40m^3 per month enters the effluent system from the tank farm off loading point rainwater interceptors and 2068m^3 (31.4%) incoming water is utilised in the products.

For 1997 (Figure 3(b)) the incoming average monthly flow was 8167m^3 resulting in 4508m^3 (55.2%) effluent discharge and 1553m^3 (19%) sanitary load. It is estimated that 1924 m^3 (23.6%) is attributed to water in products. Although the effluent generated is of similar proportions for 1997 when comparing to 1996, the sanitary load has increased (19% vs 15.9%) and the product water has decreased (23.6% vs 31.4%). The additional sanitary flow is attributed to the introduction of night shifts in the production departments and the reduction in product water is possibly a consequence of the high volumes of Elvive shampoo production which utilises less water than other products. Also an increased effluent loading existed due to increased shampoo production requiring disproportionate additional cleaning/sterilisation water as the sprayball cleaning system is utilised. The Kewash system would result in foaming due to excessive water velocities.

3.4 Untreated Effluent Analysis

3.4.1 Historic and Project Effluent Analysis

The historic data available at L'Oréal is for the years 1995 - 1997 for the untreated effluent and is detailed in Figures 3(c) - 3(e). From inspection of the profiles considerable instability is observed with minimal / no pattern or correlation to the concentrations. The exception to this is during November to March when oils, fats and greases levels increase. This is attributed to the seasonal production of Ambre Solaire which is rich in such constituents.

Such instability results in effluent plant shock loading which is problematical to respond to with the plant limitations detailed in Chapter 2. Table 3(iii), detailing the maximum, minimum and average effluent parameter concentrations, indicates that the influent nature is changing. A consistent increase in anionic detergents is shown which is attributed to the accelerated production of shampoo. The average COD loading is also increasing (35.7%) over 1996 which had decreased 16% over 1995. The ratio between max / min concentrations for 1997 is greatest for oils / fats at 2.2 which is related to the peak Ambre Solaire production periods. The ratios for suspended solids and COD are 1.33 and 1.25 respectively indicating a relationship between these parameters.

Shampoo production increases will continue however, owing to other production increases, it is not envisaged that further concentrations of anionic detergents will be found in the influent. Therefore although the estimated production output by 1998 is 150 million units, resulting in additional effluent plant hydraulic loadings only minor additions of constituent concentrations are expected.

3.4.2 Four Month Untreated Effluent Study

3.4.2.1 General

Historic data provides invaluable knowledge of effluent concentrations over a period and details monthly peaks and troughs, however more detailed information is required to assess effluent variations over a daily / weekly period for several months. Such data would be required by the

L'Oréal research and development group DGT in Paris prior to endorsing the design and specification of a plant which they must approve.

3.4.2.2 Method Statement

In October 1996 a four month influent study commenced. An AQUA 10 composite sampler was purchased from Aquamatic. The samples were taken over a 24 hour period every 20 minutes and analysed at the University of Glamorgan Wastewater Treatment laboratory on a daily basis. The samples were collected in a 10 litre chamber and a composite sample taken. As the production manufacturing sections wash out procedures never commence before 8.30am and the sample was taken by 8.00am, it was ensured that the composite was always from the preceding day and not contaminated with fresh effluent. The flow through the plant was set at a constant 1500 gph, therefore the flow proportional function of the sampler was not required. The samples awaiting transportation for analysis were maintained at 0 - 4 degrees centigrade to ensure minimum deterioration

Factory production levels were noted and categorised into a number of technical families of: Aerosols, Shampoos, Colorants, Perms, Creams, Milks and Miscellaneous products e.g. gels, lotions and these were plotted graphically, to identify any trends/correlations between production levels/types and effluent concentrations. The study commenced on 07/10/1996 and terminated on 31/01/1997. To identify the exact constituents of the effluent a Gas Chromatography Mass Spectrometer (GCMS) analysis via Hyder Environmental was performed on a sample of effluent from 17/01/1997.

3.4.2.3 Discussion of Results

The observations of the study are provided in Appendix 3 and the results detailed in Figures 3(f) - 3(h). From the profiles the effluent concentration instability is evident even on a daily basis, with suspended solids peaking and troughing at 6348 mg/l and 505mg/l respectively, COD: 20822mg/l and1786 mg/l, fats/greases: 15260 mg/l and 468 mg/l, anionic detergents: 3132 mg/l and 84 mg/l and the pH and average temperature ranged between 6.4-8.4 and 7°C-25°C respectively.

Fats, oils and greases had the highest concentration ratio of 32.6, however the 15260 mg/l peak value was only for one day and no other sample exhibited similar concentrations.

The average results are provided in Table 3(iv). As the study was undertaken in the Ambre Solaire production season the highest levels of oils / fats would have been found providing a worst case scenario.

Production data was gathered but only monthly figures of product families are recorded and unfortunately this information is too general to establish any relationship between production levels / types and effluent concentrations.

From inspection of Figure 3(f) it appears that a link between suspended solids and COD exists and merited further investigation (see Chapter 6).

From inspection of Table 3(v) the GCMS analysis for 17/1/1997 reveals that the top three significant constituents are Benzene methanol S at 25.3mg/l, Decamethyl Cyclopentasiloxane at 25.9mg/l and 1-Decanol A at 16.5mg/l. The effluent concentrations for that sample were:

Suspended solids	4680 mg/l
COD	18544 mg/l
Fats, oils and greases.	15260 mg/l
Anionic detergents	1257 mg/l
Average pH	7.1

From discussions with the Industrial Chemistry Department at L'Oréal all the above 3 constituents are associated with Ambre Solaire production which would account for such high oils and fats / suspended solids concentrations and neutral pH value. The phenol constituent is not added to any of the products therefore it is concluded that it is produced via a reaction between other constituents.

3.5 Future Effluent Plant Design Parameters

From the untreated effluent analysis it is shown that the effluent is of a variable nature with high concentration ratios between maximum and minimum values. In addition, over 800 raw materials are employed and can be used in any quantities. As L'Oréal is a market lead company constantly improving existing and developing new formulations for their products, this will impact on the effluent characteristics and the effluent today is of a differing nature to that of 20 years ago. In addition new products may have to be manufactured at the Llantrisant plant, e.g. perfumes, as a result of logistic and corporate changes. Therefore as the future influent characteristics are unknown any new plant or existing facility upgrade must be flexible and adaptable to varying constituents and concentrations and must be capable of withstanding 'shock' loads both chemically and hydraulically.

Table 3(iv) details the design parameters to which a new facility must be designed. The parameter concentrations stated have been taken from the 4 month effluent study, although the plant must be capable of treating effluents above and below these concentrations. A specification for a new plant has been provided in Chapter 6.

Figure 3(a) Schematic Diagram of Monthly Average Site Water Consumption 1996

Note: All Values in m^3

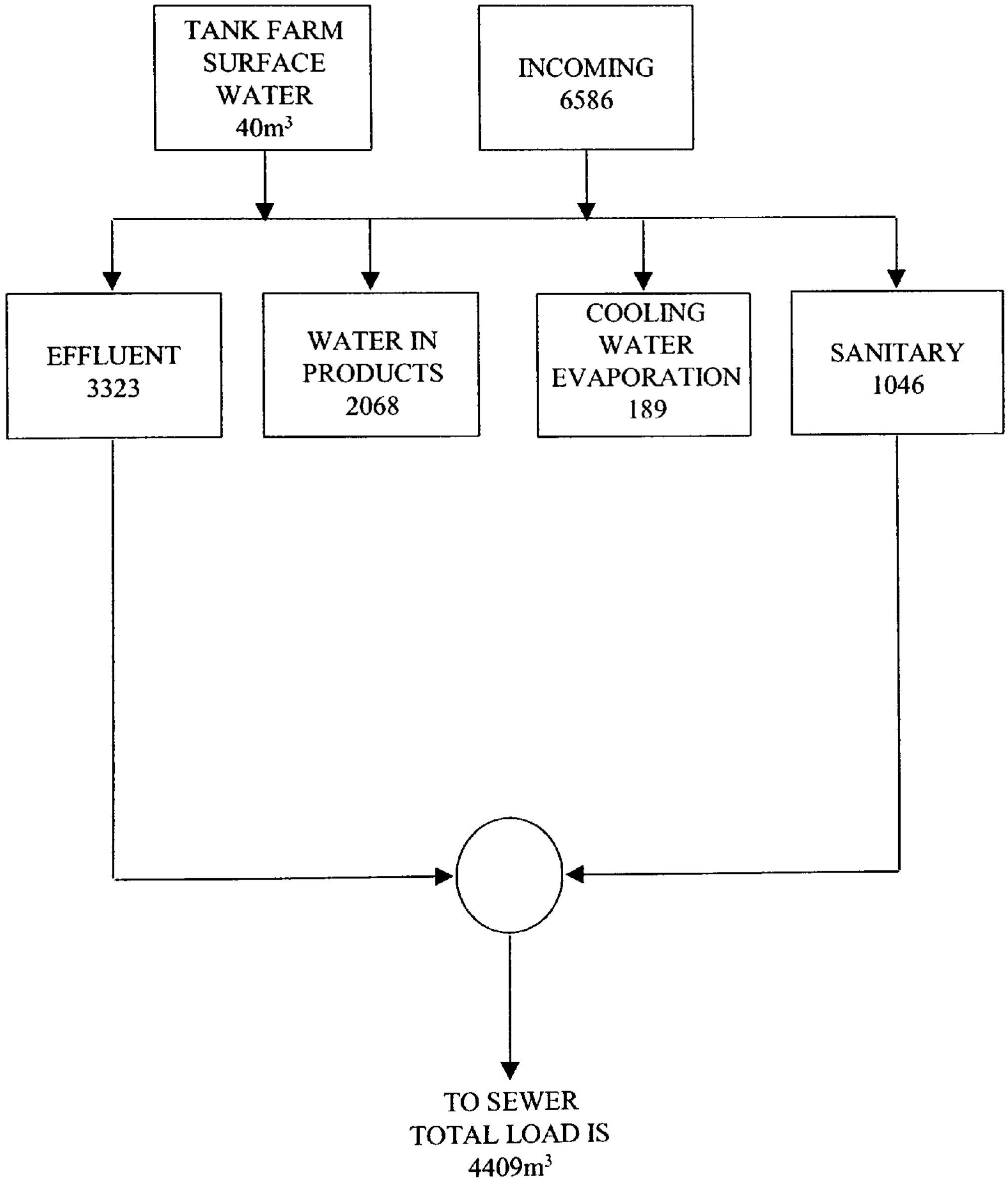


Figure 3(b) Schematic Diagram of Monthly Average Site Water Consumption 1997

Note: All Values in m^3

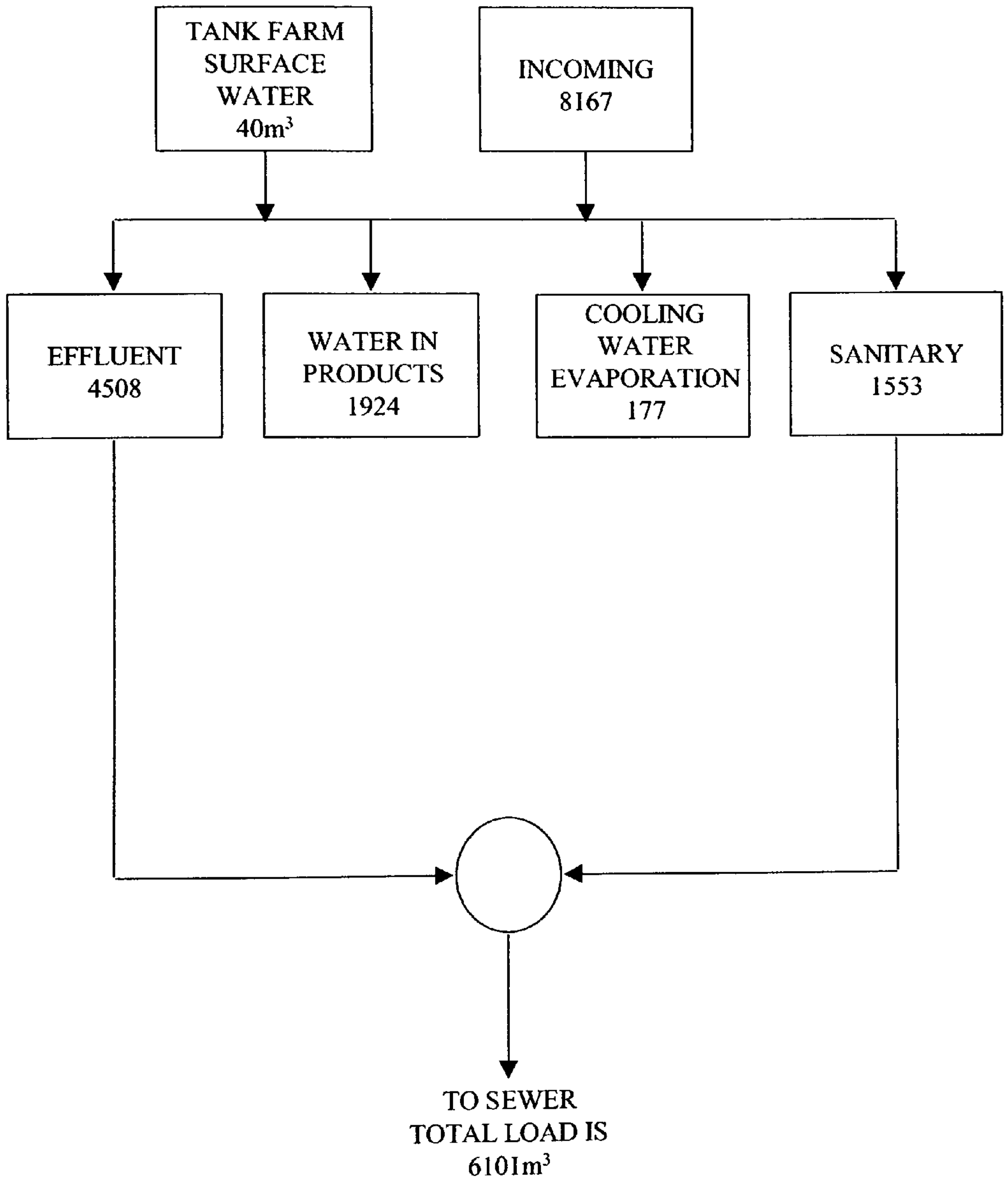


Figure 3(c) Untreated Effluent Characteristics for 1995 - 1997

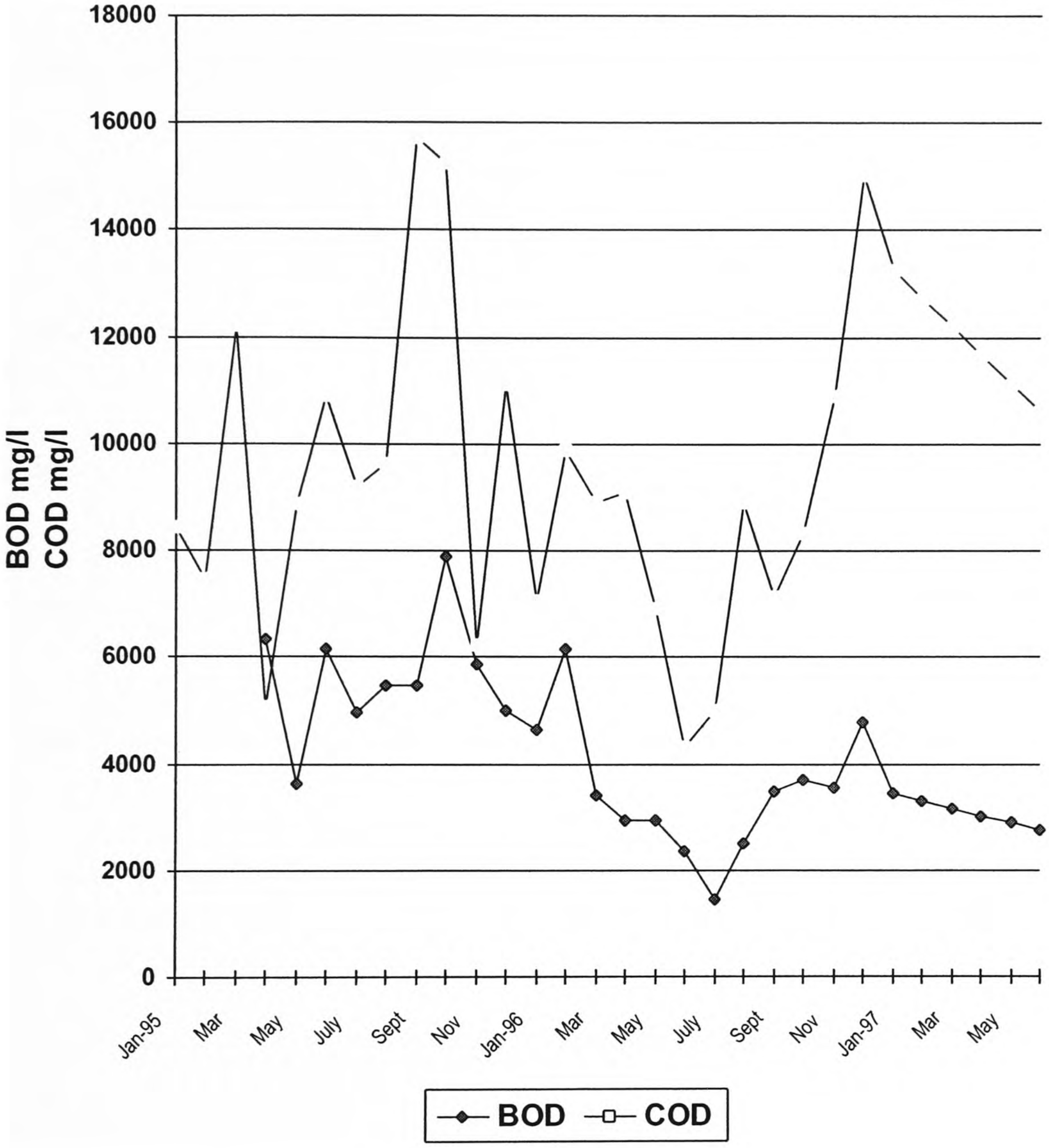


Figure 3(d) Untreated Effluent Characteristics for 1995 - 1997

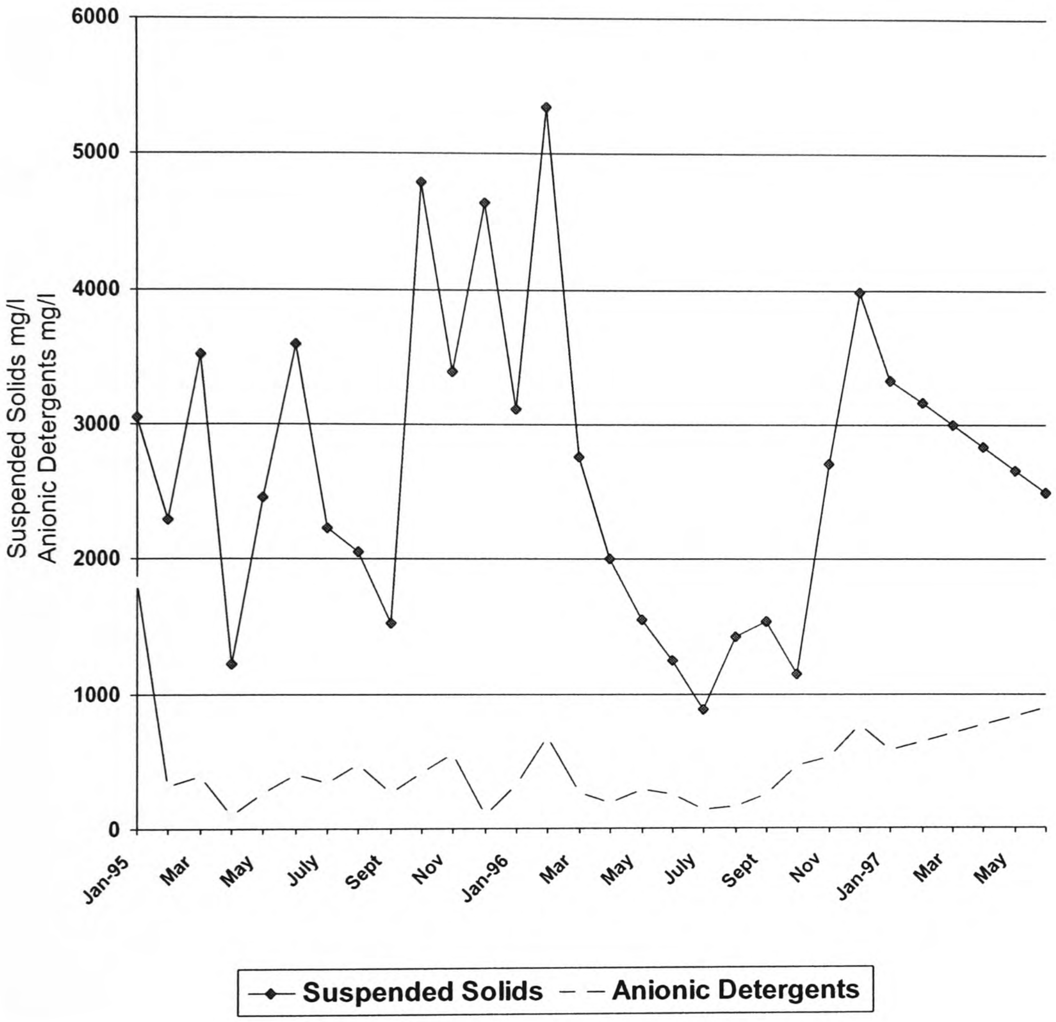


Figure 3(e) Untreated Effluent Characteristics for 1995 - 1997

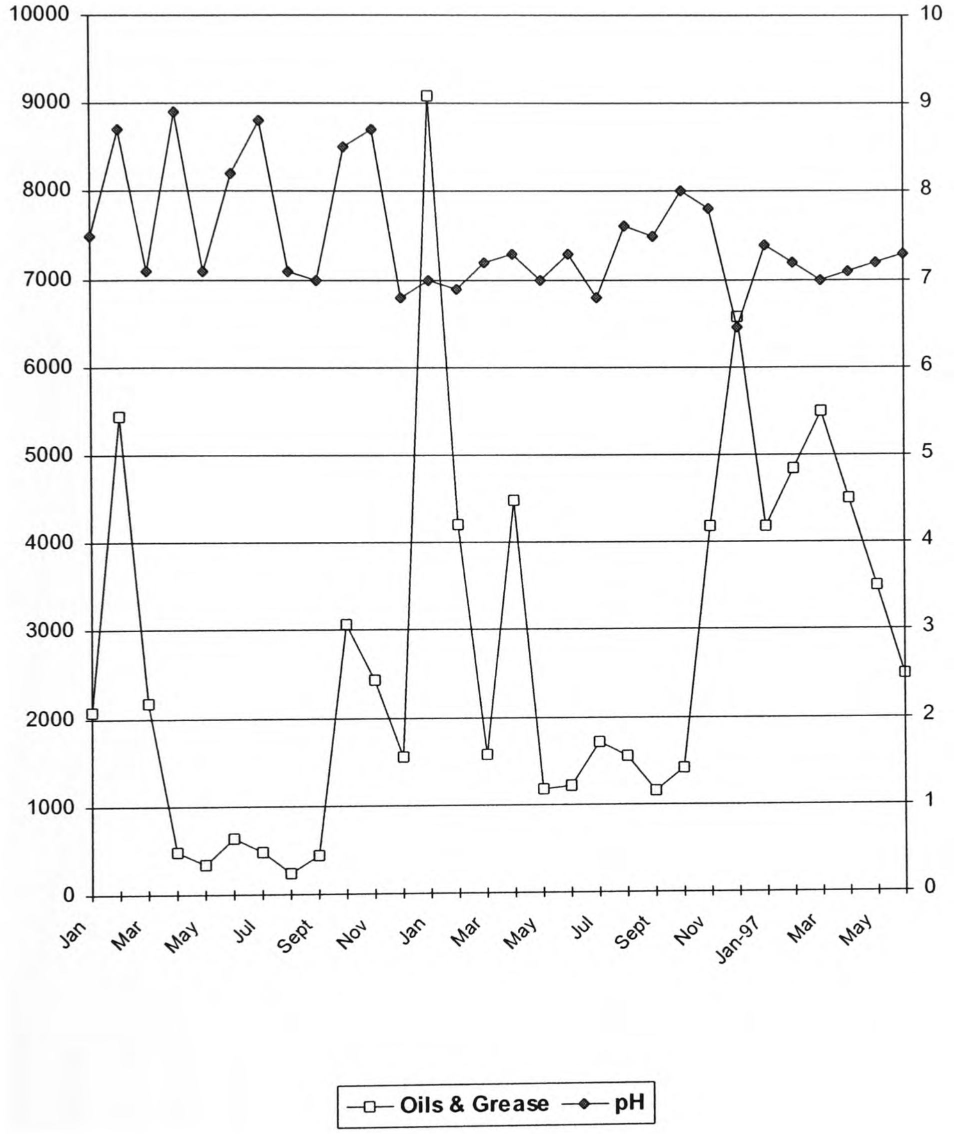
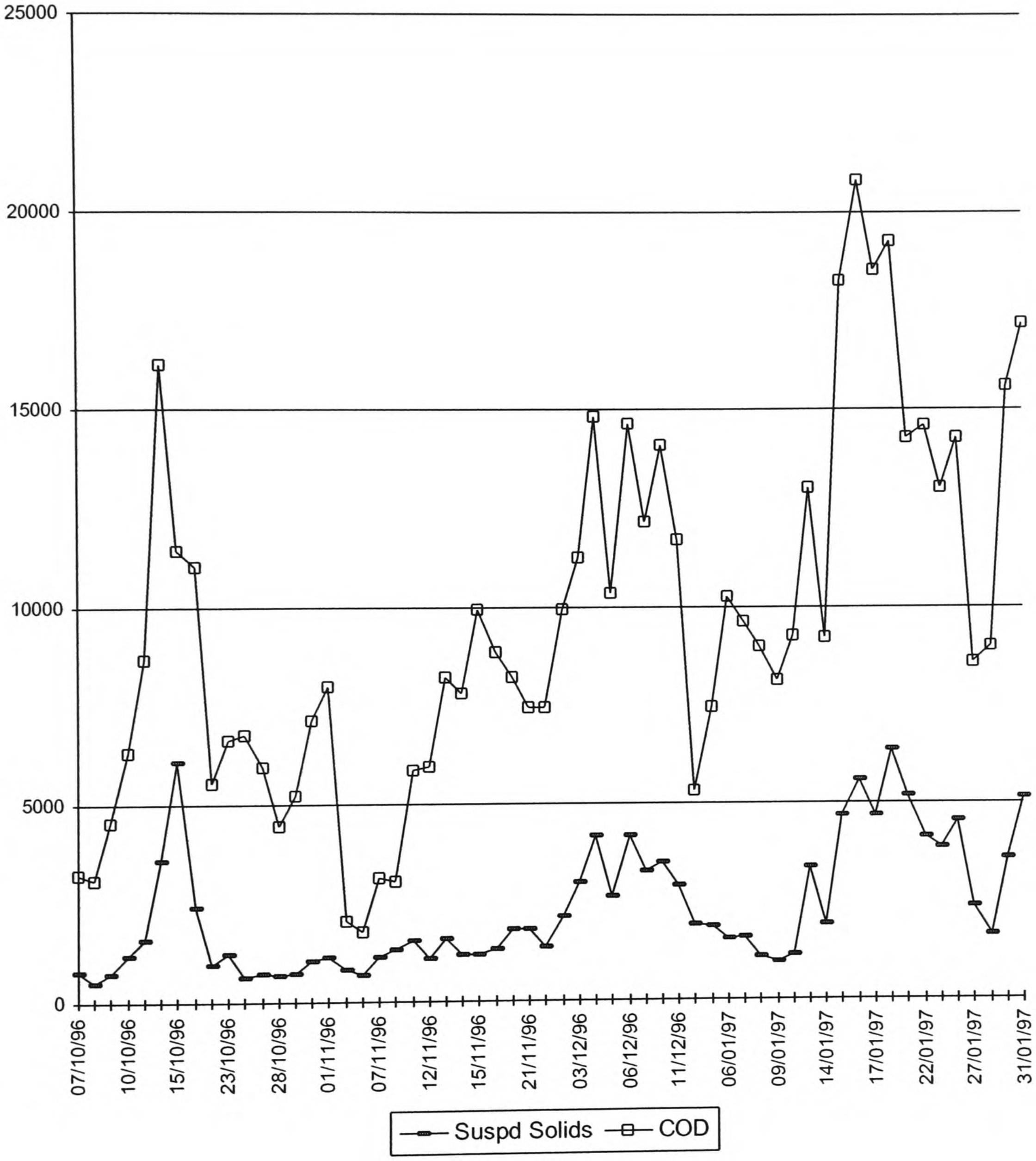


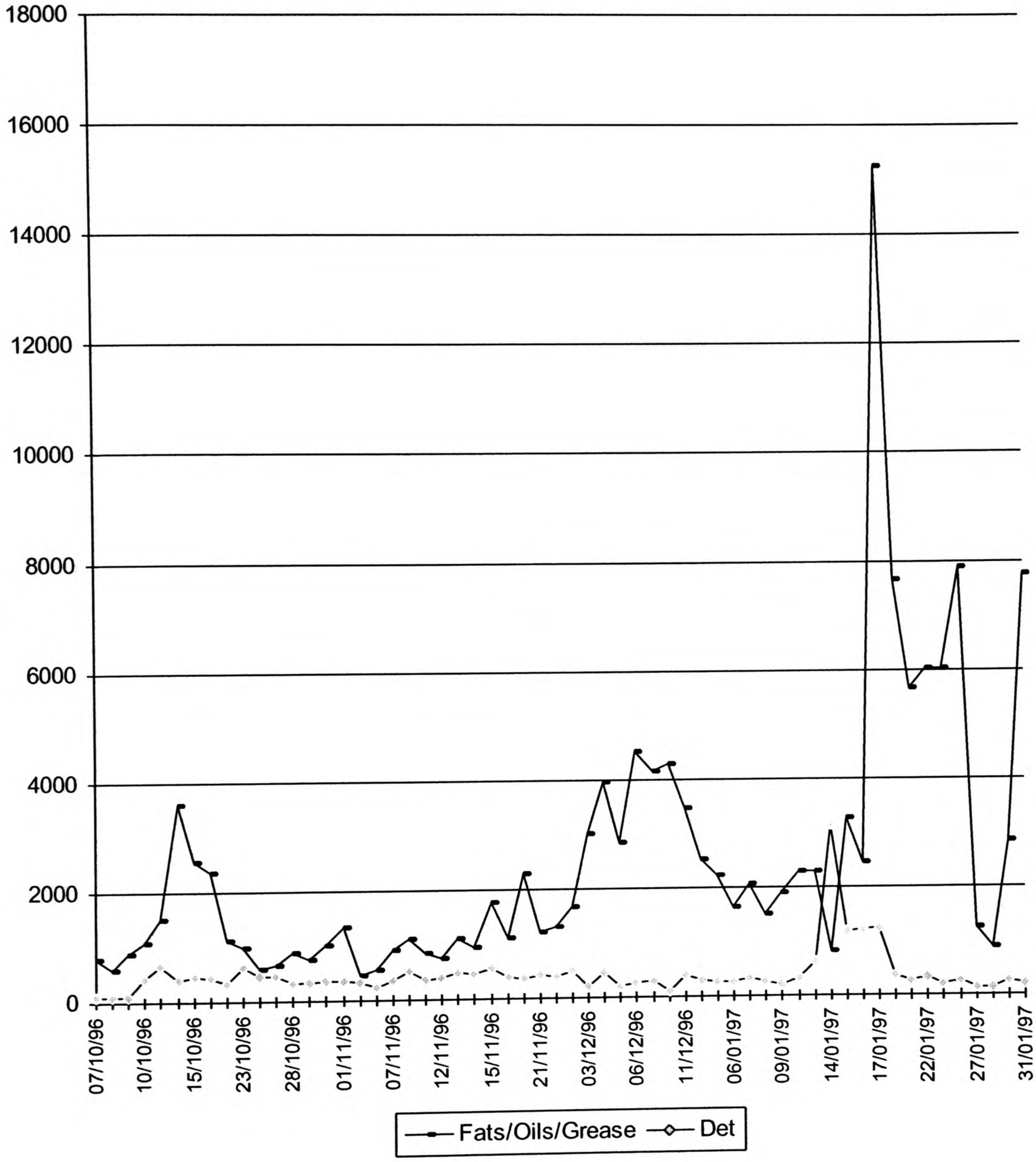
Figure 3(f) Four Months Effluent Study Results



NB: Graphical points are mean average of two samples. Variation range between samples was:

Suspended Solids	+/-1% to +/-15%
COD	+/-1% to +/-10%

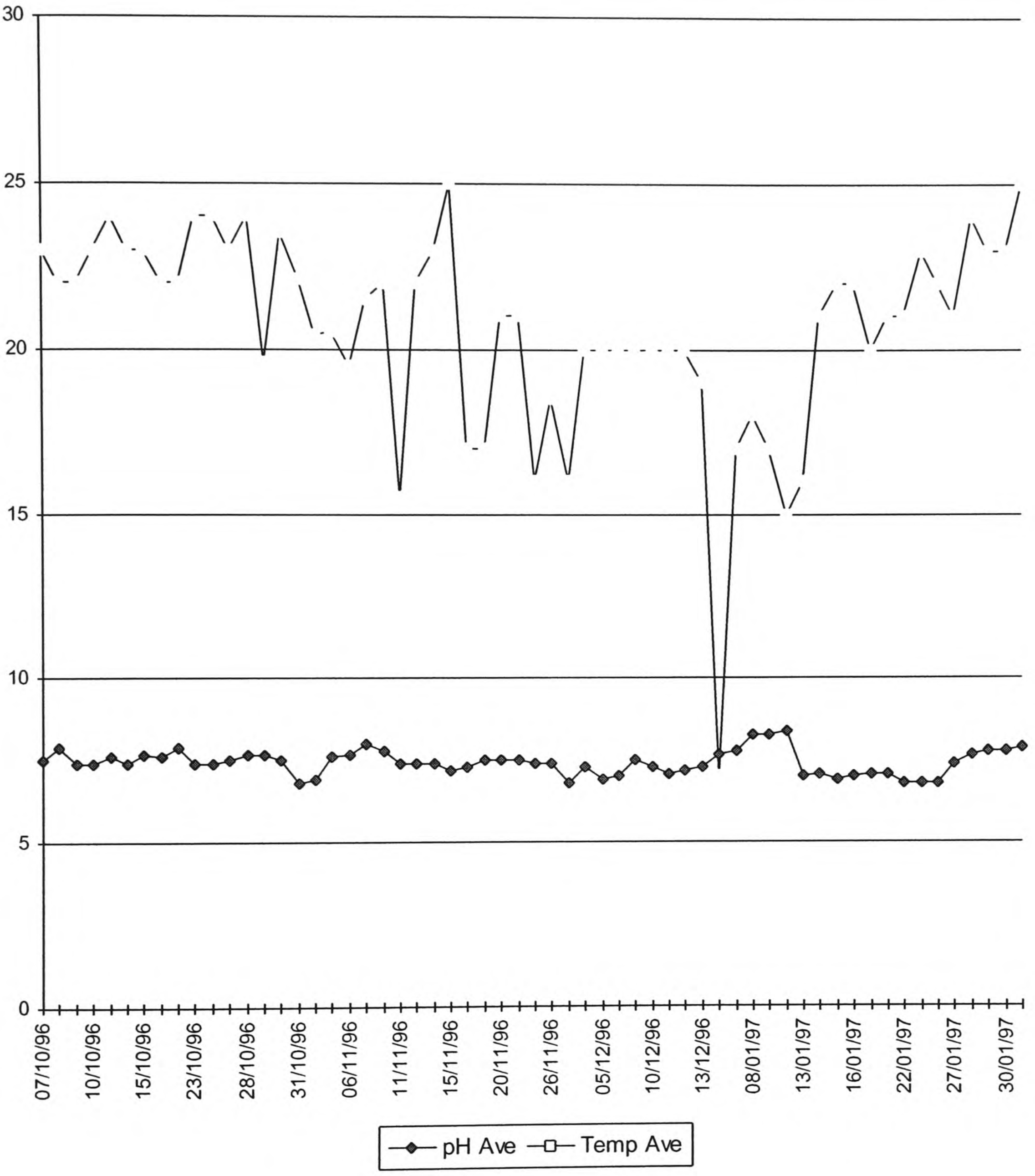
Figure 3(g) Four Months Effluent Study Results



NB: Graphical points are mean average of two samples. Variation range between samples was:

Fats, Oils, Grease	+/-5% to +/-9%
Detergents	+/-3% to +/-7%

Figure 3(h) Four Months Effluent Study Results



NB: Graphical points are mean average of two samples. Variation range between samples was:

pH	+/-4% to +/-6%
Temp	+/-10% to +/-20%

Table 3(I) Most Common L'Oréal Effluent Constituents

Constituent Description	Typical Concentration	Constituent Example
Water	99%	---
Oils & Fats	0.08% - 0.35%	Rape Seed Oil / Stearic Acid
Anionic Surfactants	0.06%	Sodium Lauryl Ethoxy Sulphate
Inorganic / Organic Salts	0.05%	Trio-Sodium Citrate
Bases	0.05%	Ethanolamine
Oxidation Dyes	0.05%	Resorcinol Hydroquinone
Pigments	0.05%	F,D+C Yellow 6
Solvents	0.05%	Ethanol
Thio Compounds	0.05%	Ammonium Thioglycolliate
Non Ionic Surfactants	0.05%	Synperonic PEL44

Table 3(ii) Product Effluent Characteristics

Product	Cleaning Method	FOG (mg/l)	SS (mg/l)	Anionic Det (mg/l)	COD (mg/l)	pH
Ambre Solaire Factor 30 Cream	Prewash	7000	15600	27.5	94864	7.52
	Sprayball	1800	1920	10.3	8325	7.00
Nutralia Body Wash	Demin Preflush	600	360	1505	5131	6.15
Ambre Solaire Factor 15 Milk	---	5000	4750	---	58080	7.27
Nutralia Shampoo	---	1467	390	4295	5325	7.10
Argeno Perm	Hose Jetting	200	180	---	7802	9.00

Table 3(iii) Table of Maximum, Minimum & Average Effluent Parameters

Year	Min COD	Max COD	Avg COD	Min BOD	Max BOD	Avg BOD	Min SS	Max SS	Avg SS	Min OFG	Max OFG	Avg OFG	Min DET	Max DET	Avg DET	Min pH	Max pH	Avg pH
1995	5074	15729	10006	3632	7900	5646	1218	4794	2898	243	5435	1613	104	1832	456	6.8	8.9	7.87
1996	4317	15032	8407	2505	6167	3491	888	5346	2288	9091	1162	3197	184	775	359	6.5	8.0	7.24
1997	10600	13263	11409	2750	3428	3089	2500	3328	3024	2500	5500	4180	575	900	575	7.0	7.4	7.20

Key:

SS = Suspended Solids (mg/l)

OFG = Oils, Fats & Greases (mg/l)

DET = Anionic Detergents (mg/l)

Table 3(iv) Results of Raw Effluent Study

Average pH	7.3
Average Temperature	20.7°C
Suspended Solids	2350mg/l
Oils, Fats & Greases	1900mg/l
Anionic Detergents	650mg/l
COD	9600mg/l
Phenol Content	1 - 8mg/l

Table 3(v) GCMS Analysis for L'Oréal Effluent Sample at 10:00am 17/01/1997

Determinand	Concentration (mg/l)
2-Butoxy Ethanol S	5.4
2-Methyl-2, 4-Pentanediol S	2.4
Octamethyl Cyclotetrasiloxane	4.0
Phenol (Disinfectant)	7.1
2-Heptenal S	5.1
Benzene methanol S	25.3
Linalool P	3.4
Benzeneethanol S	2.4
Decamethyl Cyclopentasiloxane	25.9
D_8 Naphthalene (Internal Std)	2.0
Alpha-Terpineol P	1.1
2-Phenoxy Ethanol S	7.6
Linalool 2-Aminobenzoate P	0.9
Hydrocarbon	2.2
1-Decanol A	16.5
Dodecamethyl Cyclohexasiloxane	9.1

4 Effluent Treatment Plant Performance

4.1 Introduction

This chapter discusses the performance of the effluent plant achieved predominantly during 1995 -1997 including all associated operating and maintenance costs. The author has included theory and literature search sections in addition to detailing the legislative requirements with which L'Oréal must comply.

4.2 Theory and Literature Search

4.2.1 Colloidal Theory

Generally, colloids have a diameter of 0.5×10^{-4} cm [Ellbech 1992] and require destabilisation for particle growth. Hydrophobic Sols are insoluble dispersions but their stability arises from positive electric charges. During electrophoresis colloid particles retain a thin layer of liquid and counter ions which adhere to the particle surface moving with the colloid. The electrical potential of the shear plane between the moving particle and liquid dispersion medium is termed the Zeta potential. Generally, the potential is measured at the Stern liquid layer.

Colloids are charged particles, however, their suspension is not, therefore a particle charge is balanced by an equal and opposite charge in the liquid. This is affected by a 'mobile' liquid layer near the solid / liquid interface having counter ions balancing the charge of the particle. Therefore, particles have an electric double layer. If the counter ions and colloid ions are equal no repulsive forces exist, however, if colloids pass so close that the double layers cross then coulombic repulsion occurs.

4.2.2 Chemical Coagulation

Many effluent plants have pre-treatment to reduce constituent concentrations prior to main treatment. Effluents requiring the removal of coarse heavy matter may require sedimentation tanks or screens to remove such solids, however very fine material will necessitate the use of ultrafiltration or reverse osmosis membranes, activated carbon filters, biological systems, or chemical coagulation. Chlorination to eliminate living organisms is also an option for pre-treatment.

Coagulation may be defined as the process by which fine particles in suspension join to form larger matter. All particles carry a positive or negative electric charge of various intensities, therefore particles having a different charge will attract providing they collide. Similar charges will cause repulsion unless the particles are forced to touch via agitation / natural currents and Van der Waal's force of attraction causes coagulation. Sedimentation, also classified as auto coagulation, is probably the simplest form of this process and, even with clear water, after a period of time a collection of particulate's will be observed at the base of a vessel. Such a process is generally slow and its effectiveness depends on suspended matter concentrations / characteristics and its utilisation requires large vessels for storage e.g. reservoirs. Coagulation may be accelerated via the addition of chemical catalysts which are categorised into two main groups:-

1) Coagulants **2)** Flocculants

4.2.3 Coagulants and Flocculants

There are many differing types, varying in chemical composition, availability and cost. Typical coagulants include aluminium sulphate, sodium aluminate, iron salts e.g. ferrous / ferric sulphate, ferric chloride etc. Many are available in differing forms e.g. powder, crystals, granulated blocks etc. and generally the type of coagulant and dose rate are determined on a trial and error basis.

A coagulant molecule is of a long chain type construction with a number of charges along its length and its presence in an effluent will cause particles of differing charge to be attracted. It has been revealed that the action of a coagulant is where each molecule collapses onto a particle of differing polarity, forming a larger unit with a polarity similar to the attracted particle, therefore another particle (of differing polarity) will be attracted and the cycle is repeated. Salts of iron and aluminium form hydroxides, which appear as fatty precipitates known as "flocs", which are insoluble and have a positive electric charge.

The most effective coagulants are those with a long chain molecular structure necessitating lower levels of chemical introduction into the effluent e.g. 1ppm. In addition longer molecules exhibit greater attraction forces enabling the entrapment of particles even when direct contact has not been made. When coagulants are added violent agitation must follow promoting the collision of particles.

10kg of Aluminium Sulphate ($Al_2(SO_4)_3\ 18H_2O$) containing 1.53kg of Aluminium Oxide as used in L'Oréal will theoretically form 2.34kg of "floc". The aluminium oxide content affects the price of the coagulant and is graded according to its Al_2O_3 content. In mid 1995 L'Oréal suffered excessive effluent foaming and polyamine was combined with the alum in a concentration of 1.6% minimising this reaction.

Most coagulants are acidic and will lower the pH value and subsequent correction with an alkali may be necessary. Further agitation is required to mix the alkali with the solution but care must be taken to ensure that the precipitate already formed/forming is not destroyed by this secondary mixing. Effluents with pH of 5-6.5 may be problematic to treat requiring both coagulant and alkali treatment. L'Oréal's effluent has an unpredictable pH value of 6-9 depending on the products manufactured. Generally effluents with a pH of 6.2 - 7 react well with aluminium sulphate whereas a pH of 7 - 7.8 may require excessive alum dosing and this is a common trend with L'Oréal whereby effluent with high alkalinity generally corresponds with higher alum consumptions. Such effluent characteristics indicate that perms and / or colourants are being produced and this is confirmed by the colouring of the effluent. Therefore the instability of the pH value requires the use of both a coagulant and an alkali for L'Oréal.

Further gentle agitation of the floc particles will promote the flocs to coalesce forming larger masses and this can be accelerated by the addition of a flocculant such as a polyelectrolyte. These are generally synthetic chemicals, e.g. polyacrylamides, and are added in small doses 0.05 - 0.25 mg/l.

The resultant flocs are insoluble hydroxides and can be removed from the effluent via screening, filtering or dissolved air flotation. Once they are destroyed, however, they do not reform.

Coagulation has two main theoretical requirements:-

- The mixing and agitation of chemicals into the effluent stream must be such that Power (P)x Residence time (Rt) is a minimum which is empirical.
- The shear force imposed by mixing must be less than the shear strength of the flocs being formed throughout the chemical contact chamber.

There are a number of factors which will effect the coagulation / flocculation performance, pH and chemical dose rates are of primary consideration but also agitation and retention time must be carefully calculated. Generally these are found via experimentation. Organic materials may interfere with chemical precipitation and reaction rates are very slow with very low temperatures.

4.2.4 Flotation

Previously, sedimentation was the only method of separating floc from water but flotation systems are now available. Although sedimentation was very reliable, excessive residence times are required to settle large quantities of solids and the tanks must be of a substantial size to treat the required volume throughput. In addition, such plants do not respond well to changes in conditions or to shock loading.

Flotation theory is based upon the principle that if an air bubble is attached to a particle in water the composite particle will become buoyant and follow Stokes law which defines the rate of rise or fall of a particle in a liquid.

Aluminium flocs are very buoyant requiring only a single bubble of the smallest size for particle flotation and are fairly resilient to separation from the floc. Therefore the performance of a plant is mainly attributed to the number of air bubbles which can be generated and the probability of colliding with a floc particle.

The cost of bubble production depends largely on the mass of gas utilised, however it is the quantity of bubbles generated per mass of gas which is of the greatest interest. The smaller the diameter the greater the quantity per kg of gas and the increased probability of collisions resulting in increased flotation. Large bubbles must be minimised as they will possess high velocities causing turbulence in the effluent destroying flocs and detaching existing bubbles from flocs, therefore careful bubble injection terminal design is required.

4.2.5 Literature Search

Engineering companies having effluents with anionic detergents, castor / mineral and engineering oils with on site treatment may use chemical precipitation for treatment [Gomólka 1984], with barium chloride and alum coagulation representing effective chemicals. In addition, aluminium hydroxide flocs will absorb organic constituents which are found in L'Oréal's effluent.

M. A. Hashim described that effluents taken from a Malaysian cosmetics factory contained 5544mg/l and 580 mg/l total COD and TSS respectively - considerably less than L'Oréal's effluent [Hashim 1985]. Experimentation with a chemical precipitation plant revealed that 89% TSS and 75% COD reductions were the most effective results achieved at 2200 mg/l and 1100 mg/l dosing concentrations of lime and aluminium sulphate respectively. This correlates to the 78% COD reduction most economic treatment level previously discussed with L'Oréal's plant.

The MBR system has been applied to a number of General Motors factories as discussed by P. M. Sutton [Sutton 1994] whereby effluents containing fats / greases and dissolved organics similar to L'Oréal's application must be treated. The MBR system consists of an aerobic biological reactor combined with an Ultrafiltration unit. Advantages include reductions in chemical costs, sludge production and maintenance costs. The average COD removal was over 90% for the Mansfield plant. This high performance would result in additional discharge cost savings, however the considerable shock loads to be sustained at L'Oréal would necessitate pre -treatment. The VITOX Oxygen injection system would be required to react to shock loads, increasing capital costs. An MBR system is employed at the L'Oréal Sicos plant in France. The domestic sewage is filtered and used for bacteria in the aerobic reactor with the sludge produced employed as agricultural fertiliser, while the treated effluent is suitable for river discharge [Le Febvre 1994]. Grontmij Consulting Engineers [Grontmij 1995] detailing compact MBR systems for waste water concluded they would have a place in the waste water treatment market and, although they incur higher investments, an additional advantage exists whereby materials which cannot be degraded biologically can be removed. A 17000 mg/l pharmaceutical influent was reduced by 98% to 350 mg/l.

Synthetic detergents (Linear Alkyl-benzine Sulphonate, LAS) and soaps do not deteriorate the performance of ASP and submerged filter plants as described by Mitsumasa Okada, [Okada 1993] provided the BOD loading is regulated. It was found that soaps damage biological treatment plants if the concentration is doubled (in the submerged filter plant) however, LAS presents no adverse effects even at five times that in domestic waste water. Therefore, LAS is suitable for biological treatment and Japan has banned the retail and production of phosphorus based detergents.

The characterisation of the effluent will dictate the process philosophy to be selected. Laboratory and pilot scale trials will be required and process selection will be affected by industries operating in similar areas (Environment Business Magazine May, 1997). Plant visits to operators in similar fields should be undertaken, however such a recommendation is problematical in the L'Oréal application due to the fierce competition between cosmetic companies.

L'Oréal, as many companies, is market lead and the product constituents and hence effluents are changing both in nature and in volume. The local and national water authorities must keep abreast of such progression and ensure that effluent discharges do not contain unremovable substances. Holmes has detailed that Hong Kong's water treatment systems are encountering difficulties in processing the ever increasing and varying waste waters [Holmes 1996]. Although the government has acted on certain areas, toxicity of effluents is an issue requiring a defined strategy in this Asian country. This issue is being addressed by the identification of three main requirements which are: descriptive, objective and prescriptive. However, legislative changes must always be gradual to allow industry to respond to the requirements. In addition, environmental agencies must define methods of policing the industry's response, ensuring consent compliance. From discussion with Welsh Water over the next ten years a consent limit reduction of 50% for L'Oréal's discharge parameters will gradually be imposed.

One leading competitor in the cosmetic industry, employing chemical precipitation with DAF as the separating method, utilises electrical polarity measurement of the influent, which determines the rate of chemical introduction. The dosing pumps are automatically controlled and, if the influent concentration levels are too high, the feed pump speed is reduced. Consent breaches have been eliminated and treated effluent concentrations of less than 20mg/l and less than 2,000mg/l for anionic detergents and COD respectively are easily achievable. In addition, a bypass facility is provided whereby untreatable effluent is diverted to a holding tank to be blended with less concentrated effluent for dilution. Such a system, with all the associated telemetry, would cost £500,000 to £550,000 for L'Oréal however these costs may be reduced to £400,000 if the aeration tanks and suitable existing pipework runs were utilised in the new scheme.

The 100mg/l anionic detergent discharge consent level for L'Oréal is stringent compared to another leading cosmetic manufacturer where a 1,000mg/l consent is stipulated by the water authority concerned. Such performance has been achieved through membrane filtration.

4.3 Legislative Requirements

4.3.1 Legislation - Framework in England and Wales

The principle legislation concerned with the protection of the water environment and releases from industry are:-

- **Environmental Protection Act 1990 - Part I**

Integrated Pollution Control (IPC), includes consideration of water issues. Processes releasing Red List substances generally fall under IPC, and this is incorporated into a list of Prescribed Processes and Substances [PPS 1991].

- **Water Resources Act 1991 - Part III**

This statute controls discharges to controlled waters (rivers and lakes) which must be authorised by consent.

- **Water Industries Act 1991 - Part 1V**

This statute includes the requirements for trade effluent discharges to sewer which must be authorised by consents.

- **Environmental Protection Act 1990 - Part III**

This part of the Act establishes a regulatory system for controlling statutory nuisance. Section 259 of the Public Health Act 1936 enables any pond, pool, ditch or gutter that is so foul or in such a state to be prejudicial to health to be treated as a statutory nuisance.

4.3.2 Trade Effluent Legislative Requirements

Trade effluent may be defined as any liquid which is wholly or partly produced in the activity / action of any trade undertaken at trade premises. The Trade Effluent Prescribed Processes and Substances Regulations were first established in 1989 with additions in 1992 and 1993. The Regulations prescribe certain discharges to sewer as 'special category'.

Stringent controls are exercised for the processes and substances covered by the Regulations. An effluent is considered special category if it contains any of the following:-

- Red List substances
- Carbon tetrachloride
- Effluent from certain prescribed processes

- Effluent containing more than 30 kg/year trichloroethylene or perchlorethylene.

Such discharges are required (under the Water Industries Act 1991), to have a consent from the Sewerage Undertaker and also to be referred to the Environmental Agency for authorisation. Discharge consents authorise the release of trade effluent and the concentration levels which must not be exceeded. Consents contain conditions which typically cover:-

- Volume of effluent and rate of discharge;
- Key parameters which should not be exceeded:-
  - BOD & COD, (Biological Oxygen Demand & Chemical Oxygen Demand),
  - TSS (Total Suspended Solids),
  - Temperature,
  - pH (alkalinity - acidity).
  - Oils and Greases
  - Anionic Detergents

The conditions can also include discharge times and frequency. A summary of the regulatory regime is detailed in Table 4(I).

A charging structure is established for discharging effluents to controlled waters or sewers and as L'Oréal discharges to sewers the Author has only considered this structure. The costs are based upon the following Mogdon formula [Welsh Water 1996]:

$$C = R + V + (Ot/Os)B + (St/Ss)\,S$$

4.3.3 Legislative Requirements Applied to L'Oréal

L'Oréal originally discharged its effluent to the adjacent river, holding a licence from the National Rivers Authority and consent conditions were imposed. With the development of the Llantrisant sewerage network catering for increased industrial activity a licence was granted for sewer discharge.

The local water authority impose consent conditions based on the capacity of the sewerage treatment works to which L'Oréal's effluent / sewerage will be treated and are detailed below:-

pH - 6 - 10

COD - 6000 mg/l

Suspended Solids - 1000 mg/l

Anionic Detergents - 100 mg/l

Oils, Fats & Greases - 100 mg/l

An automated composite sampler is provided and Welsh Water collects samples at unspecified intervals for charging purposes via the Mogdon formula and consent compliance.

The Environmental Agency have been informed of the typical constituents of the effluent and from inspection of The Environmental Protection of Prescribed Processes and Substances Regulations [PPS 1991] and the GCMS results in Chapter 3, no corresponding constituents are found.

The EPA Pt III covering torts of nuisance may apply to L'Oréal as many of the constituents are biodegradable, releasing Hydrogen Sulphide. The aeration tank used for storing excess effluent quantities / effluent for re-treating may pose such an issue, having a large 'open to atmosphere' surface area presenting an ideal opportunity for odour release. Fugitive emissions are also observed from the effluent plant building. Fortunately there has been a good relationship between L'Oréal and the local residents with only minor complaints.

4.4 Performance of L'Oréal's Effluent Treatment Plant Method Statement

4.4.1 Historic Data Collection

A data collection exercise / investigation commenced in April 1996 to establish historic effluent profiles and trends and to identify the overall variation in effluent from both seasonal and yearly aspects. This exercise involved extensive research into records and files in addition to liaison with Hyder Ltd to provide any missing information.

4.4.2 Effluent Treatment Plant Performance Profiles

In May 1996, an investigation was conducted into the performance of each stage of the process in order to determine plant and individual equipment efficiencies, and so that any bottlenecks or problematical items of plant could be identified. Manual composite samples were taken daily. Four 500ml samples were taken in Pyrex glass containers from each process under investigation at 8.00 a.m., 11.00 a.m. 2.00 p.m. and 5.00 p.m. and stored at 0-4 degrees centigrade via the Chemistry Department refrigerator. The effluents were then combined at the end of each day and a 1000ml composite sample was taken to the University of Glamorgan Water Treatment Laboratory for analysis. The parameters measured were: COD, Suspended Solids, Fats, Oils and Greases, Anionic Detergents and pH.

The samples were taken from the following locations:-

a) Untreated Effluent at Chemical Contact Chamber entry.

b) Treated Effluent at Chemical Contact Chamber exit.

c) Treated Effluent at Dissolved Air Flotation Unit exit.

d) Treated Effluent at Trickling Filter exit.

These tests were taken from May to December 1996 on a weekly basis. The results were combined to provide average graphical performance profiles.

An overall plant setting and performance analysis was undertaken utilising similar sampling techniques for the performance profiles. This study was conducted for the month of June. Untreated / treated effluent, COD and suspended solids were determined and the settings of alum and caustic pH, polymer dosing setting and effluent flow rate observed.

A GCMS sludge analysis was performed on a L'Oréal sample by Hyder Environmental taken at 10.00 am on 13/2/1997.

4.4.3 Total Cost Analysis

For 1996 a total cost analysis for Effluent Treatment was undertaken to identify the optimum level of treatment. The monthly records of chemical consumption / deliveries were consulted and the monthly performance data for COD and suspended solids noted. The total costs for chemicals and discharge costs were then computed and plotted against COD % reduction.

4.5 Discussions

4.5.1 Treated Effluent Performance Profiles

Figures 4(a) - 4(c) detail the treated effluent profiles from 1992 - 1997 for suspended solids, COD, BOD, oils fats and greases, anionic detergents and pH. By inspection it is shown that the treated effluent concentrations are very unstable exhibiting erratic profiles as per the untreated results discussed in Chapter 3. The curves do not indicate any correlation between the parameters except for suspended solids and COD where a relationship appeared to exist.

The maximum and minimum values for the parameters are detailed below:

	Max (mg/l)	Min (mg/l)	Concentration Ratio (CR) (max/min)
BOD	3300	500	6.6
COD	5100	1191	4.28
Anionic Detergents	110	20	5.5
Suspended Solids	705	95	7.42
Oils fats & Grease	117	21	5.57
pH	7.8	6.3	1.24

Such a high concentration ratio for all the results indicate a lack of accurate process control and that any shock influent loading is reflected in the final treated concentrations. In addition, such low minimum concentration values show that over-treating is occurring, increasing the chemical consumption unnecessarily, although a reduction in discharge cost will be observed.

The maximum values of 110 mg/l and 117 mg/l for anionic detergents and oils, fats and greases respectively indicate consent breaches. In addition, such problems would be unknown at the time of treatment and only revealed after the Hyder analysis results were received up to 10 days later.

During the winter months it is shown that the oils, fats and greases concentrations are elevated. This is attributed to the increased Ambre Solaire production (rich in such constituents) during this period, however inspection of Figure 4(c) reveals a consistent overall increase in fats / greases, indicating that many products are now incorporating such constituents.

In Chapter 3 the untreated effluent results indicated an increase in anionic detergents during 1997 which corresponds to the increased shampoo production attributed to the new Elvive product. This trend is also shown in the treated profiles showing a gradual increase to 57 mg/l in June however, from discussions with L'Oréal personnel, this increase is gradually stabilising.

4.5.2 Effluent Plant Performance Profile

Figures 4(d) and 4(e) show the performance profiles of the plant achieved between 23/5/1996 and 31/12/1996. These indicate the reduction in effluent concentrations during its progress through each stage in the plant. Table 4(ii) details the performance of each stage of the process. The chemical contact chamber is the most effective stage, reducing oils, fats / greases and suspended solids by 98% and 96.7% of the total reduction respectively, with anionic detergent and COD reductions of 97.4% and 85.7% respectively. The silo trickling filter achieved up to 6.4% reduction in COD indicating that although there is no control, biological activity is evident.

The DAF Unit performed with only 2% and 7.9% decreases in suspended solids and COD respectively. However, the function of the DAF is not to provide dramatic reductions in concentrations as in the contact chamber, but to remove the flocs which have been produced. It was observed that on several occasions the suspended solids and COD concentrations increased when comparing the 'before' and 'after' results. This is associated with the DAF plant limitations detailed in Chapter 2. Table 4(ii) also details the overall percentage reductions in concentrations with anionic detergents having the highest reduction at 96%.

Table 4.4(iii) details a GCMS sludge analysis and it is shown that significant concentrations of 1-Dodecanol are found, indicating that the plant is effective in this substances' removal. However poor alcohol and other hydrocarbon removal was observed, with only 128 mg/l and 49 mg/l found respectively. The 525 mg/l silicone compound content is associated with PC3 mousse production.

4.5.3 Effluent Plant Costs

Figures 4(f) - 4(h) show the annual plant costs for 1995-1997. The dominant costs are for chemicals , £40,330 for 1995, £50,750 for 1996 and £70,700 for 1997, representing 28% in 1995, 32.8% in 1996 and 37.2% in 1997 of the total costs.

The total costs are £143,590 for 1995, £154,570 for 1996 and £190,150 for 1997, showing a 32.4% rise in costs between 1995 and 1997. Such an increase is despite minimal / no inflationary increases in chemicals / discharge costs. The volume increase of effluent treated is mainly responsible for the cost rise, 35015m^3 vs 54100m^3 for 1995 and 1997 respectively representing a 54.5% rise. The maintenance costs increased considerably in 1996 & 1997 which is attributed to failures / breakdowns with the centrifuge. The unit is 19 years old and showing evidence of wear however, its replacement would cost £60-£70k which cannot be justified at present.

The total chemical costs for 1996 were £10,420 greater than 1995, however this increase was counteracted by a £7,940 reduction in discharge costs (£2,480 net cost increase), attributed to improved effluent quality. Therefore, although the discharge cost saving was less than the increased chemical costs, an optimum treatment level exists where treatment and discharge costs will be at a minimum. The water costs are associated with cleaning and flushing of the effluent plant and consideration is being given to utilising rain water for this task.

The Hyder sampling costs are effluent analysis for 2 samples per week. Originally untreated / treated samples were taken but as the former results were not utilised in any monitoring capacity they were not required. Therefore, commencing in February 1997, only treated samples have been taken weekly with analysis of untreated samples conducted quarterly.

The total costs determined do not include plant mechanic breakdown call outs, administration, storage of chemicals etc, which, from discussions with L'Oréal personnel, could equate to £15k p.a.

The parameters on which the costs are based are detailed in Appendix 4.

4.5.4 Overall Effluent Plant Performance

Table 4(iv) details the average plant settings and performance for June 1996 taken from daily composite samples and observations of plant settings. The alum and caustic pH settings were 4.5 and 6.4 respectively and the total costs £2.20/m^3 with an 83.3% COD reduction.

Table 4(v) details the overall performance of the effluent treatment plant for 1995-1997 employing performance indicators for comparison. 1995 had the lowest total treatment cost at £143,590 but exhibited the highest specific cost at £4.10/m^3 versus £3.88/m^3 and £3.51/m^3 for 1996 and 1997 respectively. This indicated that the treatment efficiency had marginally improved for 1996 but substantially increased in 1997. This is attributed to the fixed plant costs being distributed over a greater effluent volume.

1996 had a performance indicator of 410 litres / 1000 units of production compared to 365 litres / 1000 units for 1995, indicating that, as there were no major product changes during the year requiring different process vessel cleaning procedures, the cleaning efficiency had decreased.

The treatment costs per 1000 production units are consistent for the 3 years at £1.50 for 1995, £1.59 for 1996 and £1.58 for 1997, indicating that the plant operation is fairly well managed / operated without any extreme variations between the results. However a reduction in the 1997 costs was expected as the fixed effluent costs for zero unit production is distributed over a greater denominator.

The total volume of effluent has increased consistently over the 3 years: 102m^3/day for 1995 and 158m^3/day for 1997, equating to a 54.9% increase.

As previously discussed, an optimum treatment level will exist whereby chemical and discharge costs are at a minimum. For 1996 the treatment efficiency was assessed determining the chemical and discharge costs and plotting against a base of COD % reduction. From Figure 4(i) it is shown that a 78% reduction yields the minimum overall costs of £2.00/m^3. Such data enables a philosophy for treatment to be formulated, providing the Engineering Manager and effluent plant operator with details of the ideal treatment level. This data can be used on a monthly basis to assess performance results. The cost figure is considerably less than that for other years including 1997 where a study for April revealed overall costs of £4.37/m^3 for discharge and chemicals (see Chapter 5). The 78% COD reduction optimum efficiency will not always hold true due to the inherent instability of L'Oréal's effluent, however it forms a firm foundation for treatment philosophy by identifying the most efficient area of treatment. From inspection of Table 4(iv) the total cost of £2.20/m^3 corresponds approximately to the total cost curve associated with a 83% COD reduction in Figure 4(I) verifying that this optimum treatment level prediction is fairly accurate.

Table 4(vi) details the overall effluent plant performance for 1995 - 1997. The influent concentrations have increased by 14% for COD, 259% for oils, fats and greases, and 26.1% for anionic detergents. Minor increases in suspended solids have also been observed equating to 4.3%. Table 4(v) shows that the overall total costs have decreased per m^3 of effluent from £4.10 for 1995 to £3.51 for 1997, indicating that treatment efficiency has improved. This statement is supported by Figure 4(vi) where lower treated effluent concentrations of COD and suspended solids are achieved despite greater influent levels.

During treatment the operator has no method of assessing the influent / treated effluent COD concentrations (or similar related parameters) and is therefore unable to estimate concentration reductions. The author has investigated the possibility of such on-line monitoring in addition to plant optimisation detailed in Chapter 5.

4.5.5 Future Effluent Hydraulic Loading and Costs

It was discussed that the costs had increased 32.4% for 1997 vs 1995 against a 54.5% effluent volume increase, therefore the greater the effluent volume the greater the efficiency as the fixed charges will remain constant irrespective of treatment volumes. Based upon the results in Table 4(v), the effluent volume increase between 1995 and 1997 versus production level rise indicates that a correlation exists between production and effluent levels. The Author has examined this relationship and found an exponential correlation:

Effluent generated = $7957e^{(0.016 \times PL)}$

The base load is 7957m^3 for zero production which is associated with accidents and spillages and non production related effluent generation. Therefore accidents must be minimised to reduce such a base load. A linear correlation was suspected and greater levels of data may have yielded such a relationship, however, as shampoo vessels generally require greater levels of cleaning and the production levels are shampoo biased at present, such a correlation may be accurate.

The treatment costs are related to treated volumes and a linear relationship found:

Treatment Costs = 57274 + 2.45 x TV

Therefore fixed plant costs of £57274 are incurred irrespective of treatment volumes and a £2.45/m^3 variable cost found. The plant efficiency will increase with greater volumes treated as the fixed costs will be distributed over a greater volume output.

Based on the 1998 target of 150 million units, 87711m^3 of effluent will be produced equating to a £272166 annual treatment cost. This will require 256m^3 to be processed each day. The hydraulic capacity of the plant (primarily the domestic sump pumps) will be at full capacity, therefore a system upgrade must be considered.

It must be emphasised that the above correlations are based on only 3 years data and the graphical profiles are detailed in Appendix 6. The circular graphical points for production level vs effluent volume represent calculated values from the derived expression, with elliptical points used for the actual data as detailed in Table 4(v). For effluent volume vs plant costs the elliptical points again represent the actual data.

Figure 4(a) Quarterly Results for Treated Effluent from 1992 - 1996

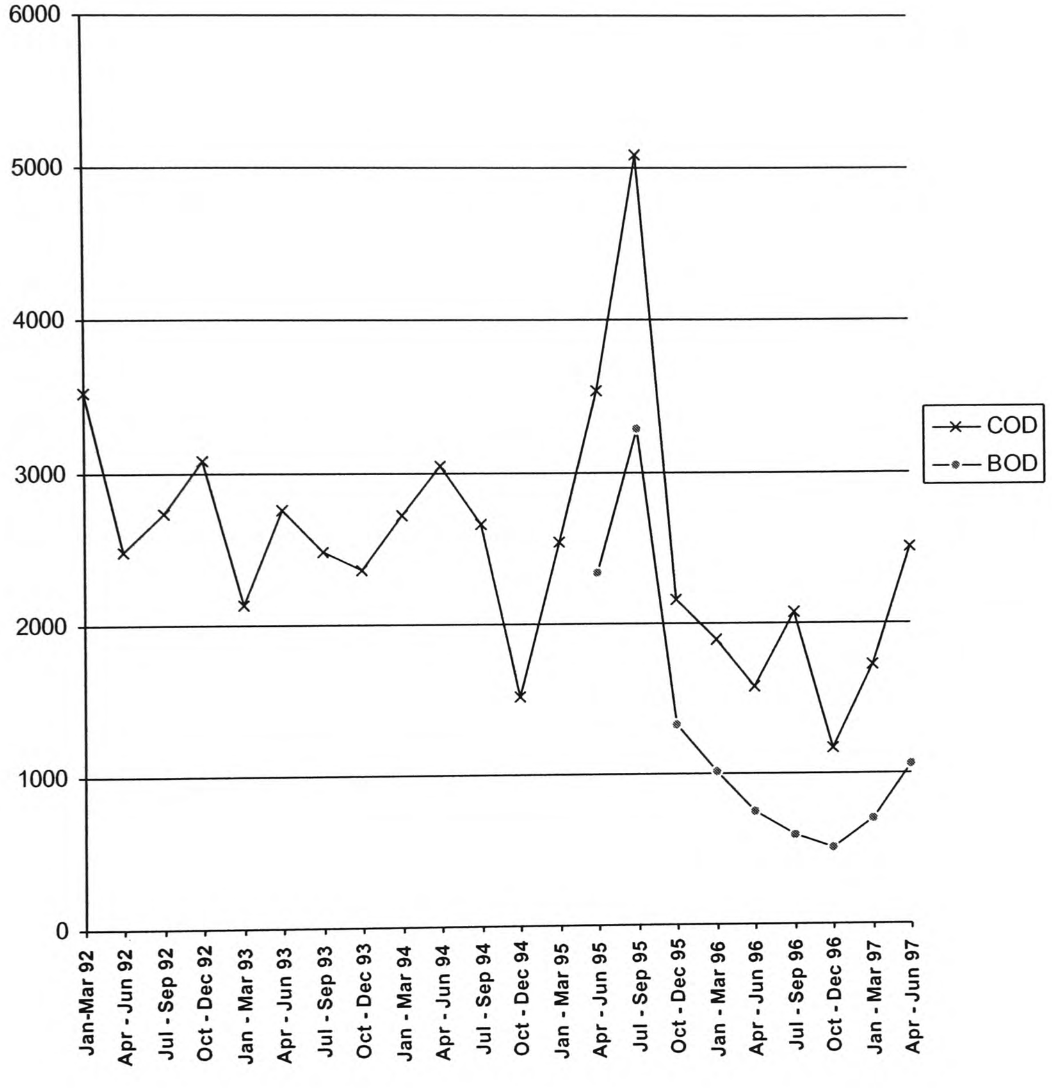


Figure 4(b) Quarterly Results for Treated Effluent from 1992 - 1996

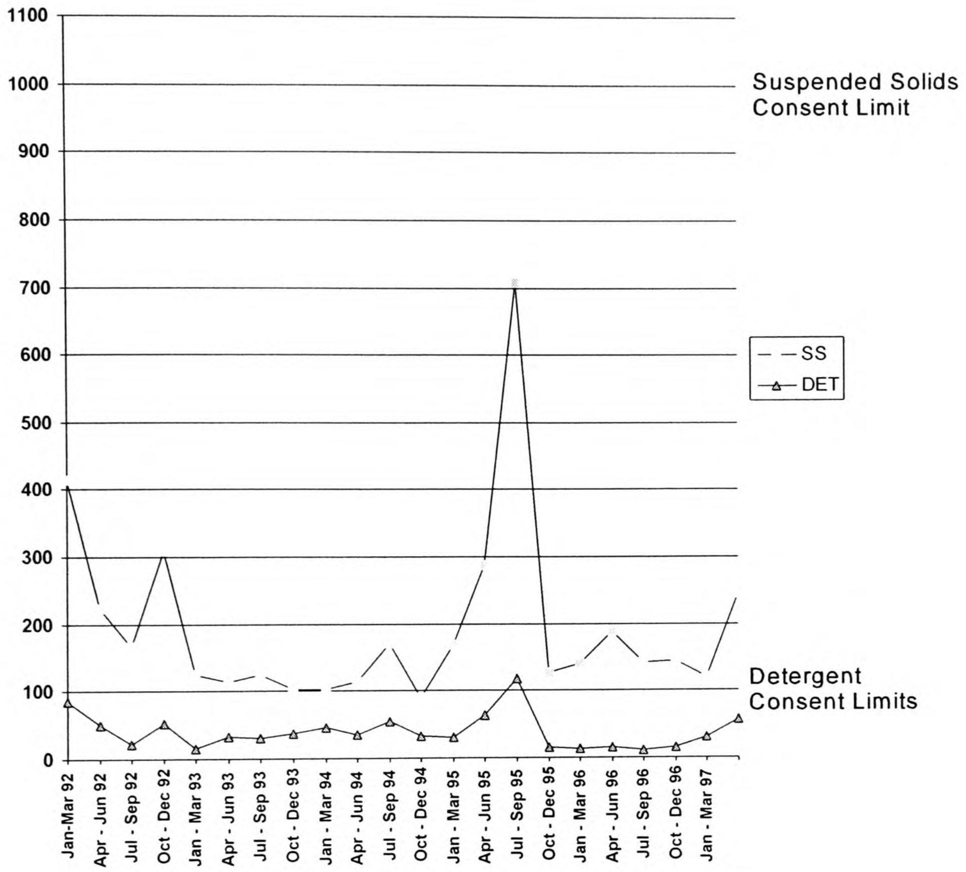


Figure 4(c) Quarterly Results for Treated Effluent for 1992 - 1996

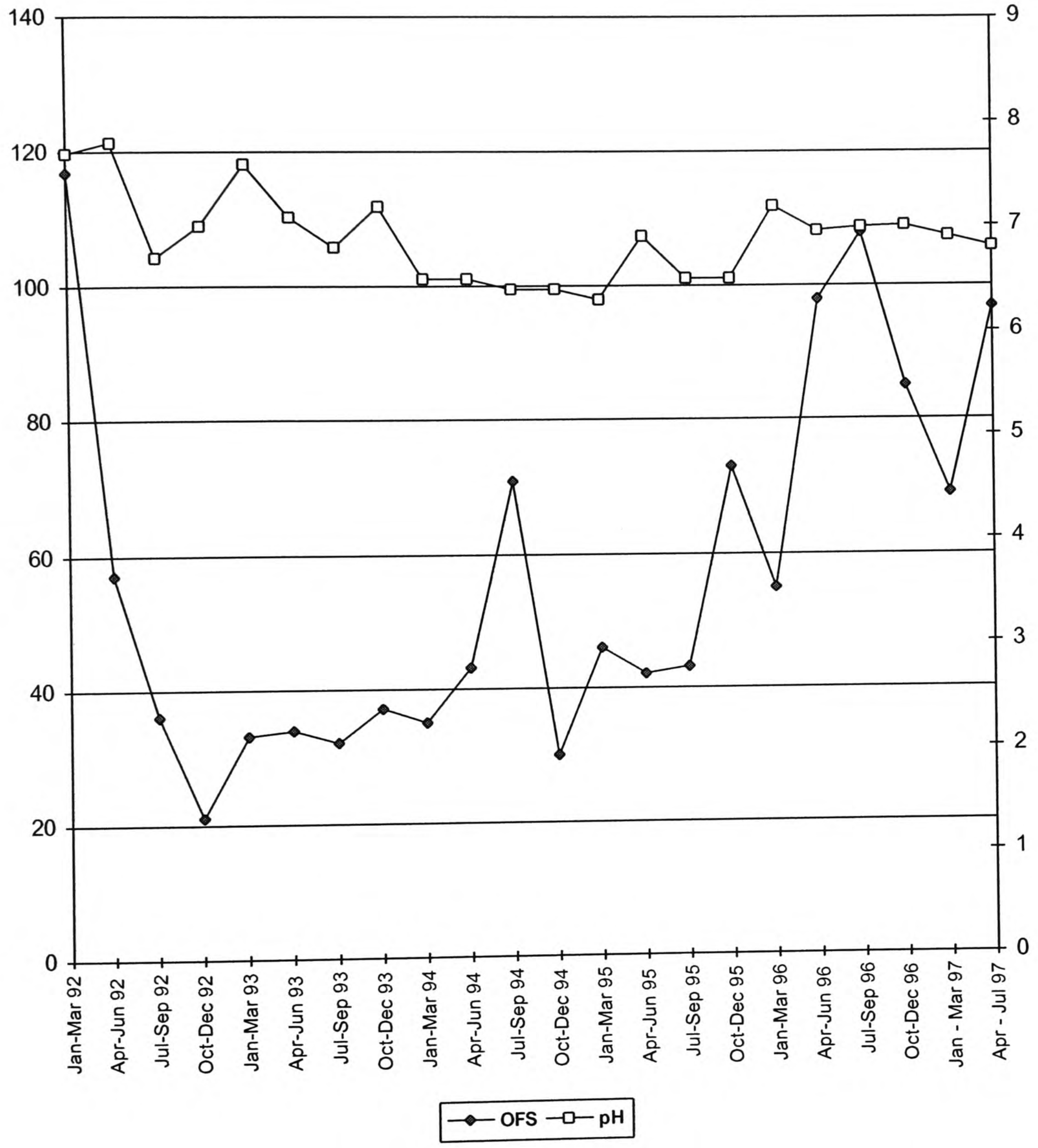


Figure 4(d) Performance Profile of Effluent Treatment Plant 23/05/96 - 31/12/96

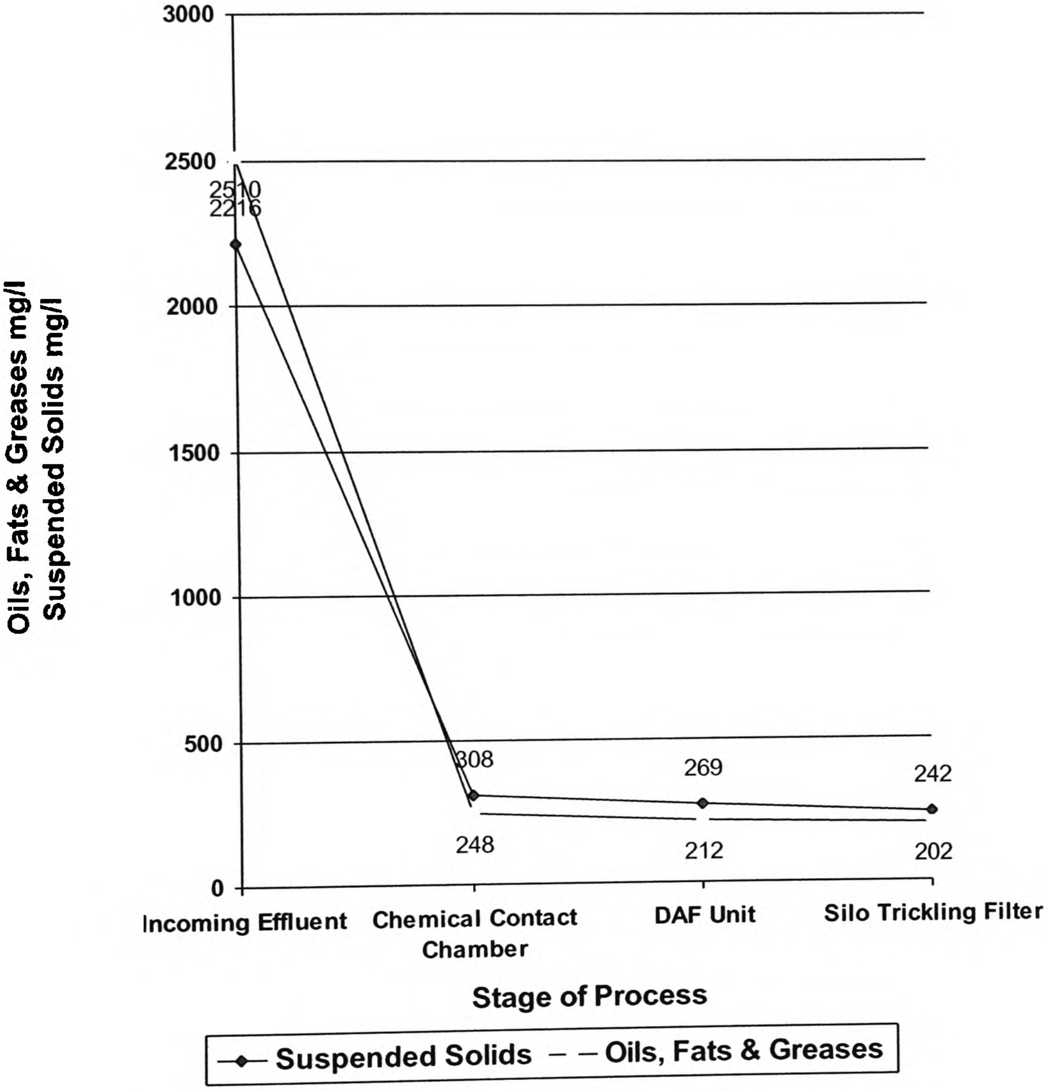


Figure 4(e) Performance Profile of Effluent Treatment Plant 23/05/96 - 31/12/96

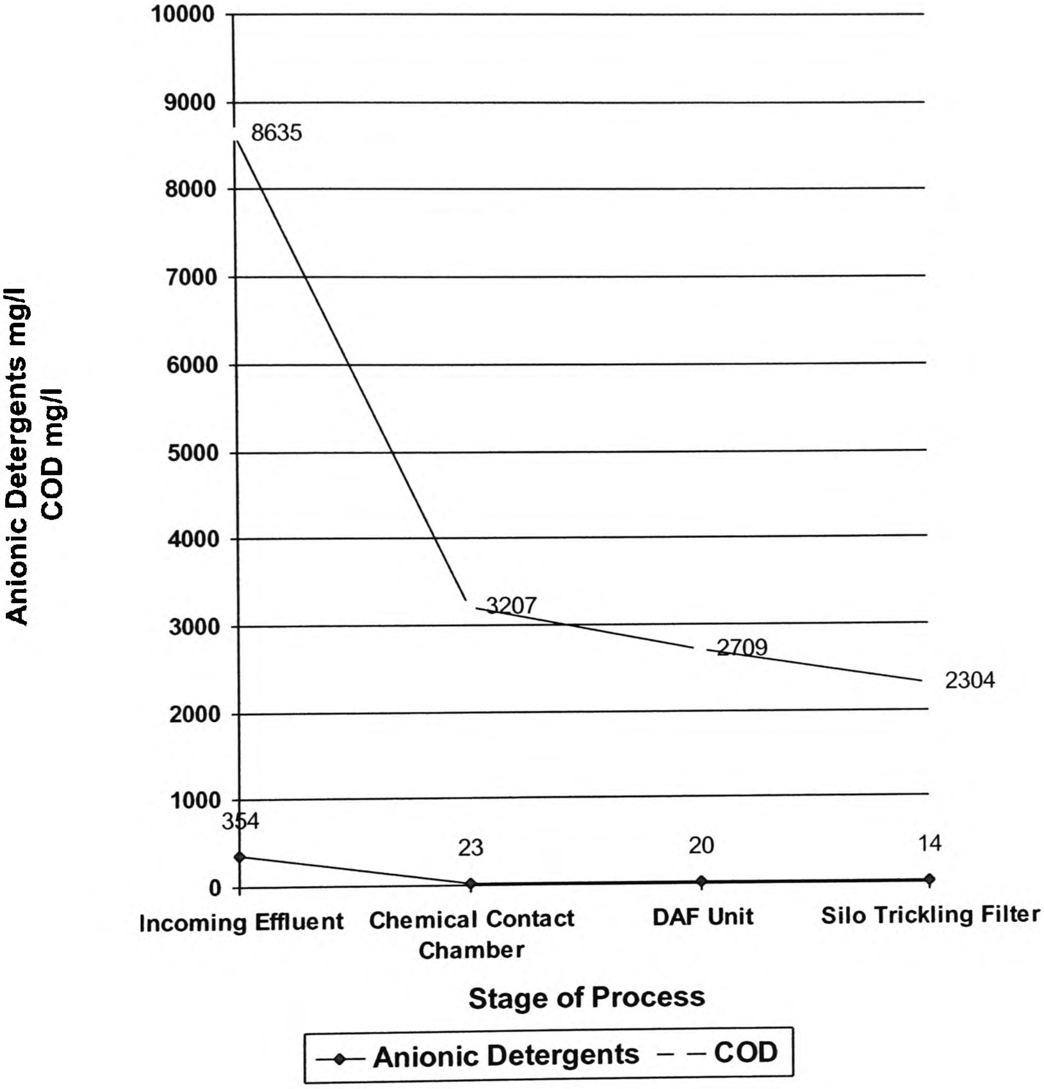


Figure 4(f) Breakdown of Effluent Plant Costings 1995

Total Costs £143,590

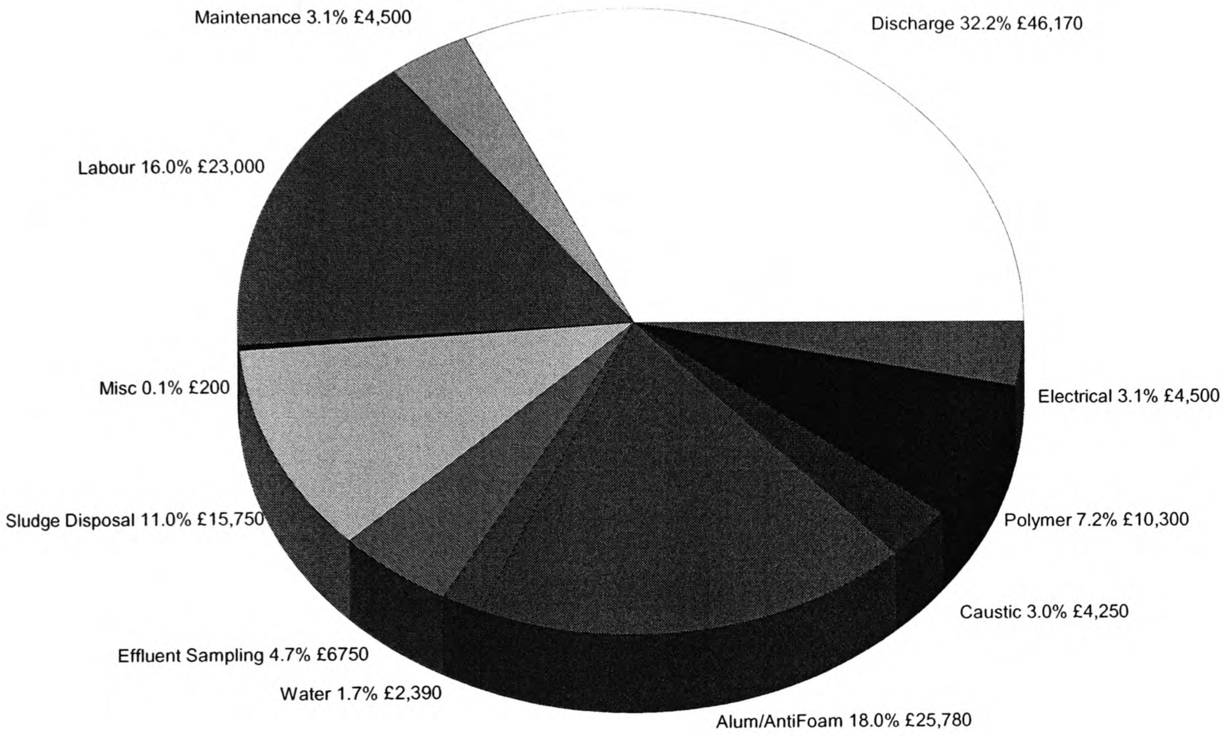


Figure 4(g) Breakdown of Effluent Plant Costings 1996

Total Costs £154,570

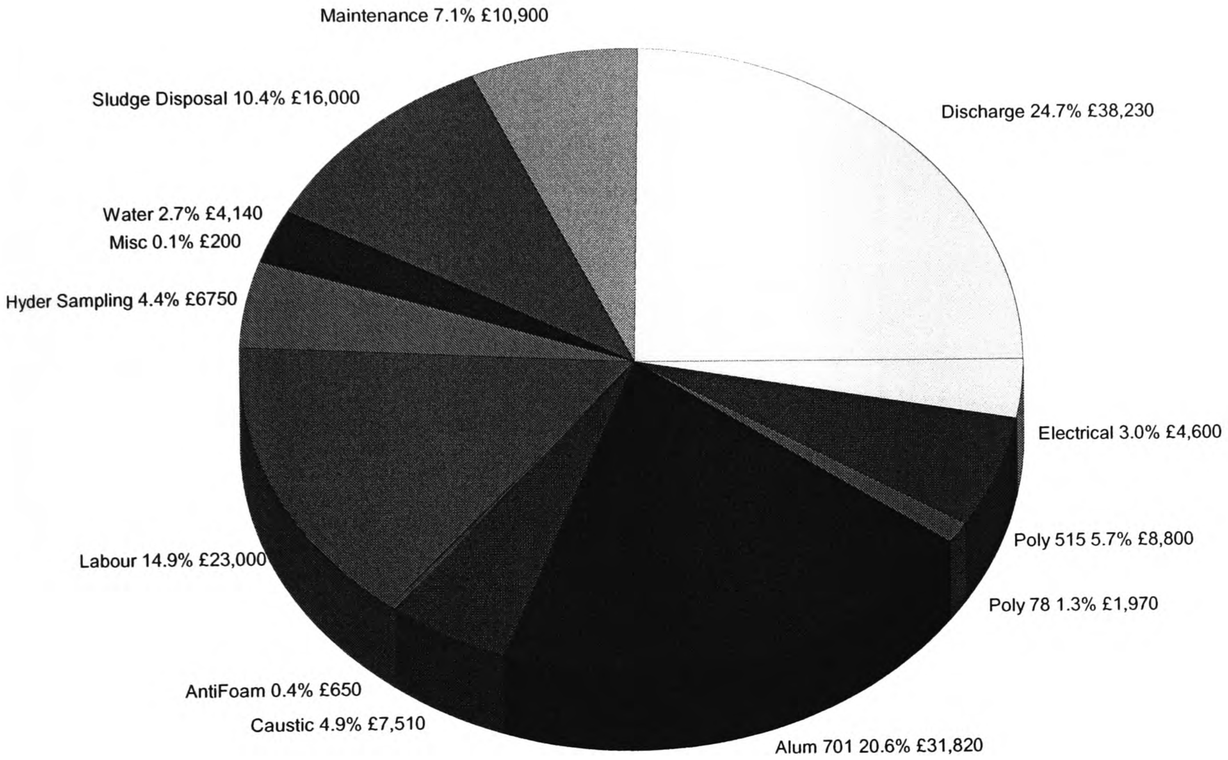


Figure 4(h) Breakdown of Effluent Plant Costings 1997

Total Costs = £190,150

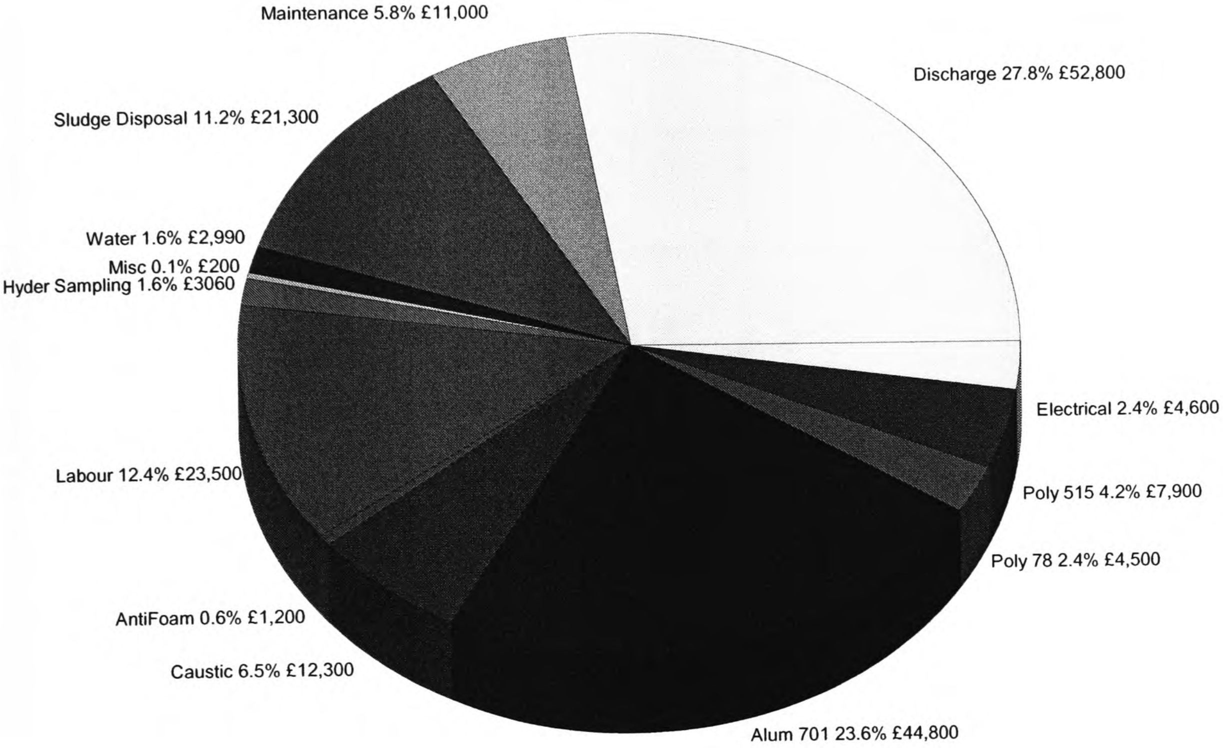


Figure 4(I) Total Cost Analysis

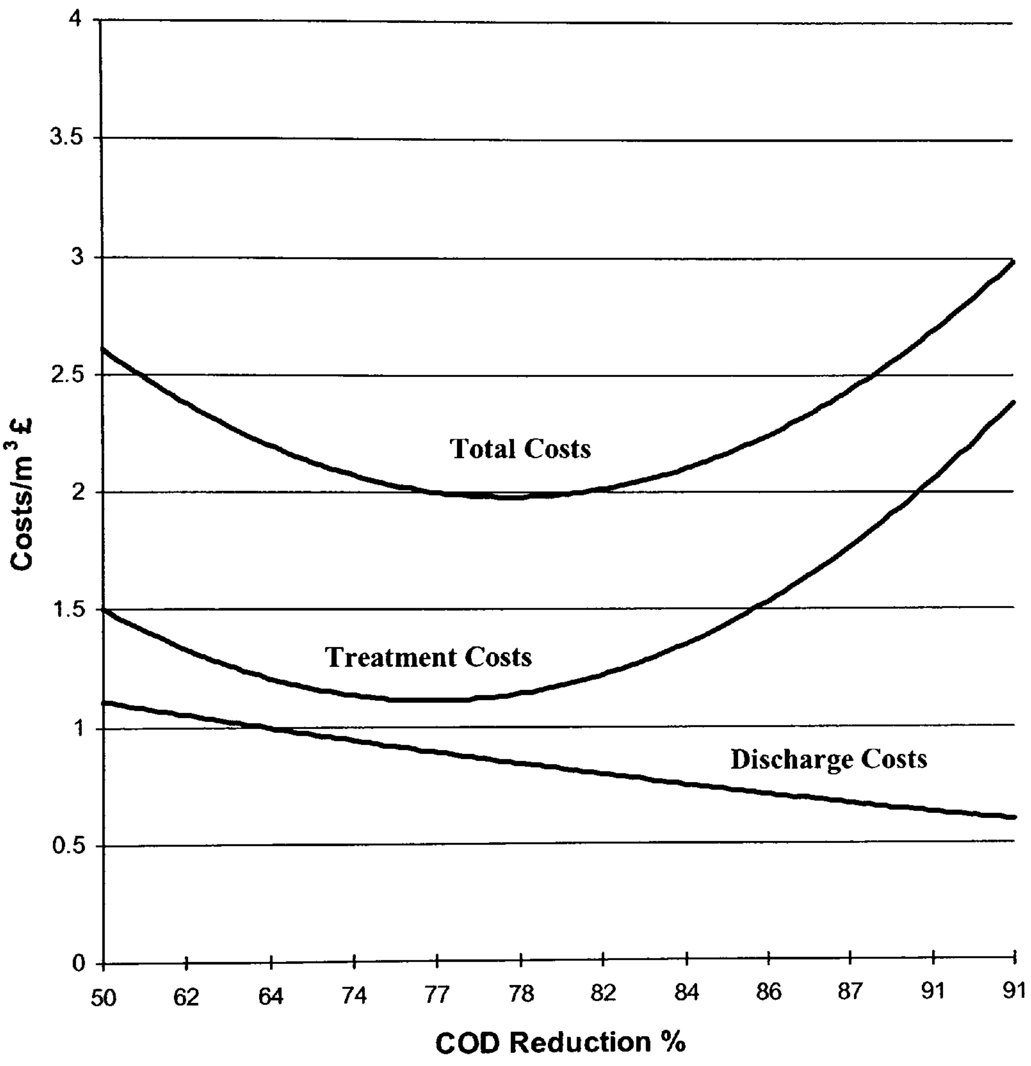


Table 4(I) Regulatory Regime - Summary

Discharge Route	England and Wales	Scotland
To Sewer	Consent from Water Service Company.	Consent from Water Authority.
To sewer with 'special category effluent'.	Consent from Water Service Company and Referral to EA.	Control from Water Authority and Referral to SEPA.
From IPC Process to Sewer.	Authorisation from E.A. (Consult with Water Service Company).	Authorisation from SEPA (Consult with Water Authority).
To controlled water.	Consent from E.A.	Consent from SEPA.
From IPC process to controlled water.	Authorisation from E.A.	Authorisation from SEPA.

Table 4(ii) Plant Performance Appraisal

	COD % Reduction	Suspended Solid % Reduction	Oils, Fats and Greases % Reduction	Anionic Detergent % Reduction
Chemical Contact Chamber	85.7	96.7	98	97.4
DAF Unit	7.9	2.0	1.6	0.9
Silo Trickling Filter	6.4	1.4	0.4	1.8

Total Parameter Concentration Reductions

COD	73.3%
SUSPENDED SOLIDS	89%
OILS, FATS & GREASES	92%
ANIONIC DETERGENTS	96%

Table 4(iii) GCMS Analysis for L'Oréal Sludge Sample

Taken at 10.00 am on 13th February 1997

Determinand	**Result** (mg/kg)
Octamethyl Cyclotetrasiloxane	178
2 -Heptenal (Solvent)	173
Decamethyl Cyclopentasiloxane	710
D_8 Naphthalene (Internal Std)	200
Hydrocarbon	49
1- Decanol	160
Silicone Compound	525
1- Dodecanol	5984
Hexadecanoic Acid	224
Long Chain Alcohol	128

Table 4(iv) Performance Analysis June 1996

Alum pH Setting:	4.5
Caustic pH Setting:	6.4
Polymer:	78 (Setting on dosing pump Handwheel range:0-105)
Volume Flow Rate:	1450 gph
COD (Untreated):	8928 mg/l
Suspended Solids(Untreated):	2046 mg/l
COD (Treated):	1492 mg/l
Suspended Solids (Treated):	141 mg/l
COD Reduction %:	83.3%
Chemical Costs/m	144p
Discharge Costs/m	75.6p
Total Costs	£2.20 /m^3

Table 4(v) Table of Results - 1995 - 1997

	1995	**1996**	**1997**
Total Quantity of Effluent Generated	35015m^3	39876m^3	54100m^3
Total Quantity of Effluent Treated per day	102m^3	116m^3	158m^3
Total Treatment Cost	£143,590	£154,570	£190150
Total No. of Units Produced	96 million	97.2 million	120 million
Effluent Generated per 1000 Units	365 Litres	410 Litres	451 Litres
Cost of Effluent per 1000 Units	£1.50	£1.59	£1.58
Cost of Effluent per m^3	£4.10	£3.88	£3.51

Table 4(vi) Overall Appraisal of Effluent Treatment Plant

	1995 Untreated Results	1995 Treated Results	1996 Untreated Results	1996 Treated Results	1997 Untreated Results	1997 Treated Results
Suspended Solids	2898	188	2288	156	3024	184
COD	10006	2671	8407	1697	11409	2108
Oils, Fats, Greases	1613	51	3197	86	4180	83
Anionic Detergents	456	36	359	14	575	44
Total Costs		**£143,590**		**£154,570**		**£190,150**

5 Taguchi Experimentation

5.1 Introduction

The Taguchi design of experiments theory has been applied successfully to many industrial manufacturing applications. Companies such as Pontiac and Chrysler have reaped the benefits of the theory through improved quality, reduced component reworking and costs. It has been claimed that Taguchi methods have been responsible for 80% of Japans quality improvements [Dean 1994].

The theory is based upon the principle that all processes have a number of controllable and variable inputs and will impact on a measurable output parameter which it is desirable to control, e.g. quality, costs etc. The application of Taguchi enables the optimum plant settings to be determined and, in addition, the level of improvement can be predicted. Another benefit is the optimisation of the existing plant, without the the need for investment in new equipment, which is often seen as the only option without establishing the real cause of the problem.

The application of Taguchi to L'Oréal's effluent plant had the following aims:

- To reduce the set up time for the plant for a wide range of effluent concentrations.
- To minimise the overall running costs of the plant with respect to chemical consumption and discharge costs.
- To improve the efficiency of the operation.

The aims were categorised into a series of objectives as follows:

- To appraise the average performance of the effluent plant at the current settings.
- To develop an experimentation regime from the Taguchi Theory and to undertake the necessary experimentation.
- From these results determine the optimum plant settings and predict the outcome of the tests.
- To undertake a confirmation run utilising the optimum settings derived.

- To determine the improvement in plant performance and costs from the application of the theory.

5.2 Taguchi Theory and Literature Search

5.2.1 Taguchi Principles

Dr Genichi Taguchi was born on the 1st of January 1924 in Japan and although he had extensive training in textile engineering, statistics were his main interest and forte. After World War 2 he was employed by the Japanese Ministry of Health and Welfare to initiate the first national study on health and nutrition. He moved to Morinaga Pharmaceutical where effective experimentation techniques were required for penicillin production and there he started to apply DOE techniques. He adopted orthogonal arrays to determine the mean result of experimentation and the variation of that result.

Taguchi's emphasis was on the minimisation of function variation which can be measured, i.e. pressure, tolerances etc, and the purpose of the experimentation is to identify the key factors which have the highest variation contribution. His definition of quality is "the minimum loss imparted by the product to society from the time the product is shipped".

5.2.2 The Loss Function

Taguchi's interpretation of loss is detailed in Figure 5(a) and loss is zero at the target value and increases if the actual value deviates from the target. Loss is continuous and can calculated using the following expression [Peace 1993]:

$$L = K (y - m)^2$$

This expression was derived from the Taylor mathematical expansion series and is quadratic in nature. Taguchi expressed loss in financial terms which is ideal when justifying DOE projects to senior management, where technical issues and benefits can converted to monetary terms which will generally be the criteria by which a project is judged.

5.2.3 Orthogonal Arrays

Dr Taguchi developed the utilisation of arrays for experimentation design and they measure the effect a factor imparts on the final result and the variation from the mean. Each factor is varied an equal number of times, providing a balanced experiment whereby the effect of one factor can be distinguished from the effects of others. The application of orthogonal arrays enables a reduced number of experiments to be performed thereby reducing time and cost. If the process is time sensitive, i.e. the product degrades with time, the reduced numbers of experiments will lessen this effect.

The term orthogonal is defined as balanced and not mixed and, with respect to matrices, means statistically independent. In an orthogonal matrix if the parameters and level settings are arranged as per Figure 5(b) it is shown that Parameter A occurs 4 times at level 1 and at level 2. When comparing column B it is shown that A is at level 2 twice and B twice also. A similar pattern emerges when comparing any two columns:

A at level 1, occurs 4 times: B at level 1 occurs 2 times

B at level 2 occurs 2 times

A at level 2, occurs 4 times: B at level 1 occurs 2 times

B at level 2 occurs 2 times

A at level 1, occurs 4 times: G at level 1 occurs 2 times

G at level 2 occurs 2 times

A at level 2, occurs 4 times: G at level 1 occurs 2 times

G at level 2 occurs 2 times

If a dramatic change to the quality characteristic being measured is observed when varying the level of one factor this is attributed to the impact of this factor.

A typical L8 array is shown in Figure 5(c) where there are 7 factors A - G and 2 levels resulting in only 8 experiments necessary. Such a benefit in time and cost is reinforced when considering 13 factors at 3 levels. With Taguchi methods only 27 experimentations are required where 1594323 would be necessary with the traditional factorial approach. Therefore such a experiment would cost 0.0017% of the traditional method.

The distortion data is the measured quality characteristic to be controlled:

where $D1 = (\sum Y)/8$

$$D1 = (Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8)/8$$

$$A1 = (Y_1 + Y_2 + Y_3 + Y_4)/4$$

$$A2 = (Y_5 + Y_6 + Y_7 + Y_8)/4$$

The same principle is employed for B, C, D, E, F and G. The mean values are inputted into a response table and the plant settings which provide the optimum quality characteristics are determined and selected for the running settings. A confirmation run is then undertaken. If the optimum settings are found to be A1, B1, C1, D1, E1, F1, G1 a prediction of the results Y1 can be calculated.

5.2.4 Robustness and Signal to Noise Ratio

Parameters are classified into noise or control factors. Humidity and operator characteristics, etc. are impossible / difficult to control and are categorised as ‘noise’. However, pressure, temperature, physical dimensions are all controllable and are classified control factors.

‘Noises’ will always be present but their effects can minimised by developing ‘robust’ processes which will withstand the effects of noise. This can be achieved by increasing a ratio known as signal to noise, i.e. S/N. The greater the ratio the greater the process ‘robustness’.

5.2.5 Summary of Taguchi Experiment Stages

- Define problem, identify factors to be varied, identify noise factors etc.

- Select experimental design, number of factor levels, orthogonal array design, 'robustness'

- Prepare for experiment, prepare data spreadsheets, plant under investigation, measuring equipment etc.

- Conduct experiment and record data

- Analysis of data, input into array and perform calculations

- Determine optimum settings, formulate response table and determine optimum settings

- Predict outcome, with optimum settings calculate Y1

- Conduct confirmation, run plant to have similar conditions as original experimental run

- Review - if not confirmed go back to 1, this may indicate that 'fine tuning' is required for one factor

5.2.6 Literature Search

Fuzzy logic control theories have been employed for controlling uncertainty in processes and has been used for regulating an Activated Sludge Plant [Tsai, Ouyang, et al 1993]. The research found that such control techniques can accommodate non linearity and uncertainty and predict process outcomes for plant optimisation. Therefore such a theory could be employed for L'Oréal's plant and is worthy of further investigation.

The Taguchi DOE methods have been applied to the purification of waters contaminated with metal ions [Barrado, Vega, et al 1996] and an L9 array was employed. The total residual concentration was to be reduced and was therefore the quality characteristic to be optimised, iron was the most influential factor with pH and time ranking second. A 99.99% maximum purification efficiency was achieved and the optimum settings provided the least efficiency variation with varying influent loads.

Taguchi DOE methods have also been applied to optimise a chemical treatment plant removing ferrites from waste waters [Barrado, Prieto, et al 1998]. Operational variables were selected as control factors and a 99.9% purification efficiency was achieved with a chemically inert sludge as the by product. The authors concluded that the Taguchi theory could be applied for optimising metal removal from waste water processes.

Chemical production processes requiring optimisation have benefitted from Taguchi experimentation such as the chlorination of gold in de-copperised anode slime with chlorine gas in an aqueous medium [Donmez, Ekinci, et al 1999]. The reaction temperature, reaction period, stirring speed and solid to liquid ratio were the control factors selected and at the optimum settings a gold extraction of 99% was achieved. It is interesting to note that the efficiency improvements in what is essentially a chemical process have resulted from a variation in the mechanical plant settings. Cobb and Clarkson (1994) optimised a polymerase chain reaction process using similar techniques.

A gas fired domestic boiler has had fuel effeciency improvements with reductions in nitric oxide emissions via the application of the Taguchi theory. A 5ppm emission level for the latter quality characteristic has been achieved [Melzig 1998].

The flexibility of the DOE theory has enabled the optimisation of many diverse systems and has even been employed in the performance evaluation of canal distributories [Raju and Pillai 1999]. Such flexibility has been recognised by Beauchamp and Youssef, who have promoted the application of Taguchi principles in Quebec by offering DOE courses within its QMA undergraduate program at the university of Quebec [Beauchamp and Youssef 1998]. Such a course demonstrates the practical and analytical aspects of the theory and eliminates scepticism which is a potential pitfall with L'Oreal's application.

The Taguchi Theory can be employed in many effluent applications. If influent concentration stability can be ensured, the application will eliminate the requirement for costly and lengthy trial and error set up philosophies. In addition, Taguchi can be employed in complex situations such as L'Oréal's, providing a rapid solution for efficiency improvement.

5.3 Effluent Plant Taguchi Design of Experiment

The initial task to be undertaken was to establish the variable input parameters and measurable outputs desired to be controlled. From the analysis and general observations of the plant the main parameters which could be varied were established as:

- Effluent flow rate.
- Aluminium sulphate flowrate.
- Caustic soda flowrate.
- Polyelectrolyte flowrate.

Unfortunately the alum and caustic soda flowrates could not be directly controlled and only the control panel pH setting could be preset for both chemicals to vary the flowrates, i.e. a lower pH setting to increase the alum flow and vice versa for the caustic soda.

The factors: incoming effluent temperature, pH value, effluent concentrations, constituents and colour were considered 'external noises' to the process as no control of these was possible. The factors temperature, effluent constituents etc. throughout the treatment process having their own variability were assigned as 'internal noises'.

The output quality characteristics by which the success of the experimentation would be appraised were COD reduction percentage and the chemical and discharge total costs.

Initially the current average settings of the four variable parameters had to be determined and as no reliable flow meters were provided for chemical consumption this was measured manually. These measurements were taken on a daily basis from 10/04/1997 to 25/04/1997 inclusive, at 12.00pm. A sample of untreated effluent was taken at the chemical contact chamber entry, followed by another treated sample at the exit, taken at a time when the sampled influent had reached this point. The COD, suspended solids and turbidity were analysed for both samples by Hyder Environmental of Bridgend. The plant settings of alum pH, caustic pH, polymer volume flow and effluent volume flow were also observed. The results were mean averaged and detailed in Table 5(I).

The maximum duty of the alum and caustic soda chemical dosing pumps were determined by the 'starvation' of treatment chemicals causing the dosing pumps to operate at maximum flow to adjust the pH values to the preset levels on the control panel. The polymer pump maximum duty was established by manually adjusting the flow rate of the unit to its maximum with the calibrated handwheel and measuring the resulting flowrate. The maximum duties were as follows.

Aluminium Sulphate dosing pump = $0.05m^3$/hour

Caustic Soda dosing pump = $0.025m^3$/hour

Polymer dosing pump = $0.06m^3$/hour

Effluent volume flow rate = 2000 gallons per hour ($9.1m^3$/hour)

Three setting levels were selected and as four parameters were to be varied a Taguchi L9 Orthogonal array was employed. The polymer dosage is the most difficult to vary therefore this was selected for variable A as only two further changes were required. Variables B, C and D were the aluminium sulphate pH setting, caustic soda pH setting and the effluent volume flow rate respectively. The settings were based on level 2 representing the 'average setting' determined and levels 1 and 3 approaching the plants minimum and maximum capacities respectively. The L9 array plant settings are detailed in Table 5(ii).

On 07/05/1997 the experiment was conducted over a period of one day. Once the plant settings had been adjusted the plant was left for one hour and samples taken before and after the contact chamber at 20 minute intervals to ensure a composite result would be achieved for the hour. The samples were analysed by Hyder Environmental of Bridgend for COD, pH, suspended solids and turbidity. The overall performance of the plant, percentage COD reduction and chemical / discharge costs were calculated. The optimum plant settings were determined and a prediction of the results calculated. Confirmation runs were conducted using the afore mentioned methods.

5.4 Initial Observations and Parameter Correlations

The observations of the initial Taguchi experiment conducted on 07/05/1997 are detailed in Appendix 5. Considerable variation in the incoming effluent concentrations were noted and the experiment was re-run for the four plant settings of 1, 5, 7 and 9 on 18/06/1997. This data was incorporated into the original observations.

The observations reveal that the most economic treatment was achieved with a percentage COD reduction of 77%, which corresponds to the 78% most economic level for 1996 detailed in Chapter 4.

From Chapters 3 and 4 it was discussed that a correlation between suspended solids and COD exists. Although the profiles for the period considered were not totally reliable and 'freak' observations were noted, there appeared to be a link for untreated and treated effluent which justified further investigation. COD and suspended solids are problematical to measure quickly, directly and without expensive sophisticated monitoring equipment, therefore another parameter which could relate COD and suspended solids was investigated. Turbidity is related to suspended solids and is fairly inexpensive and simple to measure directly on line. Therefore during the April 1997 plant monitoring (10/4 - 25/4) and all Taguchi tests, the three parameters were measured to establish whether correlations exist.

Figures 5(d) and 5(e) are the curves for untreated and treated effluent and exponential and linear relationships are found respectively. For treated effluent, the intercept of the curve is 2000 for COD and -180 for suspended solids. It is not possible to have a -180 mg/l suspended solids value which highlights limitations with this expression. The 'freak' points not following the linear nature of the curve have caused this undesirable feature, however, the relationship will approximately hold true when the curve passes the base of the x-axis where the turbidity will be 143+ FTU.

Equations for the curves have been formulated:

Untreated Effluent

Suspended solids $= 1279.7e^{(T \times 0.000364)}$

COD $= 4960.6e^{(T \times 0.000273)}$

Treated Effluent

Suspended solids $= -180 + 1.26T$

$$\text{COD} = 2000 + 3.9T$$

Figure 5(f) details the effects that percentage COD reductions and COD removal quantities have on discharge / chemical total costs for treatment between 10/4/1997 and 25/4/1997. It is shown that a percentage COD reduction and removal level of 14.5 % and 1552 mg/l yields very high specific costs. This is possibly attributed to high levels of anionic detergents present in the influent not reflected in the COD content of 10733 mg/l. Excessive alum dosing would have been required to depress the pH to the level required to initiate coagulation.

The lowest overall costs were found at a COD removal level of 9075 mg/l and a 78% COD reduction. This again confirms the 77 - 78% most efficient reduction figure previously discussed. However, by including the COD removed into the graph, it is shown that the percentage reduction is achieved with a specific removal level. Therefore the actual COD removed is crucial to the economic efficiency of the plant. As L'Oréal's effluent profile is so unstable it is not possible to predict a single effective percentage COD reduction and removal level as this would require constant influent concentrations, however the above performance indicators can be used as a basis to achieve economic treatment.

5.5 Optimum Plant Settings

The distortion data Table 5(iii) was constructed and the distortion data for percentage COD reduction and total costs calculated. For percentage reduction $\sum Y$ was found to be 491 and D1 54.6%. For total costs $\sum Y$ and D1 were 5090 and 566p respectively.

The COD % reduction signal to noise ratios were calculated on the basis of the larger the better, i.e. the greatest reduction required minimising environmental impact. Experiment 8 with an 83% reduction provided the greatest ratio demonstrating that the process was 'robust' with these plant settings. A noise factor of 27.2 was found with test 9 and by inspection of the table the only control factor that was significantly varied is the effluent volume flow. By contrast, no polymer flow variation was undertaken and it is concluded that effluent flow has significant effects on noise with minimal impact observed with polymer variation. In addition, the data suggests increased effluent throughput improves the signal to noise ratio and vice versa for reduced volume flow.

The main 'noise' encountered during experimentation was the inherent influent variability. These effects were minimised by conducting the initial tests over a one day period minimising the extreme variability exhibited on a day to day basis. Only the Author operated the plant during the tests and the chemicals used were from the same batch eliminating 'noise' through operator and chemical composition variances.

Response tables were generated to establish the optimum plant settings to achieve 'maximum percentage COD reduction' Table 5(iv) and 'minimum total cost' Table 5(v). The former was considered the most 'environmentally benign' option minimising the treated effluent concentrations and the latter the most economic. From the response tables it was found that the plant settings for optimisation of both quality characteristics were identical:

A1 + B2 + C2 + D3

Translated into plant settings these equate to:

Polymer flowrate = 333 ml/min

Aluminium Sulphate pH setting = 4.4

Caustic Soda pH setting = 6.5

Effluent volume flowrate = 1800 gph (8.2m^3/hour)

From Table 5(iv) it was noted that the polymer A1 and A2 settings achieved similar results and after extensive discussions with the plant operator 1500 gph was normally the volume flowrate permissible through the plant to achieve high levels of treatment and to reduce the hydraulic load on the domestic sump pump. Therefore four confirmation runs were to be conducted with A1 (333ml/min) and A2 (666ml/min) polymer settings and effluent flows of D2 (1500 gph) and D3 (1800 gph). The resultant confirmation runs were:

A1 + B2 + C2 + D3

A1 + B2 + C2 + D2

A2 + B2 + C2 + D2

A2 + B2 + C2 + D3

5.6 Optimum Setting Predictions

The equation used to calculate the predictions was:

$A1 + B2 + C2 + D3 - 3D_1$.

Table 5(vi) details the calculated values and, as expected, the settings of A1 + B2 + C2 + D3 are the most economical and environmentally advantageous at 97.2% and £2.02/m^3 respectively. From historic data and plant limitations it was unlikely that such performance figures would be obtained as a 97.2% COD reduction on a 10,000mg/l influent concentration would equate to a 280mg/l treated value, which is associated with biological treatment quality and has never been achieved with L'Oréal's current plant. Again the £2.02/m^3 total cost prediction was not an achievable figure.

The plant settings for experiment 2 (A1 + B2 + C2 + D2) provided more realistic predictions of 77.2% and £3.13/m^3 for percentage COD reduction and total costs respectively.

The percentage COD reduction for test 3 (A2 + B2 + C2 + D2) of 76.2% was again considered practical and achievable, however a total cost of £5.13 was too high and £4.00/m^3 approx. a more accurate assessment.

Experiment 4 (A2 + B2 + C2 + D3) provided a 96.2% COD reduction which was a similar prediction to test 1 which was not a practical value, however the £4.02/cubic metre was a feasible estimate.

5.7 Confirmation Runs

The confirmation runs were undertaken on 10/07/1997 and the results detailed in Table 5(vii). As predicted experiment 1 was the most economical at £2.96/m^3 but did not yield the greatest percentage COD reduction (67%). The results for experiment 2 provided a far greater agreement between predicted and actual results: 77.2% predicted versus 67% actual for percentage COD reduction and £3.13/m^3 predicted against £3.08/m^3 actual for total costs. Experiment 3 revealed a very close match for percentage COD reduction between calculated and achieved results (76.2% and 68% respectively), however the total costs of £4.28/m^3 were considerably less than the predicted £5.13/m^3 which was expected. Experiment 4, as 1, provided a very high percentage

COD reduction prediction (96.2%), but in practice only 70% was achieved. The theoretical cost was very close however, £3.94/m^3 actual versus £4.02/m^3 predicted.

The experiments arranged in the order of the most economical were 1, 2, 4, 3 from the predictions and the actual results agreed with this. A similar exercise was performed with the percentage COD reduction. The theoretical order was 1,4,2,3 however 4,3,1,2 was found from the test results. It must be noted that the total range of results for all tests was 67% to 70% which is a very narrow band with all results being of a similar value. In addition, individual effluent characterisations would have had their own impact on the achieved results, as the predictions were based on the results of differing effluent with again individual characteristics. It is concluded that all of the settings selected would have provided high COD reductions and therefore the final setting selected should be based on the most economical which the Taguchi theory predicted.

From these results a final confirmation run was conducted to prove if the predicted setting would again be the most economical to support previously discussed results. Four tests were undertaken with effluent flowrate as the only parameter varied. The flows were to be: 1800gph (optimum predicted), 1700gph, 1600gph and 1500gph (current practice.)

5.8 Discussion and Appraisal of Taguchi Application

5.8.1 Final Confirmation Run

The final confirmation run was undertaken on 29/7/1997 and the results are detailed in Table 5(viii). The most economical and environmentally benign results were found for the predicted setting of A1 + B2 + C2 + D3 achieving results of £3.57/m^3 and 63% for total costs and percentage COD reduction respectively. A flowrate of 1500gph yielded the worst results for both parameters at £4.19 and 48%. Additional polymer would have provided greater efficiency, improving floc quality and hence reducing COD and suspended solids resulting in lower discharge costs, however increased chemical costs would have been incurred. Experiment 3 (1600gph) provided low total costs at £3.58/m^3 just a 1 penny increase over setting 1.

5.8.2 Parameter Correlations and Monitoring and Targeting System

Relationships were found between turbidity, suspended solids and COD for treated and untreated effluent. These expressions can be used to determine the performance of the chemical contact chamber and efficiency of chemical dosing. Such knowledge will enable COD and suspended solids reductions to be determined and monitored. If the monitoring was automated and the data fed into a control panel complete with a computer, a visual display of the parameters and if the treated effluent quality is approaching / exceeding consent levels an alarm could be provided. In addition very high COD reductions would indicate over-treatment and further alarms provided accordingly. Such a system would enable L'Oréal to implement a Monitoring and Targeting program ensuring a proactive approach to treatment.

Although the correlations are approximate, an accuracy of +/-10% can be expected with the exception of occasional 'freak' results. Sophisticated monitoring equipment will provide greater accuracy, at a cost of £30-£50K however.

5.8.3 Predicted Cost Savings

Although the Taguchi theory applied to such an unstable process will exhibit limitations as the optimum settings predicted will be based on previous results which may differ from future influent characterisations, a narrow band of plant settings will be determined in which the optimum will lie. In addition both confirmation runs have proved frugal in comparison to the other settings and the average costs determined for April 1997 of £4.37/m^3.

The costs for the predicted settings from the confirmation runs were £2.96/m^3 and £3.57/m^3 equating to a mean average of £3.27/m^3. This is £1.10/m^3 (25%) less than the £4.37/m^3 found for the April test costs. The volume of effluent treated for 1997 was 54100m^3 and the average chemical and discharge costs were £2.28/m^3. Therefore this shows that the costs for April 1997 are far greater than the years average. Based upon a 25% reduction on the 1997 costs, £0.57/m^3 will be saved. Applied to the volume of treated effluent the optimum settings determined via Taguchi will yield approximate savings of £30800 p.a.

The implementation of any Monitoring and Targeting system should yield savings of 5-10%, therefore a 5% reduction in discharge and chemical costs would be easily achieved with such a program. Based on 1997 costs this equates to an annual saving of £6200 approximately.

As the set up time for the plant would be reduced this would release the operator to perform other duties. It is estimated that a 50% reduction is possible equating to £11750 p.a. saving.

The total estimated savings are therefore £48750 p.a. and a full appraisal of the overall project costs have been provided in Table 5(ix) based upon the employment of a consultant to undertake similar experimentation for plant optimisation.

The Monitoring and Targeting system costs were determined with the assistance of Sensemaster Control Systems of Newport. Based on the £34.5k implementation costs the payback period is less than 9 months, which is acceptable.

The Taguchi analysis costs would be fixed for experimentation on any plant of this nature irrespective of size. Therefore such an application to a larger facility would generate greater savings and reduced payback periods. Although the Taguchi experimentation provides the greatest savings, the Monitoring and Targeting system should also be installed to facilitate fine tuning of the plant and to continually monitor plant efficiency/performance.

Additional benefits are also achieved by such an approach to plant optimisation:

- Reduced chemical consumption will reduce environmental impact associated with their production and distribution.
- Reduced discharge concentrations will reduce loading on water authority plant resulting in reduced environmental impact.
- The approach to effluent treatment will become more proactive, rather than reactive, as other opportunities for optimisation will be identified.

5.8.4 Limitations of L'Oréal Taguchi Application

The experimentation and associated results were well received at L'Oréal, however the domestic sump pump is undersized to provide a duty of 1800gph (8.2m^3/hour). In addition the polymer dosing pump is currently set at 500 - 700ml/min to ensure excellent floc quality resisting the shearing forces caused by the tortuous pipework route to the DAF unit. Furthermore the DAF unit 'beach' is too steep, causing flocs to pass back into the DAF disturbing and shearing other floc. This forces equipment set up to be dictated by plant limitations versus cost and treatment optimisation. Therefore, to maximise the saving potential, these plant limitations in addition to those detailed in Chapter 2 must be addressed. The costs associated with such modifications are detailed in Chapter 6.

5.9 Further Investigations Recommended

Although the Taguchi experimentation was a success, further investigation is required to support and enhance the results and to identify further opportunities for optimisation. A summary is detailed below:

- Further Taguchi experimentation required for fine tuning. L9 array again employed but using narrower band for variation e.g. 4.3/4.4/4.5 for alum pH levels 1 to 3.
- Taguchi experimentation undertaken on effluent of constant concentration and confirmation run undertaken on similar effluent.
- Greater accuracy chemical flow equipment necessary.
- Confirmation runs to be undertaken over several months to identify actual savings.
- Further experimentation required to establish most efficient percentage COD reduction and COD removal level.

Figure 5(a) Taguchi Interpretation of Loss

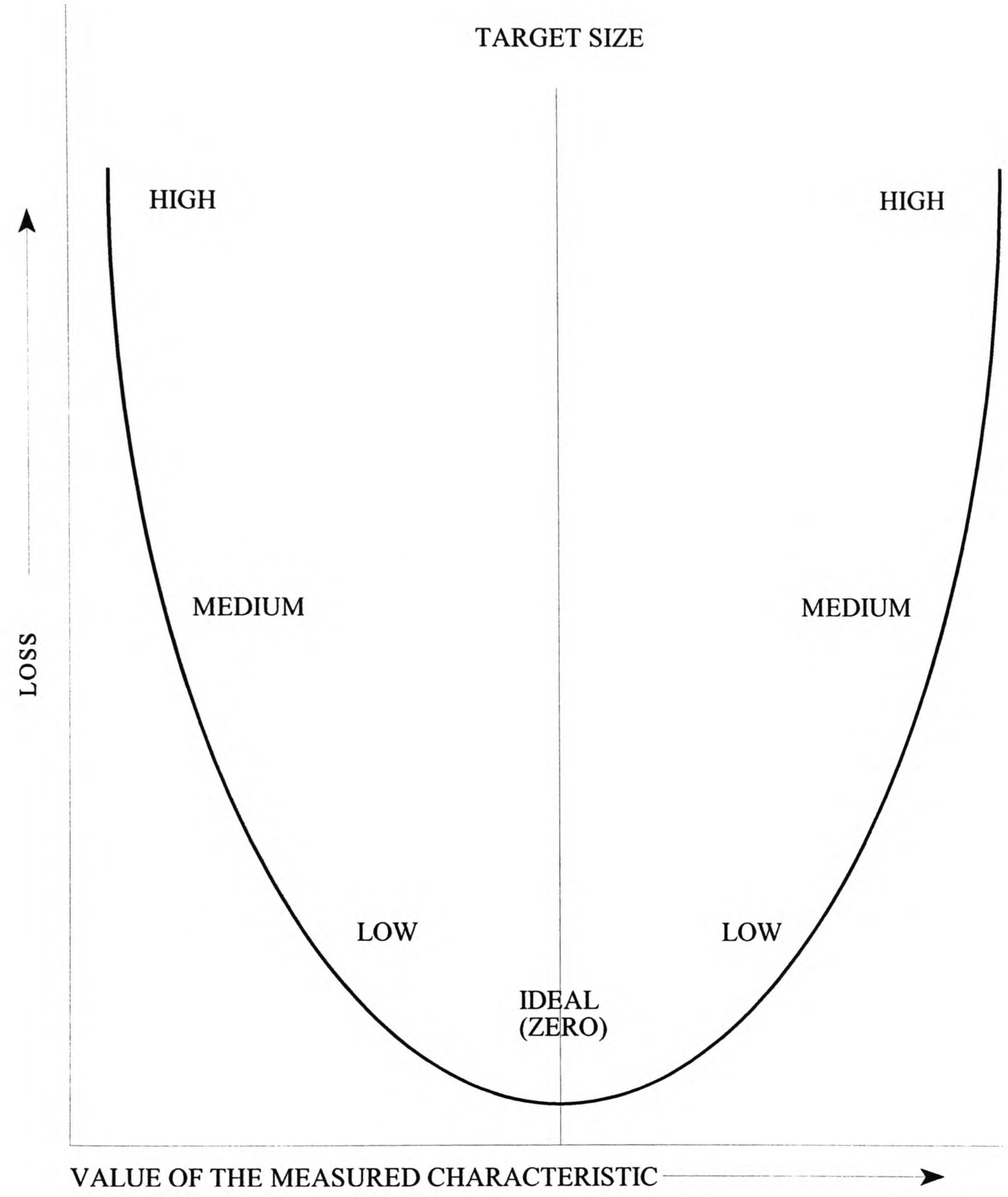


Figure 5(b) Orthogonal Array

Orthogonal Array L_8 (2^7)								
Number	**A 1**	**B 2**	**C 3**	**D 4**	**E 5**	**F 6**	**G 7**	**Results**
1	1	1	1	1	1	1	1	y_1
2	1	1	1	2	2	2	2	y_2
3	1	2	2	1	1	2	2	y_3
4	1	2	2	2	2	1	1	y_4
5	2	1	2	1	2	1	2	y_5
6	2	1	2	2	1	2	1	y_6
7	2	2	1	1	2	2	1	y_7
8	2	2	1	2	1	1	2	y_8

Figure 5(c) Orthogonal Array 7 Factors at 2 Levels & 8 Experiments

Exper't Number	**Factors & Settings**							**Results**
	A	**B**	**C**	**D**	**E**	**F**	**G**	
1	A_1	B_1	C_1	D_1	E_1	F_1	G_1	y_1
2	A_1	B_1	C_1	D_2	E_2	F_2	G_2	y_2
3	A_1	B_2	C_2	D_1	E_1	F_2	G_2	y_3
4	A_1	B_2	C_2	D_2	E_2	F_1	G_1	y_4
5	A_2	B_1	C_2	D_1	E_2	F_1	G_2	y_5
6	A_2	B_1	C_2	D_2	E_1	F_2	G_1	y_6
7	A_2	B_2	C_1	D_1	E_2	F_2	G_1	y_7
8	A_2	B_2	C_1	D_2	E_1	F_1	G_2	y_8

Figure 5(d) Untreated Effluent Correlation

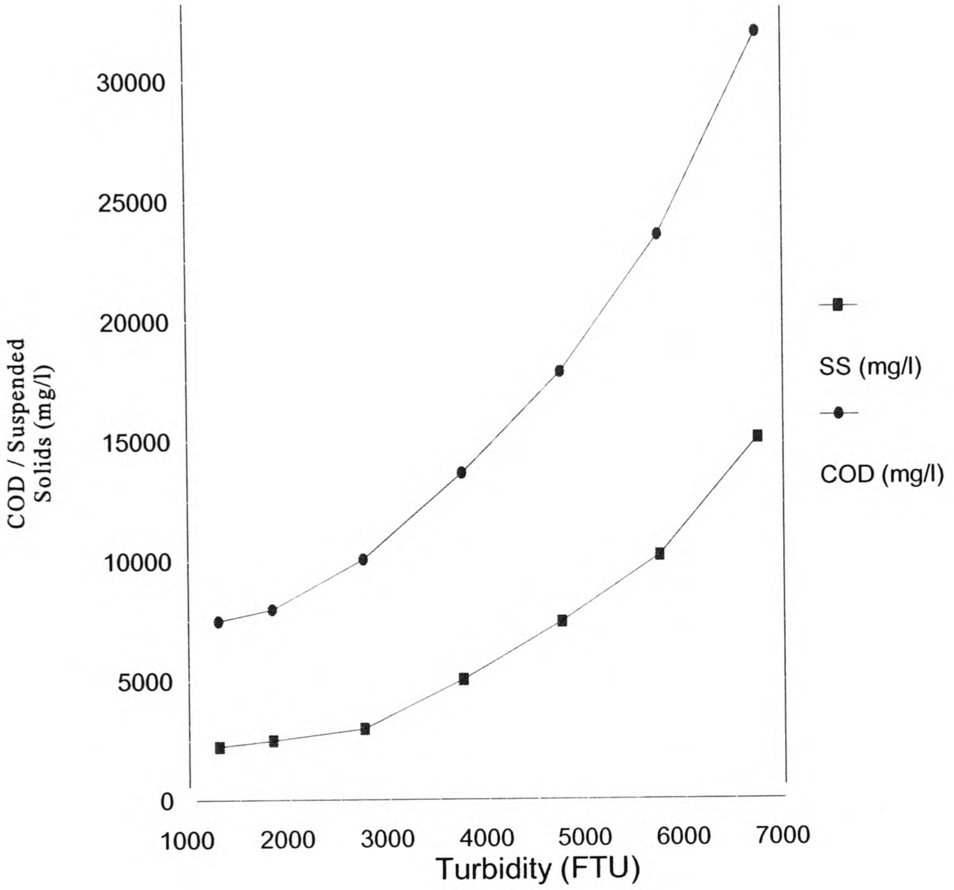


Figure 5(e) Treated Effluent Correlation

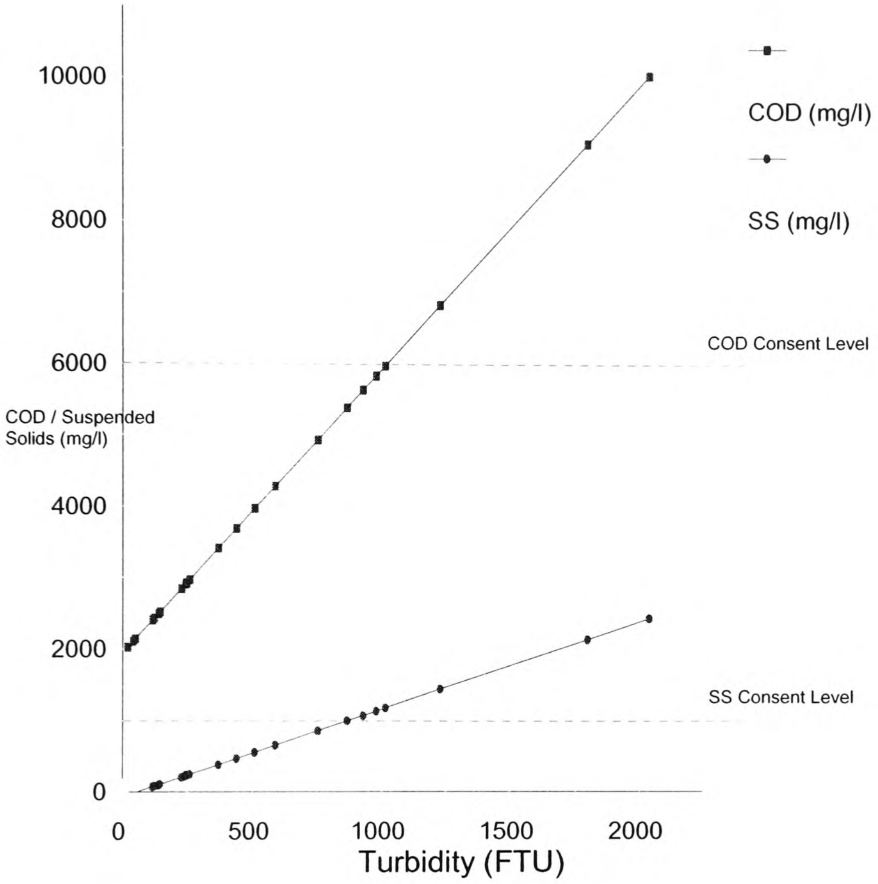


Figure 5(f) Graphical Profile of Treatment Efficiency 10/04/1997 - 25/04/1997

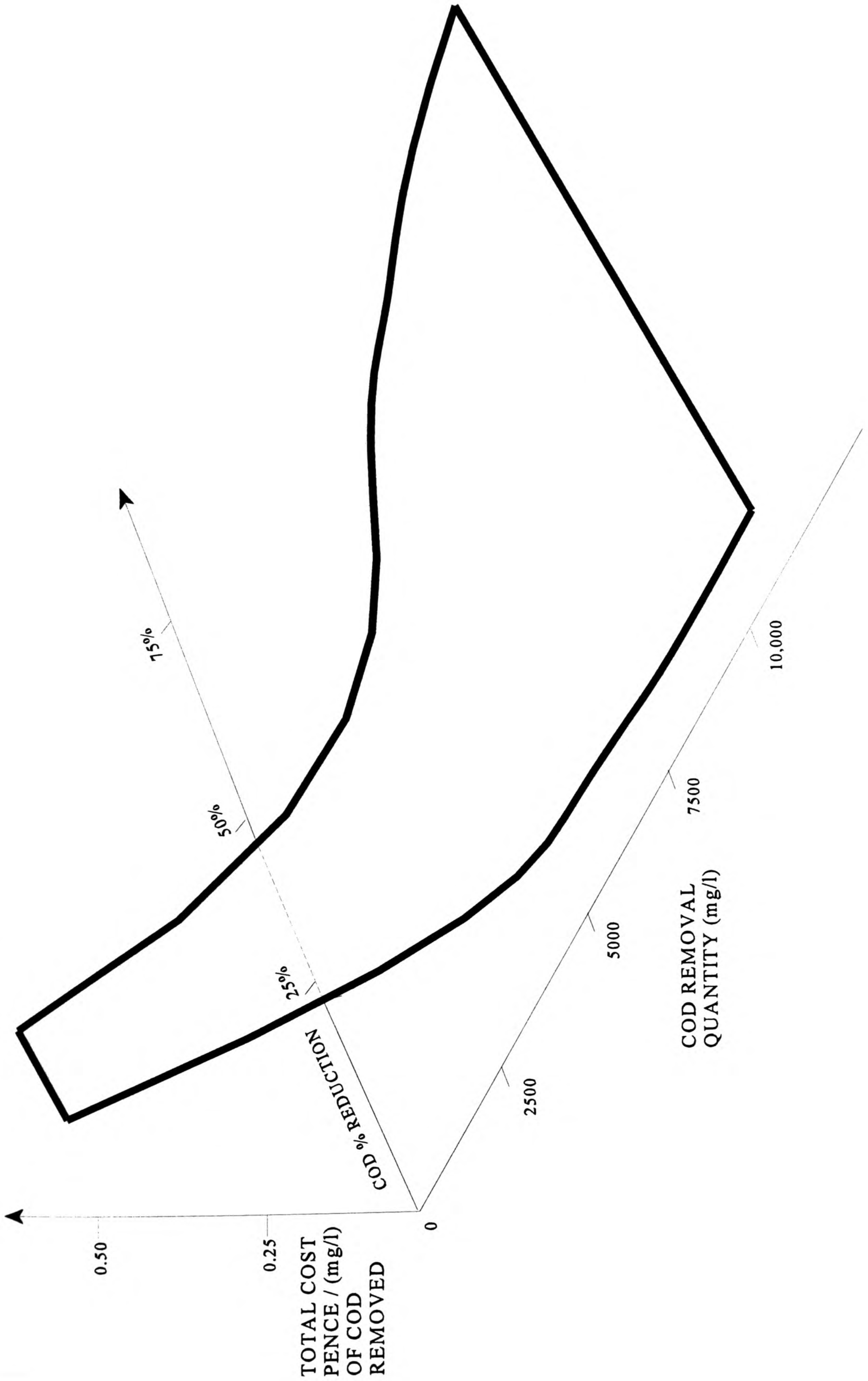


Table 5(I) Taguchi Analysis - Performance Analysis Spreadsheet

Performance Status	Normal Running
Alum pH Setting	4.34
Caustic pH Setting	6.74
Polymer Flowrate	0.0345m^3/hr
Volume Flowrate	6.84m^3/hr
pH (Untreated)	6.78
COD (Untreated)	9555mg/l
Suspended Solids (Untreated)	2720mg/l
Turbidity (Untreated)	2768FTU
pH (Treated)	6.45
COD (Treated)	2228mg/l
Suspended Solids (Treated)	256mg/l
Turbidity (Treated)	244FTU
COD Reduction	76.7%
Total Chemical Costs per m^3	£3.33
Total Discharge Costs per m^3	£1.04
Total Costs per m^3	£4.37

Table 5(ii) Taguchi Experimentation 07/05/1997

Exp No.	Time	Polymer Flow (ml/min)	Alum pH Setting	Caustic Soda pH Setting	Effluent Volume Flow Rate gph
1	0800	333	4.1	6.2	1200
2	0900	333	4.4	6.5	1500
3	1000	333	4.7	6.8	1800
4	1100	666	4.1	6.5	1800
5	1200	666	4.4	6.8	1200
6	1300	666	4.7	6.2	1500
7	1400	999	4.1	6.8	1500
8	1500	999	4.4	6.2	1800
9	1600	999	4.7	6.5	1200

Table 5(iii) Distortion Data Table

Exp No	Polymer Flow	Alum pH Setting	Caustic Setting	Effluent Volume Flow	COD % Reduction	Total Costs per m^3	COD% Reduction S/N ratio
1	333	4.1	6.2	1,200	27	544p	28.6
2	333	4.4	6.5	1,500	77	314p	37.7
3	333	4.7	6.8	1,800	70	379p	36.9
4	666	4.1	6.5	1,800	76	503p	37.6
5	666	4.4	6.8	1,200	45	591p	33.1
6	666	4.7	6.2	1,500	51	743p	34.2
7	920	4.1	6.8	1,500	39	679p	31.8
8	920	4.4	6.2	1,800	83	522p	38.4
9	920	4.7	6.5	1,200	23	815p	27.2
				ΣY	491	5090p	
				$D_1 = \Sigma Y \div 9$	54.6	566p	

Table 5(iv) Response Table Minimum COD (Max % Red)

Levels	A (Poly)	B (Alum)	C (Caustic)	D (Flow)
1	58	47	54	32
2	57	68	59	56
3	48	48	51	76

∴ Most environmentally friendly option =

$A_1 + B_2 + C_2 + D_3$

Poly (333) + Alum (4.4) + Caustic (6.5) + Flow (1800)

Table 5(v) Response Table Minimum Total Costs

Levels	A (Poly)	B (Alum)	C (Caustic)	D (Flow
1	412	575	603	650
2	612	476	544	579
3	672	646	550	468

∴ Most economic option =

$A_1 + B_2 + C_2 + D_3$

Poly (333) + Alum (4.4) + Caustic (6.5) + Flow (1800)

Table 5(vi) Taguchi Confirmation Run Predictions

Exp No	Taguchi Expression	Polymer Flow ml/min	Alum pH Setting	Caustic pH Setting	Effluent Volume Flow gph	COD % Reduction Prediction	Total Cost Prediction pence
1	$A_1+B_2+C_2+D_3$	333	4.4	6.5	1800	97.2	202
2	$A_1+B_2+C_2+D_2$	333	4.4	6.5	1500	77.2	313
3	$A_2+B_2+C_2+D_2$	666	4.4	6.5	1500	76.2	513
4	$A_2+B_2+C_2+D_3$	666	4.4	6.5	1800	96.2	402

Table 5(vii) Taguchi Confirmation Run Results 10/07/1997

Exp No	Polymer Flow	Alum pH Setting	Caustic Setting	Effluent Volume Flow	COD % Red	Discharge Costs per m^3	Chemical Costs per m^3	Total Costs per m^3
1	333	4.4	6.5	1,800	67	132p	164p	296p
2	333	4.4	6.5	1,500	67	125p	183p	308p
3	666	4.4	6.5	1,500	68	119p	309p	428p
4	666	4.4	6.5	1,800	70	118p	276p	394p

Table 5(viii) Taguchi Final Confirmation Run Results 29/07/1997

Exp No	Polymer Flow	Alum pH Setting	Caustic Setting	Effluent Volume Flow	COD % Red	Discharge Costs per m^3	Chemical Costs per m^3	Total Costs per m^3
1	333	4.4	6.5	1,800	63	184p	173p	357p
2	333	4.4	6.5	1,700	62	191p	181p	372p
3	333	4.4	6.5	1,600	59	181p	177p	358p
4	333	4.4	6.5	1,500	48	232p	187p	419p

Table 5(ix) Appraisal of Taguchi Implementation Costs and Savings

Activity Description	Estimated Costs	Total Costs
Taguchi Experimentation		
Experimentation time including all data collection, analysis and evaluation	20 days @ £500 per day	£10,000
Effluent analysis costs	50 samples total @ £30 per sample	£1500
Plant Confirmation Runs	2 days @ £500 per day	£1000
Training of operators	2 days @ £500 per day	£1000
Miscellaneous sundry items and equipment	£500	£500
Monitoring and Targeting Program and Control System		
Experimentation time, data evaluation, software programming, etc.	10 days @ £500 per day	£5000
Effluent analysis costs	50 samples total @ £30 per sample	£1500
Control panel, hardware, software cost, etc.		£5000
Turbidity Meters		£5000
Installation costs		£2500
Commissioning and Testing	1 day @ £500 per day	£500
Training of operators	1 day @ £500 per day	£500
Miscellaneous sundry items and equipment	£500	£500
Total Costs		£34500
Estimated total savings PA		£48750

6 Conclusions and Recommendations

6.1 Introduction

This chapter states the conclusions drawn from undertaking this research project and recommendations have been formulated and appraised including all associated implementation costs.

6.2 Conclusions

1. The plant exhibits design/operational limitations resulting in reduced flexibility / quality of treatment and is manually intensive in its operation requiring an operator in attendance throughout treatment, despite an upgrade in 1993 for automation. The plant is operated under the control and jurisdiction of the Engineering department with no / minimal coordination/liaison with production or industrial chemistry departments.

2. Upgrades are required to ensure that L'Oréal has the facility to accommodate increases in effluent concentration and hydraulic loadings in addition to reductions in consent levels. Such upgrades would reduce the operational / design limitations detailed in Chapter 2.

3. The plant currently achieves the following average reductions in parameter concentrations:

COD	81.5%
Suspended solids	93.9%
Oils, fats and greases	98%
Anionic detergents	92.3%

The total costs for the plant were £190150 for 1997 yielding a specific effluent cost of £3.51/m^3 and £1.51 / 1000 units of production. It is estimated that 87711m^3 will be produced for the 1998 150 million unit production forecast costing £272,166 for treatment.

4. The treatment profiles for 1992 - 1997 are very unstable demonstrating a general lack of process control and a reactive approach to treatment. General plant limitations dictate plant settings resulting in symptom treatment as opposed to the rectification of root cause problems.

5. A 77% / 78% COD reduction yielded the minimum discharge and chemical costs on several occasions, although it is concluded that such a performance indicator must be used in conjunction with COD removal levels. It was found that a 77% / 78% COD reduction and a 9075 mg/l COD removal was the most efficient treatment level.

6. Experimentation via Taguchi DOE methods for plant optimisation resulted in the following settings to achieve minimum total costs and high levels of treatment quality:

   Polymer 515 dose rate: 333 l/min

   Aluminium Sulphate pH setting: 4.4

   Caustic Soda pH setting: 6.5

   Effluent volume flow rate: 1800 gph/8.17 m^3/hour

7. For untreated effluent exponential relationships exist between turbidity and suspended solids/COD and conform to the following expressions:

   $$\text{Suspended solids} = 1279.7e^{(T \times 0.000364)}$$

   $$\text{COD} = 4960.6e^{(T \times 0.000273)}$$

   For treated effluent linear relationships exist between turbidity and suspended solids/COD and conform to the following expressions:

   $$\text{Suspended solids} = -180 + 1.26T$$

   $$\text{COD} = 2000 + 3.9T$$

8. The successful application of the Taguchi theory in this discipline demonstrates that it is flexible and adaptable to many differing engineering problems where optimisation is required. If influent concentration stability can be ensured the application will eliminate the requirement for costly and lengthy trial and error set up philosophies. In addition Taguchi can be employed in complex situations such as L'Oréal's providing a rapid solution for efficiency improvement.

9. Implementation of all the recommendations detailed in 6.3 would yield savings of £48.75k p.a. versus an implementation cost of £65k.

10. Recommendations for further work have been detailed in each chapter of this Thesis.

6.3 Recommendations

The Author has formulated the following recommendations based on the findings and conclusions of this research project.

1. 225m^3 buffer storage tank to be fitted with mechanical agitator complete with electrical interlocks to chemical contact chamber flow pump.

2. Automatic flow control valve to be fitted to chemical contact chamber effluent pipework entry complete with digital flow meter. Controller and meter to be fitted on chamber gantry enabling control to be undertaken while inspecting contact chamber treatment.

3. Polymer 515 mixing and storage tank and dosing system to be replaced. Chemical contact chamber polymer pipework to be rerouted into fourth section and associated agitator, facilitating greater retention time for aluminium sulphate and caustic soda chemicals.

4. Stainless steel pipework route from contact chamber to DAF unit to be replaced providing a maximum velocity of 0.5 m/s for the reduction of turbulence and floc shearing.

5. DAF unit beach gradient to be reduced, minimising backflow of flocs into DAF disturbing and shearing freshly formed flocs.

6. The following plant settings should be employed as a foundation for treatment. Minor fine tuning will be required for various effluent concentrations:

Polymer 515 dose rate	333 l/min
Aluminium Sulphate pH setting	4.4
Caustic Soda	6.5
Effluent volume flow rate	1800 gph/8.17 m^3/hour

7. Based on the correlations found for turbidity and suspended solids / COD a Monitoring and Targeting system should be implemented. Turbidity probes fitted at the chemical contact chamber inlet / outlet will record the values and feed this information to a control panel. This will convert the signal to suspended solids and COD via the following expressions programmed into the panel:

For untreated effluent:

$$\text{Suspended solids} = 1279.7e^{(T \times 0.000364)}$$

$$\text{COD} = 4960.6e^{(T \times 0.000273)}$$

For treated effluent:

$$\text{Suspended solids} = -180 + 1.26T$$

$$\text{COD} = 2000 + 3.9T$$

The data will be displayed on the panel including the % COD reduction and total COD removed. The most efficient area of operation is predicted as 77% - 78% and 9075 mg/l. An upper limit shall be provided to initiate a visual alarm should the treated COD level reach 4000 mg/l. An upper critical limit set at 5000 mg/l shall also be included activating audible alarms. Should the treated COD level fall to 2000 mg/l which is the minimum which can be recorded an 'over treatment' alarm shall be initiated.

A print out of the information will be generated at the end of each shift / operating day and logged by the operator. Such information can be used by the Engineering Manager on a monthly basis to assess the performance of the plant.

8. Greater communication channels should be established between the Engineering Department and Industrial Chemistry and Production department to develop a proactive approach to treatment. This will gradually result in a culture change whereby effluent is a factory wide issue and responsibility for treatment will be devolved as an engineering function. A working group should be initiated with representatives from each production centre and chemistry department.

9. Domestic sump pump to be upgraded to accommodate a combined effluent and domestic sewage hydraulic duty of 15 l/s @ a static head pressure of 16.5 m (162 kpa) [Flygt 1997].

10. In order to accommodate much greater effluent hydraulic loads, consent limit reductions and to overcome general plant limitations / age a completely new facility will be required within 3-5 years including new DAF unit, centrifuge etc. From this Thesis a design specification has been extracted and detailed in Table 6(I).

6.4 Appraisal of Recommendations

The Author has provided the approximate implementation costs and associated savings which are detailed in Table 6(ii)

From inspection of the table, the payback period is 16 months which is acceptable. Savings attributed to certain recommendations have not been detailed due to difficulty in their prediction, however further savings will achieved enhancing an already favourable payback.

The Author has estimated that if a chemical precipitation / DAF plant is the chosen method of treatment for a new facility the capital costs will be approximately £500K - £550K, although these would be reduced to £400K if the buffer storage tank, aeration tank and certain pipework runs were retained and employed for the new scheme.

Table 6(I) Specification for New Effluent Plant Design

Influent Details	
COD (mg/l)	9600
Temperature (degrees C)	20.7
Suspended Solids (mg/l)	2350
Oils, Fats and Greases (mg/l)	1900
Anionic Detergents (mg/l)	650
pH	7.3
Phenol content (mg/l)	1 - 8
Typical Constituents	Water, Stearic Acid, Rape Seed Oil, Sodium Lauryl Ethoxy Sulphate, Trio Sodium Citrate, Alkalis (Ammonia, Ethanolamine etc.), Resorcinol Hydroquinone, F,D and C Yellow 6, Ethanol, Ammonium Thioglycolliate, Synperonic PEL44, Titanium dioxide.
Treated Effluent Details	
COD (mg/l)	2000
Suspended Solids (mg/l)	350
Oils, Fats and Greases (mg/l)	35
Anionic Detergents (mg/l)	35
pH	6 -8
Hydraulic Details	
Effluent Volume flowrate (m^3/hour)	20
Surface Area available for plant (m^2)	145 (excluding buffer and aeration storage tanks)
Recommended pipework size (mm)	200

NB: The Treated Effluent Specification for Parameter Concentrations Are Approximately One Third of Current Consent Limits.

The plant must be capable of treating effluents to within the above consent conditions, having double the concentrations stated for 4 hours and 4 times the concentration for 2 hours.

Table 6(ii) Appraisal of Recommendations

Recommendation No.	Recommendation Description	Capital Costs	Cost Savings	Remarks
R1	Buffer storage tank agitation	£15K	----	----
R2	Automatic flow control valve	£2.5K	----	----
R3	Polymer mixing/ dosing system replacement	£3K	----	Savings in Polyelecrolyte will be achieved
R4	Pipework route to DAF unit replacement	£2.5K	----	Savings in discharge costs will be achieved
R5	DAF unit beach modification	£1K	----	Savings in discharge costs will be achieved
R6	Taguchi DOE derived plant settings	£14K	£42.55K	----
R7	M and T program and Turbidity/COD/ Suspended Solids Monitoring System	£20.5K	£6.2K	----
R8	Greater discussions and communication between production and industrial Chemistry Departments.	----	----	----
R9	Upgrade of domestic sump pump.	£6.5K	----	----
Total Costs		**£65K**	**£48.75K**	----

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Appendix 1 Condition Survey Appraisal

This Appendix details the results of a condition appraisal survey undertaken between 14th and 18th July 1997 on L'Oréal's effluent treatment plant. The results are presented in tabular form and the condition is expressed as a letter grade ranging from A-E. The key to the grading method is detailed below.

A = Excellent Condition, installed recently complies with all the latest legislation and British Standards.

B = Good Condition, very good working order, very reliable.

C = Average Condition, good working order, fairly reliable, replacement necessary in 2 - 5 years.

D = Poor Condition, replacement necessary in 1 - 2 years.

E = Very Poor Condition, corroded, imminent replacement necessary.

The scope of the survey only included major plant items.

Item No	Description	Manufacturer	Serial No.	Duty/ Rating	Age	Condition
1	Trade sump pumps	ABS, (West Germany), Flygt, (Nottingham)	-	2.2Kw	15 yrs	C
2	50,000 gallon tank discharge pumps	Flygt, (Nottingham)	3082 - 180-66325	2.2Kw	15 yrs	C
3	50,000 Gallon tank & level controls	-	-	-	15 yrs	B
4	Chemical Contact Chamber	Environmental Engineering Ltd, (Lincolnshire)	-	11.4m^3/hr, 3m^3 Total Volume	5 yrs	B
5	Polymer Storage/ Mixing tank	-	-	2.0m^3 Approx. Volume	15 yrs	D
6	Polymer Dosing Pump	-	-	950ml/min max. duty	20+ yrs	E
7	Caustic Soda Storage Tank (2 No.)	J A Welch (London)	-	2050 litre capacity x 2	5 yrs	B

Item No	Description	Manufacturer	Serial No.	Duty/ Rating	Age	Condition
8	Alum Transfer Tank	-	-	9 Tonne Capacity	5 yrs	C
9	Alum Storage Tank	Surmet (Surrey)	-	4050 litre Storage Tank	5 yrs	B
10	Alum Dosing Pump	Kopkit	930111930	240 gpd	5 yrs	B
11	Caustic Soda Dosing Pump	Kopkit	930910190	120 gpd	5 yrs	B
12	DAF Unit	Aquatec Ltd, (Lowton, Warrington)	-	12m^3/hr	15 yrs	C/D
13	DAF Unit Air Compressor	SIP Industrial Products (Leicestershire)	-	-	2 yrs	A
14	Centrifuge	Centriquip (Derbyshire)	3080	1m^3/hr	19 yrs	C
15	Domestic Sump Pumps	ABS (West Germany) Flygt (Nottingham)	-	2.2Kw	15 yrs	C
16	Main Control Panel	Field & Grant (Birmingham)	-	-	15 yrs	B
17	Aeration Tank Transfer Pumps	Crest Pumps Ltd	PF1891	5.5kW	15 yrs	C/D
18	Alum / Caustic Control Panel	Stranco Ltd	-	-	5 yrs	B/A

Appendix 2 Effluent Analysis Norms/ Standards and Legislative Substance Lists

This Appendix details the norms and standards employed by the University of Glamorgan and Messrs Hyder Environmental for the analysis of the effluent samples taken throughout the research.

For each parameter to be measured a brief test description is provided with the associated Messrs Hyder Environmental code No.

Schedule 5 Legislative substance list (Red List) from Section 4.8 of the PPS Regulations 1989 is also provided.

Hyder Ref No. SBE 7 - Chemical Oxygen Demand of Waters & Effluents

Organic and oxidisable inorganic substances are oxidised by potassium dichromat in strong acidic conditions at 160 +/-5^{0}c.

Silver sulphate is present to catalyse the oxidation of alcohols and low molecular weight acids. Mercuric sulphate is added to eliminate the interference of chloride.

Any unreduced potassium dichromat is titrated with standard ammonium ferrous sulphate.

Range of Application	up to 400 mg/l
Quoted Limit of Detection	20 mg/l.

Hyder Ref No. SBE 8 - The Biochemical Demand (BOD5)

The BOD is defined as the mass of dissolved oxygen required by a specified volume of liquid for the process of biochemical oxidation over 5 days at 20^{0}C in the dark.

The method consists of placing the sample in a full, air tight bottle and incubating the bottle under specified conditions (see above). The dissolved oxygen is measured initially and after incubation. The difference in these measurements is the oxygen used by the micro-organisms and from it the BOD can be calculated.

Allylthiourea is added to suppress nitrification during the course of the test. The result is then referred as BOD (ATU).

Quoted Limit of Detection	1 mg/l

Hyder Ref No. SBE - 9 Suspended Solids in Waters & Effluents

The suspended solids are defined as those solids which are retained by a glass-fibre filter. The weight of recovered matter is determined by drying at 105^{0}C and weighing.

The range of Application is dependent upon the volume of sample used

Quoted Limit of Detection	5 mg/l

Hyder Ref No. SBE 10 - The pH of Sewage and Trade Effluent Samples

The pH of a solution is determined by measuring the electromotive force (emf) of a cell containing the test solution and comparing it with the emf of a similar cell containing a standard buffer solution.

The measuring electrode is a glass electrode which has a pH sensitive membrane. This membrane has the property that a potential difference is developed between its two surfaces when it separates two solutions of different pH.

Results are quoted to two decimal places in pH units.

Hyder Ref No. SBC 33 Determination of Anionic Surface Activated Material as Aerosol OT by the Methylene Blue Extraction Method in Effluents and Waste Waters

Automated solvent extraction (water / chloroform), and colorimetric measurement of the anionic surfactant as its methylene blue complex.

The intensity of the colour formed is measured at a wavelength of 650nm using the SKALAR continuous flow system and is proportional to the original concentration of Aerosol OT.

Range of Application	0 - 20 mg/l as Manoxol OT (Aerosol Ot)
Quoted Limit of Detection	0.5 mg/l

Schedule 5 Release Into Water: Prescribed Substances (UK Red List)

(1) Substances	(2) Amount in excess of background quantity released in any 12 month period (Grammes).
Mercury and its compounds	200 (expressed as metal)
Cadmium and its compounds	1000 (expressed as metal)
All isomers of hexachlorocyclohexane	20
All isomers of DDT	5
Pentachlorophenol and its compounds	350
Hexachlorobenzene	5
Hexachlorobutadiene	20
Aldrin	2
Dieldrin	2
Endrin	1
Polychlorinated Biphenyls	1
Dichlorvos	0.2
1,2 - Dichloroethane	2000
All isomers of trichlorobenzene	75
Atrazine	350*
Simazine	350*
Tributyltin compounds	4
Triphenyltin compounds	4
Trifluralin	20
Fenitrothion	2
Azinphos-methyl	2
Malathion	2
Endosulfan	0.5

* Where both Atrazine and Simazine are released, the figure in aggregate is 350 grammes.

Appendix 3 Four Month Effluent Study Observations

This Appendix details the observations from the four month effluent study discussed in Chapter 3.

Observations of Raw Effluent Study

Date	pH Max	pH Min	pH Ave	Temp Max °C	Temp Min °C	Temp Ave °C	Fats/Oils/Greases (mg/l)	Suspd Solids (mg/l)	Anionic Det (mg/l)	COD (mg/l)
07/10/96	7.8	7.3	7.5	25	20	23	800	785	84	3205
08/10/96	7.9	7.8	7.9	27	21	22	600	505	95	3106
09/10/96	7.5	7.2	7.4	24	20	22	900	720	110	4550
10/10/96	7.8	7.3	7.4	26	21	23	1066	1187	432.1	6306
11/10/96	7.7	7.5	7.6	26	22	24	1520	1577	643.5	8685
14/10/96	7.7	7.2	7.4	26	20	23	3607	3593	390.8	16142
15/10/96	7.8	7.5	7.7	25	21	23	2555	6070	446	11422
16/10/96	7.8	7.1	7.6	25	20	22	2367	2390	423.7	11045
17/10/96	8	7.6	7.9	24	20	22	1124	953	316	5532
18/10/96	---	---	---	---	---	---	---	---	---	---
21/10/96	---	---	---	---	---	---	---	---	---	---
22/10/96	---	---	---	---	---	---	---	---	---	---
23/10/96	7.9	7.2	7.4	26	21	24	972	1243	620.3	6627
24/10/96	7.9	7.3	7.4	25	22	24	600	657	466	6746
25/10/96	7.7	7.3	7.5	25	20	23	653	733	459.4	5952
28/10/96	7.7	7.2	7.7	27	20	24	880	677	330.3	4438
29/10/96	7.8	7.6	7.7	20.5	18.6	19.6	767	710	336	5232
30/10/96	7.7	7.3	7.5	25	22.3	23.5	---	---	---	---
31/10/96	7	6.6	6.8	24.2	20.5	22.1	1004	1033	366	7142
01/11/96	7.2	6.7	6.9	22	20.1	20.4	1357	1150	376	7969
04/11/96	---	---	---	---	---	---	---	---	---	---
05/11/96	7.8	7.5	7.6	21.5	19	20.5	468	820	322.7	2056
06/11/96	7.9	7.6	7.7	20.5	18	19.5	560	693	220.3	1786

07/11/96	8.1	7.9	8	21.7	21.4	21.5	903	1127	372.7	3108
08/11/96	8.1	7.5	7.8	23	21	22	1097	1300	510.8	3042
11/11/96	7.7	6.9	7.4	18	12.5	15.5	845	1556	349.9	5833
12/11/96	---	---	---	---	---	---	760	1100	382.2	5952
13/11/96	7.6	7.2	7.4	23	20	22	1120	1585	503.2	8202
14/11/96	7.7	7.2	7.4	24	21	23	936	1193	469.4	7805
15/11/96	7	7	7.2	26	23	25	1765	1186	568	9920
18/11/96	7.5	7.1	7.3	19	15	17	1104	1300	396	8849
19/11/96	---	---	7.5	---	---	---	2297	1820	358	8214
20/11/96	7.8	7.2	7.5	22	21	21	---	---	---	---
21/11/96	8.1	---	---	---	---	21	1212	1820	417	7420
22/11/96	---	---	---	---	---	---	1320	1373	408	7420
25/11/96	7.4	7.1	7.4	17	15	16	---	---	---	---
26/11/96	7.6	7.2	7.4	19	18	18.5	1673	2140	487	9955
27/11/96	---	---	---	---	---	---	---	---	---	---
28/11/96	---	---	---	---	---	---	---	---	---	---
02/12/96	---	---	---	---	---	---	---	---	---	---
03/12/96	7.2	6.7	6.8	18	15	16	2995	2976	201	11244
04/12/96	7.5	7.2	7.3	21	20	20	3947	4160	473	14835
05/12/96	7.2	6.8	6.9	---	---	---	2840	2640	190	10346
06/12/96	7.2	6.8	7	20.5	19	20	4513	4160	246	14640
09/12/96	7.8	7.4	7.5	22	19	20	4170	3251	304	12166
10/12/96	7.4	7.2	7.3	21	19	20	4300	3512	105	14107
11/12/96	7.4	7	7.1	20	19	20	3470	2920	402	11721
12/12/96	7.3	7.1	7.2	21	20	20	2510	1900	309	5310

13/12/96	7.4	7.1	7.3	20	18	19	2221	1878	259	7437
06/01/97	7.9	7.7	7.7	7	7	7	1632	1546	246	10273
07/01/97	8.3	---	7.8	17	17	17	2050	1574	332	9629
08/01/97	8.6	8.3	8.3	18	18	18	1493	1100	248	8985
09/01/97	8.8	8.5		19	18	17	1907	937	208	8126
10/01/97	8.6	8.4	8.4	16	14	15	2280	1143	324	9247
13/01/97	7.1	6.9	7	17	16	16	2280	3374	609	13014
14/01/97	8.3	7.3	7.1	22	20	21	832	1894	3132	9198
15/01/97	7.1	6.8	6.9	22	21	22	3260	4680	1184	18284
16/01/97	7	6.9	7	22	22	22	2470	5600	1218	20822
17/01/97	---	---	7.1	22	20	20	15260	4680	1257	18544
20/01/97	---	---	---	---	---	---	7653	6348	374	19286
21/01/97	7.2	6.6	7.1	22	19	21	5670	5172	274	14289
22/01/97	7.3	6.7	6.8	21	21	21	6024	4108	314	14601
23/01/97	6.9	6.8	6.8	24	22	23	6007	3852	200	13039
24/01/97	---	---	6.8	24	20	22	7893	4532	250	14289
27/01/97	7.6	6.8	7.4	22	20	21	1230	2366	146	8589
28/01/97	7.8	7.7	7.7	25	23	24	897	1644	131	8979
29/01/97	8.1	7.1	7.8	25	22	23	---	---	---	---
30/01/97	8.6	7.6	7.8	25	24	23	2840	3572	266	15616
31/01/97	8.5	7.6	7.9	25	24	25	7747	5108	207	17178

Appendix 4 Costing Information

This Appendix details costing information employed to formulate the total plant costs in Chapter 4 including all discharge costs.

COSTING INFORMATION

Water Intake Cost; = 77.15p/m^3

Hyder Sampling Cost for; COD, Suspended Solids, oils, fats and greases, anionic detergents & pH = £30 / sample

Effluent Operator Costs; = Obtained from liaison with Personnel Department

CHEMICAL COSTS

Aluminium Sulphate = 23p/Kg

Caustic Soda = 21p/Kg

Polymer SIS = £4.00/Kg

Polymer 78 = Only gross costs found and detailed in Chapter 4.0

Antifoam = Only gross costs found and detailed in Chapter 4.0

DISCHARGE COSTS

R = 11p/m^3

V = 7.23p/m^3

Vb = 2.89p/m^3

B = 16.68p/m^3

S = 11.78p/m^3

Appendix 5 Taguchi Observations

This Appendix Details the Observations from the Taguchi experimentation.

Taguchi Experimentation Observations 1

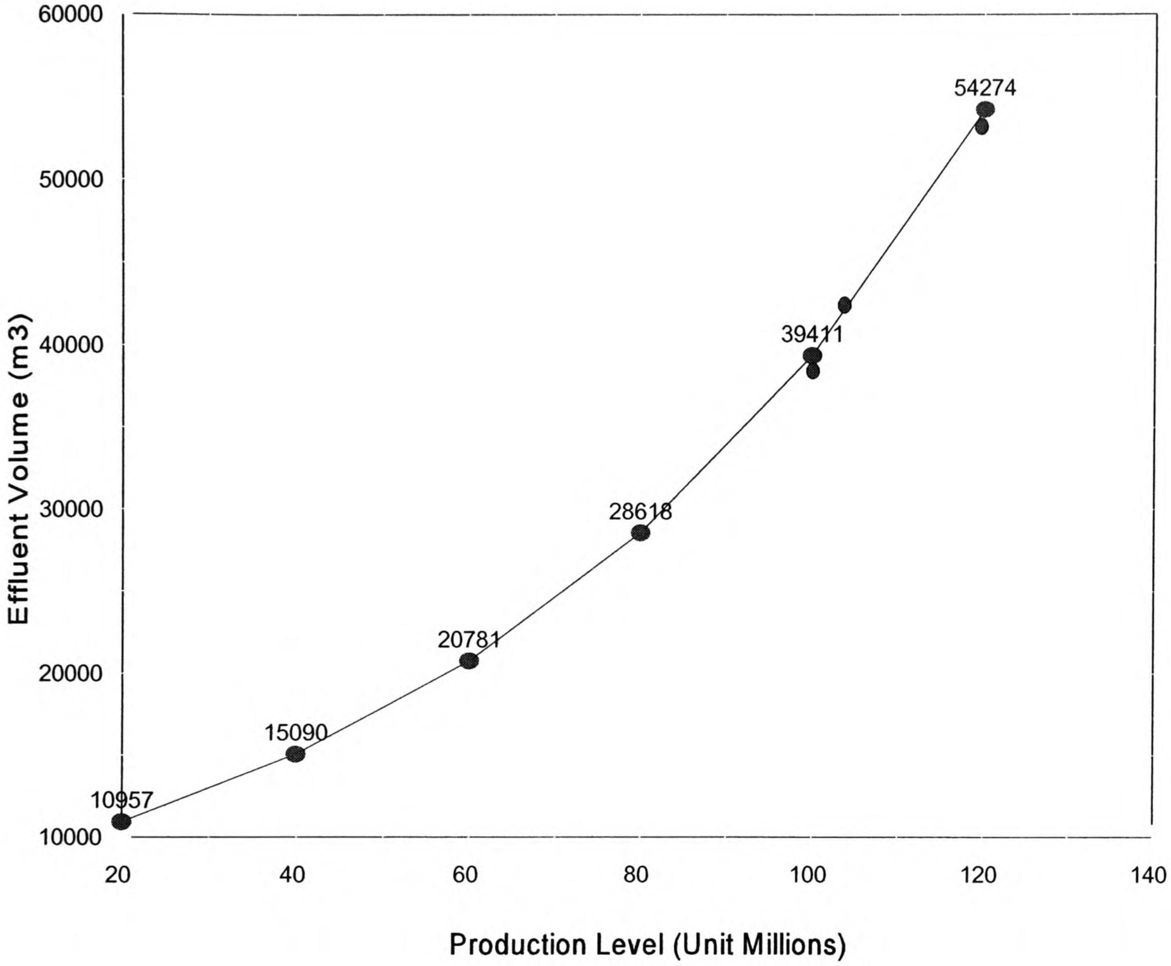
Exp No	Polymer Flow	Alum pH Setting	Caustic Setting	Effluent Volume Flow	COD % Red	Discharge Costs per m^3	Chemical Costs per m^3	Total Costs per m^3
1	333	4.1	6.2	1,200	87	82p	315p	397p
2	333	4.4	6.5	1,500	77	94p	220p	314p
3	333	4.7	6.8	1,800	70	224p	155p	379p
4	666	4.1	6.5	1,800	76	146p	357p	503p
5	666	4.4	6.8	1,200	86	147p	410p	557p
6	666	4.7	6.2	1,500	51	443p	300p	743p
7	920	4.1	6.8	1,500	29	118p	510p	628p
8	920	4.4	6.2	1,800	83	144p	378p	522p
9	920	4.7	6.5	1,200	86	188p	425p	613p

Taguchi Experimentation Observations 2

Exp No	Polymer Flow	Alum pH Setting	Caustic Setting	Effluent Volume Flow	COD % Red	Discharge Costs per m^3	Chemical Costs per m^3	Total Costs per m^3
1	333	4.1	6.2	1,200	27	261p	283p	544p
2	333	4.4	6.5	1,500	77	94p	220p	314p
3	333	4.7	6.8	1,800	70	224p	155p	379p
4	666	4.1	6.5	1,800	76	146p	357p	503p
5	666	4.4	6.8	1,200	45	202p	389p	591p
6	666	4.7	6.2	1,500	51	443p	300p	743p
7	920	4.1	6.8	1,500	39	217p	462p	679p
8	920	4.4	6.2	1,800	83	144p	378p	522p
9	920	4.7	6.5	1,200	23	339p	476p	815p

Appendix 6 Production Level vs Effluent Volume and Effluent Volume vs Plant Cost Profiles

Graph of Production Level vs Effluent Volume



Graph of Effluent Volume vs Plant Costs