

# APPLYING CLEANER PRODUCTION AND OPTIMISING HEAT PROCESS OPERATIONS IN DAIRY PROCESSING PLANTS – A REVIEW

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## Abstract

It is often claimed that Cleaner Production techniques do not yet exist or that, if they do, they are already patented and can be obtained only through expensive licenses. Neither statement is true. Applying cleaner production and optimising heat process operations in dairy processing plants is a critical and topical issue in today's global food industry hence the appropriateness of this review article. This review paper discusses issues of cleaner production for the dairy industry, the methodologies and approaches in optimising heat processes. The paper also identifies the cleaner production opportunities for production processes, cites a case study of pasteurization and gives appropriate recommendations for dairy plants.

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**Keywords:** Cleaner production assessment; optimisation; methodologies; process models

## Introduction

It is often claimed that Cleaner Production techniques do not yet exist or that, if they do, they are already patented and can be obtained only through expensive licences. Neither statement is true, and this belief wrongly associates Cleaner Production with 'clean technology'. Firstly, Cleaner Production depends only partly on new or alternative technologies. It can also be achieved through improved management techniques, different work practices and many other 'soft' approaches. Cleaner Production is as much about attitudes, approaches and management as it is about technology. Secondly, Cleaner Production approaches are widely and readily available, and methodologies exist for its application. While it is true that Cleaner Production technologies do not yet exist for all industrial processes and products, it is estimated that 70% of all current wastes and emissions from industrial processes can be prevented at source by the use of technically sound and economically profitable procedures (Baas et al., 1992).

Dairy processing occurs world-wide; however the structure of the industry varies from country to country. In less developed countries, milk is generally sold directly to the public, but in major milk producing countries most milk is sold on a wholesale basis. In Ireland and Australia, for example, many of the large-scale processors are owned by the farmers as co-operatives, while in the United States individual contracts are agreed between farmers and processors. Dairy processing industries in the major dairy producing countries have undergone rationalisation, with a trend towards fewer but larger plants operated by fewer people. As a result, in the United States, Europe, Australia and New Zealand most dairy processing plants are quite large. Plants producing market milk and products with short shelf life, such as yogurts, creams and soft cheeses, tend to be located on the fringe of urban centres close to consumer markets. Plants manufacturing items with longer shelf life, such as butter, milk powders, cheese and whey powders, tend to be located in rural areas closer to the

milk supply. The general tendency world-wide, is towards large processing plants specialising in a limited range of products. There are exceptions, however. In Eastern Europe for example, due to the former supply-driven concept of the market, it is still very common for 'city' processing plants to be large multi-product plants producing a wide range of products. The general trend towards large processing plants has provided companies with the opportunity to acquire bigger, more automated and more efficient equipment. This technological development has, however, tended to increase environmental loadings in some areas due to the requirement for long-distance distribution. Basic dairy processes have changed little in the past decade. Specialised processes such as ultra filtration (UF), and modern drying processes, have increased the opportunity for the recovery of milk solids that were formerly discharged. In addition, all processes have become much more energy efficient and the use of electronic control systems has allowed improved processing effectiveness and cost savings.

Since the production of safe products is becoming increasingly important, predictive models for product contamination greatly benefit the food industry, especially if it is possible to optimize the process operation in relation to the desired product quality and safety. In general, three types of predictive models are necessary for optimization and improvement of food heat treatments:

- **Model Type I** : Process models that describe the production chain in terms of model reactors. In general, process models are based on energy and mass balances of the liquid phase and not on the food components or contaminants. For example, a plate heat exchanger can be described by at least four plug flow reactors in series: upstream regenerative section, heater, holding tube and downstream regenerative section. All the plug flow reactors must have the same volume and specific surface area as the equipment itself (De Jong, 1996). The main output of such models is a temperature–time history of the food product. In cases where water is removed (e.g. evaporating, drying), the local water content is important, since an additional concentration change of food components and contaminants is introduced.
- **Model Type II**: Kinetic models that predict the transformation of food components and contaminants related to the food properties recognized by the consumer. These models include, for example, the denaturation and aggregation of proteins, the inactivation of enzymes, bacteria and spore inactivation, contamination and the formation of reaction products (pigments, (off-)flavours). In some cases, the models are quite complex. For example, to predict the contamination of bacteria in the production chain, a predictive model for the concentration of microorganisms as a result of growth, adherence, release and inactivation is needed.
- **Model Type III**: Predictive kinetic models for estimation of the operating costs related to process operation. In many processes, the operating costs are governed by microbial and physical fouling. In cases where it is possible to predict the amount of protein and mineral deposits and the number of adhered and growing bacteria, it is relatively simple to estimate the operating costs.

In order to simulate a heat treatment in the food production chain with respect to food properties and operating costs, the model types II and III are integrated with the process model (type I). All three types of kinetic models have been developed and validated for industrial application. In this section, a general procedure for optimization of the heat treatment in the food production chain is described. The operating costs of many food production chains primarily depend on microbial and physical fouling of the equipment. In general, process operating times at relatively low temperatures (<70°C) are due to adherence and growth of bacteria. The operating time of equipment at temperatures above 80°C is determined largely by the deposition of protein and minerals. The amount of fouling can be

related to the costs due to cleaning, changeover (rinsing losses), depreciation, energy, operator, pollution and product losses (De Jong, 1996).

### **Description**

Impact of Dairy Processing- The need for cleaner production

For many other food processing operations, the main environmental impacts associated with all dairy processing activities are the high consumption of water, the discharge of effluent with high organic loads and the consumption of energy. Noise, odour and solid wastes may also be concerns for some plants. Dairy processing characteristically requires very large quantities of fresh water. Water is used primarily for cleaning process equipment and work areas to maintain hygiene standards. The dominant environmental problem caused by dairy processing is the discharge of large quantities of liquid effluent. Dairy processing effluents generally exhibit the following properties:

- high organic load due to the presence of milk components;
- fluctuations in pH due to the presence of caustic and acidic cleaning agents and other chemicals;
- high levels of nitrogen and phosphorus;
- fluctuations in temperature.

If whey from the cheese-making process is not used as a by-product and discharged along with other wastewaters, the organic load of the resulting effluent is further increased, exacerbating the environmental problems that can result. In order to understand the environmental impact of dairy processing effluent, it is useful to briefly consider the nature of milk. Milk is a complex biological fluid that consists of water, milk fat, a number of proteins (both in suspension and in solution), milk sugar (lactose) and mineral salts. Dairy products contain all or some of the milk constituents and, depending on the nature and type of product and the method of manufacturing, may also contain sugar, salts (e.g. sodium chloride), flavours, emulsifiers and stabilisers. For plants located near urban areas, effluent is often discharged to municipal sewage treatment systems. For some municipalities, the effluent from local dairy processing plants can represent a significant load on sewage treatment plants. In extreme cases, the organic load of waste milk solids entering a sewage system may well exceed that of the township's domestic waste, overloading the system. In rural areas, dairy processing effluent may also be irrigated to land. If not managed correctly, dissolved salts contained in the effluent can adversely affect soil structure and cause salinity. Contaminants in the effluent can also leach into underlying groundwater and affect its quality. In some locations, effluent may be discharged directly into water bodies. However this is generally discouraged as it can have a very negative impact on water quality due to the high levels of organic matter and resultant depletion of oxygen levels. Electricity is used for the operation of machinery, refrigeration, ventilation, lighting and the production of compressed air. Like water consumption, the use of energy for cooling and refrigeration is important for ensuring good keeping quality of dairy products and storage temperatures are often specified by regulation. Thermal energy, in the form of steam, is used for heating and cleaning. As well as depleting fossil fuel resources, the consumption of energy causes air pollution and greenhouse gas emissions, which have been linked to global warming. Dairy products such as milk, cream and yogurt are typically packed in plastic-lined paperboard cartons, plastic bottles and cups, plastic bags or reusable glass bottles. Other products, such as butter and cheese, are wrapped in foil, plastic film or small plastic containers. Milk powders are commonly packaged in multi-layer kraft paper sacs or tinned steel cans, and some other products, such as condensed milks, are commonly packed in cans. Breakages and packaging mistakes cannot be totally avoided. Improperly packaged dairy product can often be returned for reprocessing; however the packaging material is generally discarded. Emissions to air

from dairy processing plants are caused by the high levels of energy consumption necessary for production. Steam, which is used for heat treatment processes (pasteurisation, sterilisation, drying etc.) is generally produced in on-site boilers, and electricity used for cooling and equipment operation is purchased from the grid. Air pollutants, including oxides of nitrogen and sulphur and suspended particulate matter, are formed from the combustion of fossil fuels, which are used to produce both these energy sources. In addition, discharges of milk powder from the exhausts of spray drying equipment can be deposited on surrounding surfaces. When wet these deposits become acidic and can, in extreme cases, cause corrosion. For operations that use refrigeration systems based on chlorofluorocarbons (CFCs), the fugitive loss of these gases to the atmosphere is an important environmental consideration, since CFCs are recognised to be a cause of ozone depletion in the atmosphere. For such operations, the replacement of CFC-based systems with non- or reduced-CFC systems is thus an important issue. Some processes, such as the production of dried casein, require the use of hammer mills to grind the product. The constant noise generated by this equipment has been known to be a nuisance in surrounding residential areas. The use of steam injection for heat treatment of milk and for the creation of reduced pressure in evaporation processes also causes high noise levels. A substantial traffic load in the immediate vicinity of a dairy plant is generally unavoidable due to the regular delivery of milk (which may be on a 24-hour basis), deliveries of packaging and the regular shipment of products. Noise problems should be taken into consideration when determining plant location. Hazardous wastes consist of oily sludge from gearboxes of moving machines, laboratory waste, cooling agents, oily paper filters, batteries, paint cans etc. At present, in Western Europe some of these materials are collected by waste companies. While some waste is incinerated, much is simply dumped.

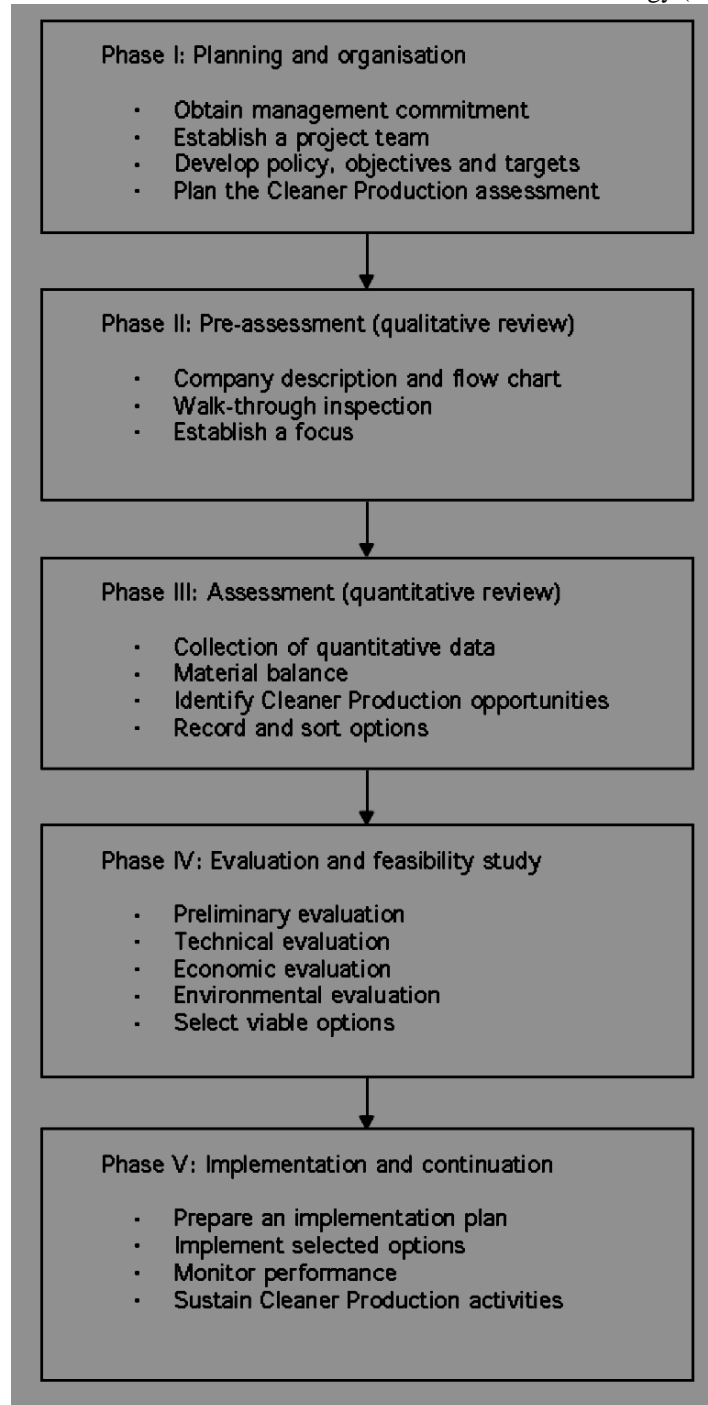
### Cleaner Production Assessment

A Cleaner Production assessment is a methodology for identifying areas of inefficient use of resources and poor management of wastes, by focusing on the environmental aspects and thus the impacts of industrial processes. Many organisations have produced manuals describing Cleaner Production assessment methodologies at varying levels of detail. However, the underlying strategies are much the same. The basic concept centres around a review of a company and its production processes in order to identify areas where resource consumption, hazardous materials and waste generation can be reduced. Table 1.0. lists some of the steps described in the more well-known methodologies.

Table 1.0. Methodologies for undertaking a Cleaner Production Assessment

Organisation	Document	Methodology
UNEP, 1996	<i>Guidance Materials for the UNIDO/UNEP National Cleaner Production Centre</i>	Planning and organisation Pre-assessment Assessment Evaluation and feasibility study Implementation and continuation
UNEP, 1991	<i>Audit and Reduction Manual for Industrial Emissions and Wastes. Technical Report Series No. 7</i>	Pre-assessment Material balance Synthesis
Dutch Ministry of Economic Affairs, 1991	<i>PREPARE Manual for the Prevention of Waste and Emissions</i>	Planning and organisation Assessment Feasibility Implementation
USEPA, 1992	<i>Facility Pollution Prevention Guide</i>	Development of pollution prevention programme Preliminary assessment

Figure 1.0: Overview of the Cleaner Production assessment methodology (UNEP, 1996)



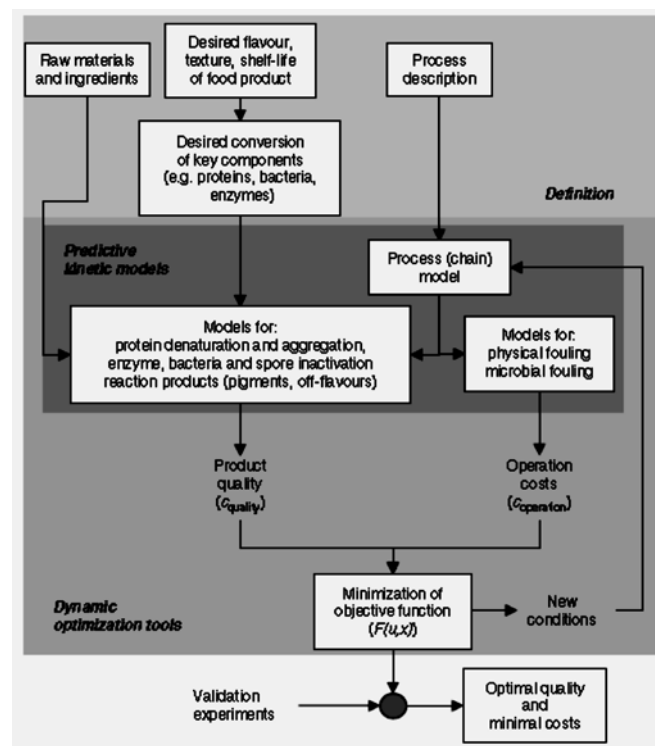
**Approach in optimising heating processes**

For the application of models in the food industry, an approach is needed that integrates the three types of models (process, product and costs model). Another need is kinetic data. The increasing availability of predictive kinetic models and necessary kinetic data has stimulated a reaction engineering approach to obtain optimal product quality (0). The functional properties of the product and the operating costs of the equipment are largely determined by conversion of so-called key components in the raw materials processed. The main control factors for product and process optimization are the temperature–time relationship and the configuration of the processing equipment. In order to determine the optimal values of the control variables, a general objective function is used:

### $F(u,x) = \alpha c(u,x) + \beta c(u)$ quality operation (1.8)

where  $u$  is a vector of process control variables (e.g. temperature, flow), and  $x$  is a vector of desired product properties related to food quality and safety. The value of  $c$  quality depends on the outcomes of the predictive models for contamination and transformation of food components cooperation is related to the operating costs. The optimal configuration and operation of a production chain are achieved by minimization of the objective function. To avoid trivial and undesired solutions, the weight factors  $\alpha$  and  $\beta$  are introduced. These weight factors give the relative importance of each term of the objective function. For example, too high a value of  $\beta$  may result in a very clean and cheap production process but an inferior product quality. Figure 2.0. shows a general approach for process and product development by use of predictive kinetic models. In order to optimize a production chain, first the available raw materials and ingredients, the desired product properties and a general process description should be known. Based on the desired product properties, the desired conversion of key components is determined. Embedding the predictive models for product properties (II) and for physical and microbial fouling (III) into the process

Figure 2.0. Schematic representation of process and product development of heated milk products using predictive kinetic models. Source: Britz.J.T and Robinson.R.K. 2008



Model (I), the values of  $c$  quality and cooperation can be calculated. Next, the evaluation of objective function results in improved conditions (i.e. control factors) for the production chain and the evaluation of the predictive models is repeated. This process goes on until the minimum of the objective function is obtained, i.e. the optimal conditions are found. Before the optimization results are applied, some validation experiments can be performed. Some examples of recent industrial applications that accelerated the process and product development are:

- improvement of the performance (extended operating time) of a cheese milk pasteurizer; examination of two evaporator designs with respect to bacterial growth;
- determination of critical points in the downstream processing of whey;
- extended operating time (200%) of a production chain for baby food.

For the Dutch dairy industry, it has been calculated that in terms of energy, the reduction of fouling and contamination by predictive models has already a savings potential of 90 million m<sup>3</sup> of gas (De Jong and Van der Horst, 1997).

### **General Analysis**

Identifying Cleaner Production Opportunities for production Processes

An analysis of the production processes in Milk and Dairy processing reveals the following:

### **Receipt and storage of milk**

Cleaner Production opportunities in this area focus on reducing the amount of milk that is lost to the effluent stream and reducing the amount of water used for cleaning. Ways of achieving this include:

- avoiding milk spillage when disconnecting pipes and hoses;
- ensuring that vessels and hoses are drained before disconnection;
- providing appropriate facilities to collect spills;
- identifying and marking all pipeline to avoid wrong connections that would result in unwanted mixing of products;
- installing pipes with a slight gradient to make them self-draining;
- equipping tanks with level controls to prevent overflow;
- making certain that solid discharges from the centrifugal separator are collected for proper disposal and not discharged to the sewer;
- using 'clean-in-place' (CIP) systems for internal cleaning of tankers and milk storage vessels, thus improving the effectiveness of cleaning and sterilisation and reducing detergent consumption;
- improving cleaning regimes and training staff;
- installing trigger nozzles on hoses for cleaning;
- reusing final rinse waters for the initial rinses in CIP operations;
- collecting wastewaters from initial rinses and returning them to the dairy farm for watering cattle.

### **Separation and standardisation**

Cleaner Production opportunities specific to this area are related to reducing the generation of separator sludge and optimising its collection and disposal. Ways of achieving this include:

- reducing the frequency with which centrifugal separators are cleaned, by improving milk filtration at the receiving stage or by clarification of the raw milk;
- collecting the sludge and disposing of it along with other waste solids.

Also of importance is the optimisation of cleaning processes, to make them water and energy efficient.

### **Pasteurisation and homogenisation**

Cleaner Production opportunities in this area focus on improving energy efficiency. Ways of achieving this include:

- replacing batch pasteurisers with continuous process incorporating plate heat exchanger (PHE) pasteurisers, where feasible. PHE pasteurisers are more energy efficient than batch pasteurisers because the heat from the pasteurised milk can be used to preheat the incoming cold milk (regenerative counter current flow);

- installing new manufacturing equipment, which will result in less waste of milk products than the equipment currently used in many dairies;
- avoiding stops in continuous processes. The more constant the production, the less milk will be lost, since most waste comes from cleaning of batch process equipment. In the event of upgrades to process equipment, high-volume pasteurising units should be considered;
- reducing the frequency of cleaning of the pasteuriser. Particularly for small dairies, optimising the size of balance tanks before and after the pasteuriser will allow continuous operation of the pasteuriser and reduce cleaning frequency;
- planning production schedules so that product change-overs coincide with cleaning regimes;
- collecting and recovering the milky wastewater generated at start-up of pasteurisation and supplying it to farmers as animal feed.

Also of importance is optimisation of cleaning processes, to make them water and energy efficient. To make possible the reprocessing of excess milk returned from the market, dairy plants may wish to consider developing policies which allow for the reprocessing of milk without affecting the quality of the freshly pasteurised product. The introduction of poorer quality milk into the pasteurisation process can result in milk scale and coagulation problems due to higher acidity.

This may cause higher milk losses in the pasteuriser due to the need for more frequent cleaning in order to remove milk scale. These issues should be weighed against the benefits of reprocessing returned milk. The controlled return and reprocessing of milk from the market may require training of sales representatives. Alternatively, penalties could be applied for inappropriate ordering, or bonuses paid for extended periods of no market returns

### **Deodorisation**

Water used for the vacuum pump can be recirculated to reduce or eliminate the necessity to discharge it.

### **Storage and packaging**

Cleaner Production opportunities in this area focus on improving the energy efficiency of refrigeration systems and optimising CIP processes to reduce both water use and the organic load discharged into the effluent stream. Ways of achieving this include:

- clearing milk residues from the pipes using compressed air before the first rinse;
- collecting the more highly concentrated milk wastewater at start-up and shut-down for use as animal feed;
- optimising the accuracy of filling operations. This will not only result in improved efficiency, but will also reduced potential for waste and spillage. Minor variations in filling performance can have significant cumulative effects particularly for small unit fill quantities;
- improving procedures for recovering milk from wrongly filled containers;
- emptying and collecting product from wrongly filled containers for use as animal feed;
- reducing energy consumption through improved insulation, closing of doors to cold areas, good maintenance of room coolers and regular defrosting;
- using direct ammonia-based cooling systems instead of CFC-based systems.



### **Butter production**

Cleaner Production opportunities in this area focus on reducing water use and loss of product. Ways of achieving this include:

- minimising the number of times the pasteuriser is cleaned. Particularly in small butter dairies, optimising the size of balance tanks before and after the pasteuriser will allow it to operate continuously, resulting in less need for cleaning;
- installing modern pasteurising equipment. This will reduce waste of cream in many dairies, because improvements in plate design now give a more gentle and constant heat treatment. This decreases the build-up of overheated solids on heating surfaces. In the event of upgrades to process equipment, high-volume pasteurising units should be considered;
- collecting the more highly concentrated milk wastewater generated when starting up the pasteuriser, for use as animal feed.

### **Butter churning**

Cleaner Production opportunities in this area focus on reducing loss of product. Ways of achieving this include:

- ensuring that the buttermilk is collected separately and hygienically so that it can be used in other processes, such as a base for low fat spreads;
- collecting all first rinses, and separating the residual fat for use in other processes;
- preventing the build-up of milk scale deposits;
- maintaining butter makers on a regular basis;
- avoiding spills by ensuring that the buttermilk collection facilities are large enough to hold all the liquid.

#### **Butter packaging**

Cleaner Production opportunities in this area focus on reducing water use and loss of product. Ways of achieving this include:

- collecting first rinses while still warm and separating the milk fat residues for use in other processes;
- reducing the disposal of packaging material by having personnel constantly optimising operation of the packaging machines.

### **Butter storage**

Cleaner Production opportunities in this area focus on improving the energy efficiency of refrigerated storage. Ways of achieving this include:

- installing insulation;
- keeping doors closed in cold areas;
- undertaking regular defrosting of cold rooms and regular maintenance of refrigeration systems;
- avoiding refrigerants that contain CFCs. Refrigeration systems based on ammonia cooling are preferred.

### **Cheese production**

A number of opportunities exist for the recovery of the valuable high-grade protein from sweet whey. However it has only been in recent years that they have become technically and economically viable. The method used is ultra filtration (UF), followed by spray drying of the protein. This process is costly, so is only worthwhile when large quantities of fresh whey are available. Spray-dried whey powder contains between 25% and 80% protein and is used in food products, where it performs a similar function to egg proteins. Whey powder is

highly soluble, even at high acidity, and is capable of forming stable foams and gels when heated. Whey protein powder is therefore used in the manufacturing of bakery and meat products, where its gelatinous properties are particularly useful. Other options available for whey utilisation are:

### **Evaporation followed by spray drying to produce whey powder**

One of the problems associated with this solution is that the lactose tends to caramelise, making any heating process difficult. Unless special precautions are taken, the resulting product is very hygroscopic due to the high concentrations of lactose (70–75%). Whey powder in this form is not suitable for use as a food ingredient because it is very sticky and absorbs moisture during storage, forming hard lumps. Non-hygroscopic whey powder can be produced by precrystallising the lactose before drying. In this way, most of the lactose is present in the alpha-crystalline form, which is nonhygroscopic. Higher-quality whey powder can be produced by incorporating a secondary crystallisation step after spray drying. Powder is removed from the drying chamber at 8–14% moisture. The moisture remaining in the powder permits almost complete crystallisation of the lactose and the residual moisture can then be removed in a secondary drying system (e.g. a fluid bed) before the powder is cooled and packaged.

### **Feeding it to animals**

In most countries where this is practised, the whey is normally fed to pigs or cows. This is a low-cost solution but the price obtained for whey, after transport costs are considered, is often only a very small fraction of the cost of the original milk. The advantages are that there are no capital costs and no effluent charges.

### **Demineralisation, or reduction of the mineral content of whey**

This increases the range of opportunities for its use as a food ingredient. Ion exchange treatment or electrodialysis is used in the demineralisation process, and demineralised whey is spray-dried in the same way as whey powder. The main use of demineralised whey powder is in the manufacture of infant milk formulations, where it is used in combination with skimmed milk powder to give a similar composition to that of human milk. Another use of demineralised whey powder is in the manufacture of chocolate. Electrodialysis, or ion exchange technology, is comparatively expensive but it does give an end product with a higher value.

### **Anaerobic digestion and fermentation**

Whey can be anaerobically digested to produce methane gas, which can be captured and used as a supplementary fuel on site. Whey can also be fermented to produce alcohol. In addition, there are a number of Cleaner Production opportunities for reducing the loss of product from the process, which include:

- preventing the loss of curds by not overfilling cheese vats;
- completely removing whey and curds from the vats before rinsing;
- segregating all whey drained from the cheese;
- sweeping up pressings instead of washing them to drain;
- screening all liquid streams to collect fines.

### **Cheese packaging**

All cheese scraps should be collected separately from other waste and either used as raw material for processed cheese manufacturing (where possible) or sold as animal feed. Liquid wastes should be treated, together with other effluent streams.

### **Cheese storage**

Methods for reducing energy consumption and minimising the impacts of refrigerant use are:

- installing good insulation;
- keeping doors to cold rooms closed;
- undertaking regular defrosting and maintenance of refrigeration systems;
- avoiding refrigerants that contain CFCs. Refrigeration systems based on ammonia cooling are preferred.

### **Evaporation in Evaporated and dried milk production**

Cleaner Production opportunities in this area focus on ensuring the efficient operation of the evaporators, including:

- maintaining a liquid level low enough to prevent product boil-over;
- using entrainment separators to avoid carry-over of milk droplets during condensation of evaporated water;
- recirculating low concentration milk and other feedstocks until a required concentration is reached;
- prior to scheduled shut-downs, processing rinse waters with solids content greater than 7% or evaporating them during the next run rather than discharging them to the effluent stream;
- draining equipment thoroughly before starting rinsing and washing;
- collecting the first rinse water for animal feed;
- reducing the frequency of cleaning operations as much as possible;
- reusing condensate as cooling water after circulation through a cooling tower, or as feed water to the boiler.

### **The drying process**

Methods for avoiding the release of fine milk powder to surrounding areas include:

- minimising emissions to air by using fabric filters or wet scrubbers;
- undertaking wet cleaning only when absolutely necessary, and plan for it to coincide with a change of product;
- controlling air emissions and taking corrective action if levels are beyond acceptable limits.

### **Packaging and storage of milk powder**

The Cleaner Production opportunities in this area focus on the prevention of emissions of milk powder dust, including:

- ensuring the proper management of storage operations;
- installing exhaust ventilation to minimise dust in the work place.

### **Cleaning**

For dairies without CIP systems, consideration should be given to their installation. CIP systems make the recovery and reuse of cleaning solutions possible, and systems equipped with in-line monitoring can control the quality of cleaning solutions, thereby maximising the use of detergents and minimising water use. For dairies with CIP equipment, it is important to determine and maintain optimum operational settings to reduce the consumption of both water and detergents. Further water reductions can be achieved by providing facilities for the collection of final rinse waters so that they can be reused as the initial rinse water in the next CIP cycle. Detergents and disinfectants can be significant

sources of pollution if too much is used. It is very important, therefore, to monitor their consumption. An optimum detergent concentration for cleaning should be determined. Operators should ensure that tanks, pipes and hoses are as completely empty as possible before they are cleaned. Empty pipelines can be blown with compressed air before cleaning in order to reduce any milk film that may have adhered to the walls of vessels and pipelines. Cleaning of floors and equipment often consumes large quantities of water, due to the traditional cleaning method in which the operator directs a jet of water from a hose onto equipment and floors until the milk and solids float down the drain. Solid wastes, such as curd particles in the cheese making process, can be collected using a brush or broom rather than being rinsed down the drain. The use of pigging systems to remove product residues from the internal surfaces of pipeline prior to cleaning can help to reduce the pollutant load of cleaning wastewaters and also allow for product recovery. Spray nozzles are subject to wear that causes deterioration of the orifice and distortion to the spray pattern. This results in an increased flow rate of water and reduced effectiveness. In general, 10% nozzle wear will result in a 20% increase in water consumption (McNeil and Husband, 1995)

### **Crate washing**

Cleaner Production opportunities in this area therefore focus on reducing the consumption of water. Ways of achieving this include:

- optimising water consumption by monitoring the water pressure and the condition of the water spray nozzles;
- installation of spray nozzles of the optimum dimensions;
- fixing leaks promptly;
- turning off the crate washer when not in use;
- recirculating wash water through a holding tank.

### **Refrigeration and cooling**

CFC-based refrigerants should be replaced by the less hazardous hydrogenated chlorofluorocarbons (HCFCs) or, preferably, by ammonia. In the long run both CFCs and HCFCs should be replaced by other refrigerants according to the Montreal Protocol. Replacing CFCs can be expensive, as it may require the installation of new cooling equipment. Minimising the ingress of heat into refrigerated areas can reduce energy consumption. This can be accomplished by insulating cold rooms and pipes that contain refrigerant, by closing doors and windows to cold areas, or by installing self-closing doors.

If water and electricity consumption in the cooling towers seems high, it could be due to algal growth on the evaporator pipes. Another reason could be that the fans are running at too high a speed, blowing the water off the cooling tower. Optimising the running of the cooling tower can save a lot of water.

### **Actualisation**

#### **Case Study of Pasteurisation (optimisation of heating processes)**

To illustrate the application of the described procedure for optimizing food production chains, the following case study has been performed. A heating process with a capacity of 40 tonnes of skim milk per hour consists of a regenerative section, a heating section, two holder sections and a cooler. In Fig. 3.0. , the scheme of the process is shown with some preliminary temperatures and residence times. In order to have a process model, the equipment is transformed to a cascade of model reactors. Details of the characteristic dimensions are given in the literature (De Jong *et al.*, 2002b). The objective is to develop a process that meets the specifications as given in Table 2.0. . The objective function is defined as:

$$F(u, x) = \sum_{i=1}^3 \alpha_i \left( \frac{x_{i,des} - x_i(u)}{x_{i,des}} \right)^2 + F_{cost}$$

Figure 3.0: Scheme of the pre-design of the pasteurization process.

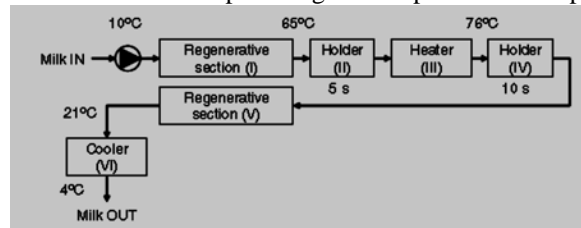


Table 2.0. Product and process specifications of pasteurization (process variables). Source: Britz.J.T and Robinson.R.K. 2008

Process variable	Desired value ( $x_{i,des}$ )	Weight factor ( $\alpha_1$ )
$\beta$ -Lactoglobulin denaturation	72–80	4–8
Decimal reduction <i>Strep thermophilus</i>	130–145	75–90
Production costs	142–150	60–85

Where

$$F_{cost} = \frac{c_{operation} t_{operation} + c_{solids} t_{production} \iint_{x,t} J_{x,t} dt dx}{t_{production} \phi} \tag{1.1.0}$$

where the integral term is the total amount of deposits after 1 h of production, and  $\phi$  is the capacity of the process in tonnes per hour and:

$$t_{production} = \frac{t_{operation} t_{run}}{t_{run} + t_{cleaning}} \tag{1.1.1}$$

and

$$t_{run} = t \text{ if } (C_{Strep.thermophilus} > 0.0001 \text{ cfu ml}^{-1}) \tag{1.1.2}$$

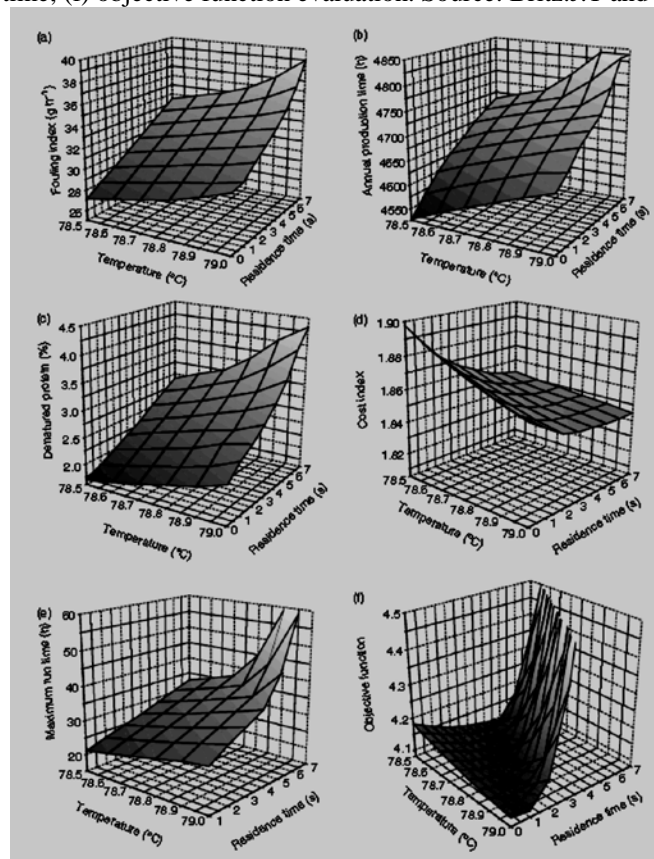
Values of several constants are given in the literature (De Jong *et al.*, 2002b). The weight factor  $\alpha_1$  is introduced to avoid trivial and undesired solutions; for example, a low-cost process resulting in an inferior product quality. The chosen values of the weight factors are determined by the relative importance of the different product properties. However, since the relationship between the weight factor values and the optimization results are not clear beforehand, the determination of the weight factor value is an iterative process in consultation with industrial experts. In this case, the control variables ( $u$ ) are limited to two, the heating temperature and the residence time at this temperature in the second holder section. With two control variables, surface plots can present the results of the computer model simulations. Figure 4.0. shows the results of the model evaluations. According to Equation 1.12, in this case it is assumed that the maximum run time is limited by contamination with *Strep. thermophilus* and not limited by the deposition of proteins and minerals on the wall surface. At a temperature lower than 79°C and run times shorter than 30 h, the deposition layer does not result in insufficient heat transfer. Related to that, the objective function accounts for the increasing amount of product losses. According to Fig. 4 d, the operating costs per tonne of heated product decrease with temperature and residence time. This is due to the increased operating time (Fig. 4 e) resulting in an extended annual production time (Fig. 4b). However,

at higher temperatures and longer residence times, the amount of denatured proteins exceed the desired value of 2.5% resulting in a substantial contribution to the objective function (Fig. 4 f). Catalase activity was not a key parameter in the temperature and residence time region applied. At a temperature of 78.5–79.0°C and a residence time of 1 s or longer, the activity was <0.1%. In Table 3.0, the optimal values of the control variables and the related process variables are listed. Compared with the initial preliminary design (10 s, 76°C), the operating costs could be decreased by 14%. At an annual production time of 4700 h, this means an estimated cost saving of €8 000.

Table 3.0. Optimization of the pasteurization process Source: Britz.J.T and Robinson.R.K. 2008

Variable	Reference	Optimal
<b>Control variable</b>	<b>760</b>	<b>78.7</b>
Heating temperature (°C)	10	3
Residence time (s)		
<b>Process variable</b>		
Catalase activity (%)	1.6	0.01
β-Lactoglobulin denaturation (%)	0.84	2.46
Decimal reduction <i>Streptococcus thermophilus</i>	6	6
Production costs (€ton <sup>-1</sup> )	2.16	1.86

Figure 4.0: Results of the optimization for different aspects of the objective function as a function of the control variables: (a) fouling index; (b) annual production; (c) protein denaturation; (d) cost index (€ ton<sup>-1</sup>); (e) maximum run time; (f) objective function evaluation. Source: Britz.J.T and Robinson.R.K. 2008



### Case study of Cleaner Production - Campina Melkunie Maasdam- The Netherlands

The Cleaner Production assessment for this Dutch company was carried out as part of the PRISMA project (Dutch Ministry of Economic Affairs, 1991). The project identified five Cleaner Production opportunities:

- better emptying of production tanks;
- elimination of rinsing between yogurt batches;

- reduced rinsing at product change-over;
- optimisation of cleaning operations;
- .recovery of low-grade heat.

This case study demonstrates that even when considerable effort has already been made to improve the environmental performance of a company, it may still be possible to identify additional Cleaner Production opportunities through a formal Cleaner Production assessment process.

### **Company description**

Campina Melkunie Maasdam is part of the Campina Melkunie Holland cooperative. The company employs 170 people, who work two shifts. The company produces a wide range of milk, custard and yogurt products. In total 105 million litres of milk is processed per year; 92 million litres for market milk and 13 million litres for other dairy products.

### **Process description**

The milk is delivered to the plant in milk tankers, after which it is separated. Depending on the required end product, the milk may then be mixed with non-separated milk to obtain the correct fat content. The milk is pasteurised and homogenised, and packed into cardboard or glass packaging. A proportion of the milk is processed further into yogurt, custard and buttermilk. During the production process, product clings to the internal surfaces of pipes and equipment, which can lead to reduced product quality. To avoid this, the entire process is cleaned and sanitised after each production day, and specific pieces of equipment may also be cleaned throughout a production day. Cleaning agents containing, among other things, sodium hydroxide, hydrogen peroxide and peracetic acid are commonly used.

### **Environmental aspects**

Like all dairy processing plants, the company generates a warm, liquid effluent stream containing milk constituents and cleaning and sanitising agents. The quantity of effluent discharged per year is 130,000 L. The organic loading of this wastewater averages about 1240 mg COD/L, which is equivalent to 3600 pollution units (pu), where 1 pu equals the organic pollution load generated by one person. The company is not connected to a wastewater treatment plant and therefore discharges treated effluent directly to surface water. The cost for discharging effluent is calculated according to the Dutch Pollution of Surface Water Act and amounts to US\$120,000 per year, based on US\$33 per pu. Emissions to air principally result from the combustion of fossil fuels in the boiler for steam generation. Pollutants emitted include NO<sub>x</sub>, CO, CO<sub>2</sub> and PAHs, but the quantities have not been measured. The company has three chemical waste streams: ink, solvents and laboratory waste. About 10 litres per year of each of these wastes are generated. This is taken away to the small municipal chemical waste depot. By far the largest proportion of the company's solid waste stream is of packaging materials, particularly the cardboard containers used to package milk. Approximately 125,000 containers are lost as waste per year, which represents approximately 0.25% of the total number of cartons consumed. The value of this waste stream has been estimated to be about US\$6000. Paper wastes are reused off site wherever possible and reject glass bottles are also recycled off site. The company generates its own steam in an on-site boiler for heating and processing, and other energy needs are met using electricity. Prior to the PRISMA project waste prevention measures had already been taken by the company, driven by financial and efficiency considerations. A lot of energy was used for the production of milk products. With the high energy prices of the 1970s it was cost-effective to take energy-saving measures. A lot of water was also used. For the production of 1 litre of milk ten years ago, 10 litres of water were needed. This has since been reduced to

1.4 litres of water. The preventive measures taken primarily involved reuse options, such as using the cooling and rinse water several times before discharging it. Another measure, to reduce the effluent charge, is to return waste product to the production process or collect it separately and take it away as cattle feed. Only if this is not possible is the product discharged.

### The Cleaner Production assessment

Based on previous studies of product losses undertaken by the company, it was possible to identify areas where relatively large amounts of waste and emissions were being produced. The primary sources of pollution load are product loss to the effluent stream and the use of cleaning agents. This is caused by, among other things, batch production processes, which lead to the need for frequent cleaning and subsequent losses during start-up and shut-down.

Another area of concern was the high energy consumption for heating and cooling. To reduce the pollution load fourteen preventative measures were drawn up. Since then, eight of them have been implemented. Three options still have to be looked at more closely and three have been found to be impracticable for various reasons. The result has been as follows:

- a reduction in product loss by 24,000 litres (3.4% reduction);
- a 23% saving in consumption of chemicals;
- a reduction in pollution load by 198 pu./yr (a 5.5% reduction);
- a 138,000 m<sup>3</sup>/yr saving in natural gas consumption.

Total savings have amounted to US\$68,000 per year, and possibly an additional US\$26,000 in reduced effluent charges. This was achieved by a single investment of US\$32,000.

Table 4.0. Identified Cleaner Production options

	<b>Projects implemented</b>	<b>Projects still to be implemented</b>	<b>Feasibility study required</b>
<b>Loss of product</b>	<b>Improvements to procedures</b> <b>Improvements to tank emptying practices</b>	<b>Replacement of cooling installation</b>	
<b>Cleaning operations</b>	<b>No rinsing between yogurt batches</b> <b>Optimisation of cleansing process</b> <b>Reduced rinsing</b>		<b>Substitution of cleansing agents</b> <b>Reuse of sour products</b>
<b>Energy</b>	<b>Pre-heating milk for buttermilk</b> <b>Custard heating</b>	<b>Pre-heating milk for yogurt production</b>	
<b>Miscellaneous</b>	<b>Replacement of ink injector</b>		

### Discussion

The life cycle of milk and milk products commences with the production of fresh cow's milk on dairy farms. Milk is then processed to produce pasteurized and homogenized market milk, butter, cheese, yogurt, custard and dairy desserts etc. It may also be preserved for a longer shelf life in the form of long-life (UHT), condensed, evaporated or powdered milk products. The various products are packaged into consumer portions and distributed to



retail outlets. For fresh dairy products, refrigerated storage is required throughout the life of the products to maintain eating appeal and prevent microbiological spoilage. Following use by the consumer, packaging is either discarded or recycled.

The processing of milk to produce dairy products is a significant contributor to the overall environmental load produced over the life cycle of milk production and consumption. Therefore the application of Cleaner Production in this phase of the life cycle is important. As in many food processing industries, the key environmental issues associated with dairy processing are the high consumption of water, the generation of high-strength effluent streams, the consumption of energy and the generation of by-products. For some sites, noise and odour may also be concerns. Investing in Cleaner Production, to prevent pollution and reduce resource consumption is more cost effective than continuing to rely on increasingly expensive 'end-of-pipe' solutions. When Cleaner Production and pollution control options are carefully evaluated and compared, the Cleaner Production options are often more cost effective overall. The initial investment for Cleaner Production options and for installing pollution control technologies may be similar, but the ongoing costs of pollution control will generally be greater than for Cleaner Production. Furthermore, the Cleaner Production option will generate savings through reduced costs for raw materials, energy, waste treatment and regulatory compliance. The environmental benefits of Cleaner Production can be translated into market opportunities for 'greener' products. Companies that factor environmental considerations into the design stage of a product will be well placed to benefit from the marketing advantages of any future eco labeling schemes.

### **General recommendations**

Recommendations regards Cleaner Production are derived from perceived environmental impacts associated with each production process and they represent a range of available options, from profitable activities that require no investment to other activities that may increase the production plant's costs:

### **Water pollution**

- Site small dumps or waste treatment sites far away from surface or groundwater water sources.
- Separate harmful chemical waste from organic waste, and use more care in handling chemical waste. Dispose of chemical waste in methods in a manner that prevents chemicals from leaching into ground or surface waters (such as clay- or concrete-lined pits).
- If the enterprise stores waste temporarily before transporting it to a treatment facility or landfill, make sure it is not leaking into the ground.

### **Working Conditions**

- Maintain safety equipment and reinforce safety training. Safety measures may already be in place, but workers should be reminded often; designate one person as the safety trainer and have that person train others. Check existing safety equipment regularly, and replace elements like dust filters frequently.
- Create a prevention strategy. Sometimes small changes such as buying a face mask or rubber gloves can dramatically reduce incidences of harm to workers. Find ways of preventing accidents.
- Find ways of reducing harmful by-products. For example, clean the floors in between production cycles to get rid of excess dust, or install drip trays to catch acidic fruit juice.

### **Spoilage**

- Ensure that the building structure is secure not only from people but also from animals. Screens should be placed over drains and windows to keep out disease-carrying rodents and flies.
- Storage areas should be well-ventilated and large enough so that excessive heat and moisture do not cause spoilage in milk products.

### **Solid waste**

- Re-use organic waste. Some organic waste such can be used as animal fodder.
- Modify waste disposal to facilitate faster decomposition/breakdown of organic material. Add layers of dirt and dry organic material to waste pits, or spread waste over large areas of land. This type of composting and “land spreading” can speed up decomposition and quickly lowers waste volume. Ensure material does not attract disease-carrying vectors including birds, rodents and insects.
- Minimize wastes by improving production processes. Identify and change elements of production that may be inefficient or produce excess waste. For example, improved techniques for cutting food produce can reduce waste and yield more product.

### **Poorly maintained machinery**

- Schedule regular machine maintenance checks and repairs. Ensure up-to-date training in operation and maintenance. Do not wait until machinery is broken before checking it; leaks can occur long before serious equipment breakdown and may be costing you money. If possible and cost-effective, replace faulty machinery with more efficient machinery. If machinery is difficult to access, then monitor wastes or emissions to detect leaks. For example, check for puddles underneath machinery or chemical/fuel smells.
- Use wood shavings, drop cloths and/or oil/water separators to catch spills and leaks.
- If you are disposing of organic and chemical wastes separately, ensure that chemical or fuel waste does not contaminate the organic waste.
- If it is not cost-effective to replace or to repair machinery, make sure harmful effects are minimized. Increase ventilation around any machinery that has high gas or chemical emissions.

### **Water use**

- Decrease water usage through “dry cleanup.” Dry cleanup involves an initial cleaning without water (sweeping, wiping down) before washing. This method reduces the amount of water required to dislodge solid wastes from floors or machinery.
- Regulate water flow. Using high-pressure water hoses can ease cleaning and cut water use; usually this only involves adding a new nozzle to the end of a hose.
- Reuse water. Some food processors use steam to purify or clean packaging materials; a closed-loop system can cycle hot water back into the system. This process saves money on both water and energy costs.

### **Liquid waste**

- Practice water reduction strategies mentioned above, including "dry cleanup," to minimize the amount of wastewater created and the amount of waste materials in the wastewater.
- Separate fats, grease and solids from wastewater. Oil separators or oil traps can be purchased or made at relatively low cost and can reduce the amount oil in wastewater

dramatically. Drain stagnant pools of liquid or water away from holding pens and working areas.

- Consider constructing waste treatment ponds. Both solid and liquid waste can be treated in these, which can aid decomposition and reduce disposal costs. Since they may attract mosquitoes and other insects, site such ponds away from animals and places of human activity.

### Noises and odours

- Locate waste disposal sites away from housing or town centres.
- Modify waste disposal or production practices to minimize odours. For example, if treating waste in lagoons or compost pits, make sure they are large enough to accommodate the volume of waste that is produced—if too small, the effectiveness of the treatment decreases and smell increases.
- Provide earplugs for workers.
- Repair and maintain machinery so that excessive grinding or squeaking is minimized. This may increase the machinery's efficiency and make it last longer.

### Conclusion

Cleaner Production is the most effective way to design and operate industrial processes and to develop and produce products and services. The costs of wastes and emissions, including negative environmental and health impacts, can be avoided or minimised by applying the Cleaner Production concept from the beginning and apply it continuously and throughout the entire life cycle. The costs of the traditional, reactive environmental strategy - the end-of-pipe strategy - are well known. These costs continue to grow, and as regulations become more aggressive and precise will increasingly add to the burden of business. In contrast, when Cleaner Production is applied, processes become more efficient because they require fewer raw materials and/or generate less waste. Cleaner Production approaches recognise that change has to come from within and sustainable change cannot be imposed from external sources against the needs or desires of the firm. Generally with a Cleaner Production approach, there are inevitably substantial economic benefits that can be directly related to the program

Heating of milk has been rationalized to a great extent by introducing the chemical engineering approach. In this approach, the milk is described as a fluid with a number of key components and the equipment is described as a number of chemical model reactors. Processes for heating can be designed on the basis of the desired product specifications. After determination of the optimal temperature–time combination, the appropriate heating equipment can be selected and designed. Although heating is a well-developed and relatively robust preservation technology, there are still a number of challenges for improvement. For example, to improve the nutritional value of heated dairy products, there is a need for heating technologies that realizes hyper-short treatment at high temperature. Developments such as the ISI technology should be encouraged. Also, for a number of products, the (bio)fouling of the heating equipment and its related negative consequences limits the application

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