

THE ESTABLISHMENT OF WATER AND WASTE MANAGEMENT PROGRAM AND  
THE STUDY OF STAINLESS STEEL MICROFILTRATION PROCESS IN A FLUID  
MILK/ICE CREAM PROCESSING PLANT

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Requirements for the Degree

of

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**THE ESTABLISHMENT OF WATER AND WASTE MANAGEMENT PROGRAM  
AND THE STUDY OF STAINLESS STEEL MICROFILTRATION PROCESS  
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**BY**

**SAU HAN V. YIP**

**A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba  
in partial fulfillment of the requirements of the degree of**

**MASTER OF SCIENCE**

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## ABSTRACT

As the world strives to protect the environment, governments everywhere are imposing more stringent restrictions and costs on waste discharges. Biochemical oxygen demand (BOD), suspended solids, grease and pH are used by the municipality in evaluating the pollution strength of food industrial waste. Food industries can rely on public facilities for treatment but face substantial surcharges for BOD and suspended solids over 300 mg/L and 350 mg/L respectively. The most cost effective method for controlling food industrial pollutants is to conduct a water and waste management program within a plant.

With the establishment of the water and waste management program in the study model, problem areas which contributed to high chemical oxygen demand (COD) and suspended solids were identified. The evaluated problem areas included discharge of return (expired) products, sludge from the separator (separator flush) and excess milk from the milkotester (fat analyzer) of the HTST. A reduction in COD from 15,000 mg/L to 1,800 mg/L was observed when return products were disposed as animal feed. Sediments from the separator flush were separated from the skim milk by the centrifuge method. The supernatant, with similar solids content and slightly lower protein content, could be recycled for fluid milk processing. Total annual saving of this skim milk was estimated to be \$ 127,380. A reclaim system was capable of recycling the excess warm milk from the milkotester for processing with an annual saving of \$23,000 on product and a potential reduction on surcharges.

The use of a porous stainless steel micro membrane system (Microsteel) as a means of chemical recovery and effluent pretreatment was investigated. With a volume recovery of 89%, the recovered chemical solutions (permeate stream) such as caustic (AC 101 without the addition of stabicip), chlorinated alkali (Liquid Super Klenz), and acid (AC Special) retained their strengths. As a result of the reduction in suspended solids (89 to 100%), protein (73.42 or greater), and fat (85.28 or greater), the chemical solutions can be reused. The microsteel system also effectively removed suspended solids (94-100%), fat (96.71-99.93%) and protein (94.83-99.60%) of controlled dairy products and combined dairy effluents. This corresponded to a 74 to 78% removal of COD obtained observed in combined dairy effluents. With an initial BOD of 820 to 2,400 mg/L, the BOD of the effluents after the microsteel membrane treatment was estimated to be 216 to 631 mg/L. Under ideal conditions, this reduction could lead to an annual saving of \$108,000 on surcharges. The use of coagulation/flocculation and ultrafiltration prior to or after microsteel system served no benefits in terms of COD and solids removal.

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## 1 INTRODUCTION

In view of the increasing emphasis on environmental safety, the disposal, treatment and utilization of food industrial effluents has become a subject of growing importance (Mans, 1993). In a study conducted by Carawan (1992), it was indicated that more than 5% of all milk received by a typical dairy plant is lost into the sewer. It was also shown that more than 90% of a dairy plant waste load arose from milk or milk products. Generally, this indicates a profit loss, reflective of the degree of shrinkage (product loss) and subsequent treatment costs (surcharges) based on the amount of product discharged into the sewer. Current data indicates that the food industry in Winnipeg paid substantial surcharges ranging from \$15,000 to \$200,000 in 1992 (Anonymous, 1992). In addition to rapid increments in these surcharges, regulations to control pollution have become more stringent. In response to the above, food companies are investigating the use of different waste treatment programs as a control measure (Sperber, 1993).

The waterworks, waste and disposal department in Winnipeg measures the pollution strength of food industrial waste in terms of biochemical oxygen demand (BOD), suspended solids, grease and pH (Author. of Council of City of Wpg, 1988). The quantification of some of these analytical parameters (BOD, and suspended solids) serves as the base for determining the amount of surcharges paid by a food industry to the government (Permut, 1993).

In the absence of publicly owned treatment facilities, there are two waste

treatment options available to the food industry for the reduction of food industrial wastes and the subsequent surcharges. These options include establishing an in-plant water and waste management program, or a waste pretreatment program (Mans, 1993). The first logical step towards the minimization of sewage surcharge is to establish an in-plant water and waste management program. As indicated by Marshall (1984) and Carawan (1992), a majority of the 5% milk lost into the sewer results from mishandling of milk products during processing. A detailed investigation of the plant followed by the appropriate plant modification which can minimize product loss while maximizing product reuse is an essential part of the water and waste management program.

A number of waste pre-treatment programs have been extensively researched and applied commercially to the dairy industry. Presently, one of the novel pretreatment options with the potential advantages of saving water, chemicals, marketing by-products and reducing the strength of effluents is membrane technology (Cartwright, 1990). Membrane technology (microfiltration, ultrafiltration, nanofiltration, electrodialysis, and reverse osmosis) is versatile and efficient in the utilization and treatment of dairy effluents especially in the cheese manufacturing area (for example, cheese whey and brine) (Jelen, 1979; Merin and Daufin, 1990). A newly developed porous stainless steel (Microsteel) membrane system has been proposed to the dairy industry as a means of recycling different cleaning solutions (Membrane System Specialists, 1993).

Without a waste pre-treatment system, a milk processing plant, located in the city of Winnipeg, paid over \$110,000 on surcharges in 1992 (Anonymous, 1992). Using this plant as my study model, **the main objective of this research was to lower its pollution strength (parameters such as BOD and suspended solids), and**

subsequently minimize its sewage surcharges.

The specific objectives of this research were to:

- (A) Conduct a water and waste management program at the study model site.
- (B) Evaluate the porous stainless steel (Microsteel) membrane system as a means of:
  - (a) chemical recovery and
  - (b) effluent pre-treatment.

## 2 LITERATURE REVIEW

### 2.1 Background

In the early 1970's, various nations including the United States and Canada recognised the effect of pollution on the environment and passed legislation with respect to this concern (Green and Kramer, 1979). The U.S. Environmental Protection Agency (EPA) was established in 1970 to update existing, or create new antipollution laws and regulations. One of the greatest concerns of all food processors is the Clean Water Act. Amended in 1977, the Clean Water Act regulates the point source (end-of-pipe) discharges of waste effluents to rivers, lakes, and ground water. In the same year, the National Pollution Discharge Elimination System (NPDES) which set limitations on the type and quantities of pollutants that can be discharged by various industries was established (Moore and Buxton, 1977). Enforced by municipalities, penalty fines in the form of sewage surcharges were imposed upon industries with sewage discharge greater than the established limits in an effort to partly offset the money used to expand municipal sewer treatment plants. In the past two decades, this surcharge rate has steeply risen. The extent of this increment could be demonstrated by sewage surcharges increasing from approximately \$2,000 to \$4,000 per month to \$10,000 to \$20,000 per month during a 5 year period (Schexnayder, 1991).

Dairy processors have recognised the effect of sewage surcharges on their survival and competitiveness. An alternative for paying sewage surcharges to publicly owned treatment facilities was the establishment of a partial or complete in-house



treatment system (Campbell, 1994). Figure 1 illustrates a logical approach to industrial waste management (Cartwright, 1992). In the last two decades, a tremendous effort has been made by researchers and manufacturers to study the existing systems and develop innovative technologies to minimize water usage and product wastage, improve water and product recycling, and implement effluent pretreatment. As such, a wide range of technological and management options has become available to dairy processors.

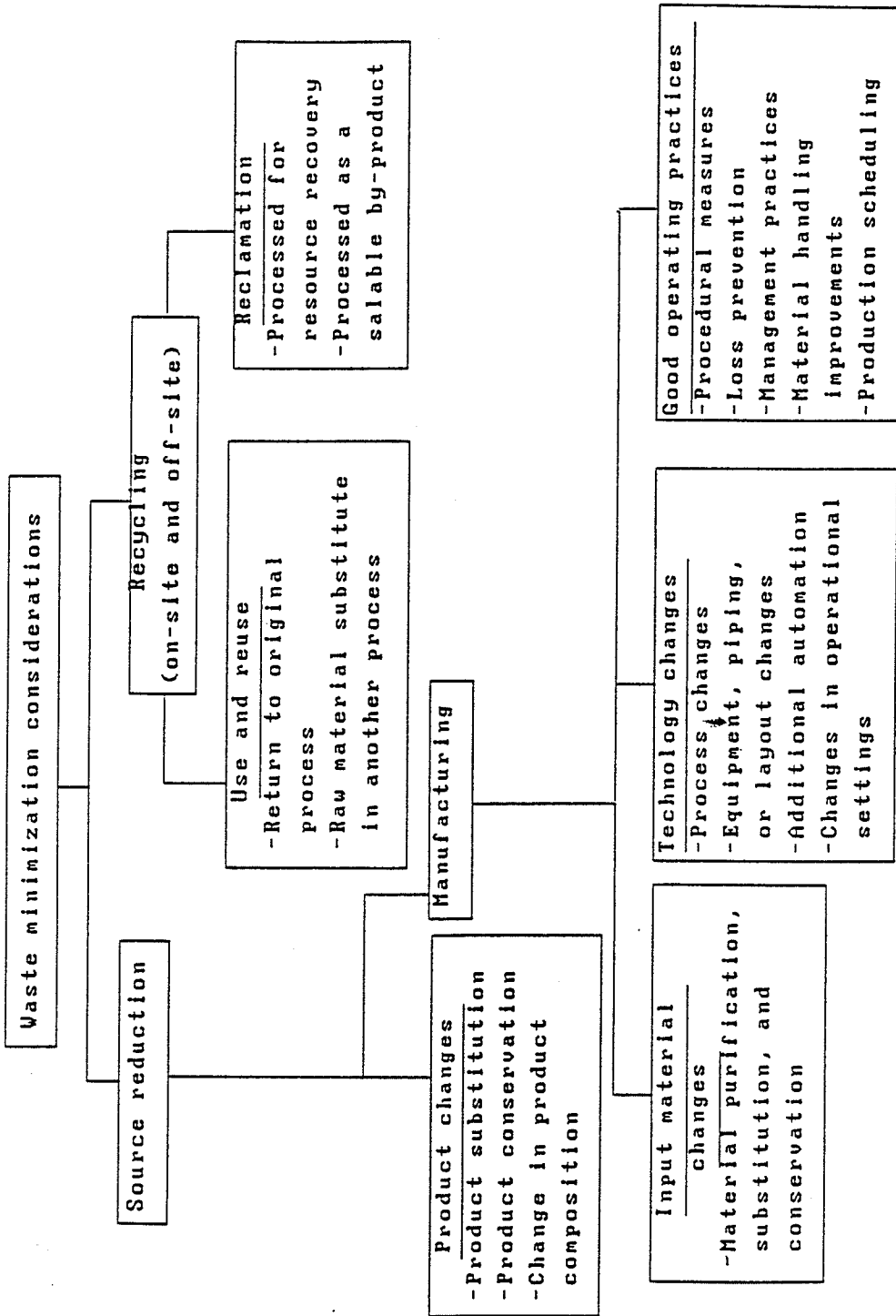
## 2.2 Winnipeg By-Law

The by-law set by the city of Winnipeg over a 24 hour sampling period and monitored 4 times a year established the maximum pollution loading limit as a BOD concentration of 300 mg/l, 350 mg/L of suspended solids (SS), 150 mg/L of grease, and pH values between 5.5 to 9.0 (Author. of Council of City of Wpg, 1988). A surcharge rate using equation (a) is levied on a plant based on BOD and suspended solids values exceeding those indicated above (Anonymous, 1992).

$$\left[ 0.34 \left( \frac{\text{SS}-350}{350} \right) + 0.44 \left( \frac{\text{BOD}-300}{300} \right) \right] * 42.2 = \text{cents/kiloliter} \quad (\text{a})$$

The total sewage surcharge for a three month period is based on the calculated surcharge rate and the total volume of effluent discharged. The total volume of effluent discharge is usually calculated by the summation of all water resources (city and well water) for a three month period. Therefore, the amount of water used in the plant has a significant impact on the total sewage surcharge.

Figure 1. An approach to an industrial waste minimization (Cartwright, 1992).

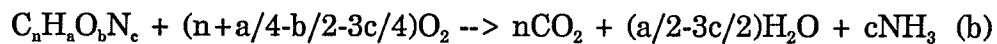


## 2.3 Methods of Food Industrial Waste Analyses

The common analytical methods used by the municipality to evaluate food industrial discharge include biochemical oxygen demand, suspended solids, fat and pH.

### 2.3.1 Biochemical oxygen demand

Biochemical oxygen demand (BOD) analysis involves the measurement of oxygen before and after a 5 day testing period in conditions similar to those that occur in nature. Theoretically, BOD measures the amount of oxygen consumed by microorganisms during the decomposition of organic matter under aerobic conditions (American Public Health Association, 1985). Equation (b) represents the quantitative relationship between the amount of oxygen required to convert a definite amount of any given organic compound to carbon dioxide, water and ammonia (Sawyer and McCarty, 1978).



The biological degradation of organic matter in nature is carried out by a diverse group of microorganisms. As such, it is important that a mixed group of microbes (seed) is used during BOD analysis (American Public Health Association, 1985). Other adequate conditions for BOD analysis include the presence of accessory nutrients for bacterial growth, absence of toxic substances that may retard the breakdown of organic matter by the seed and an incubation temperature of 20°C. The inconsistency of these experimental conditions do result in the poor reproducibility of BOD results. However, BOD analysis remains the standard expression of effluent pollution strength (Sawyer and McCarty, 1978).

### **2.3.2 Suspended Solids**

Suspended solids is measured as the amount of residue retained on a standard glass fiber filter after filtration (American Public Health Association, 1985). It is one of the major parameters that serves to evaluate the strength of wastewater and assess the efficiency of treatment since deposition is expected to occur through biological and chemical flocculation. Generally, the measurement of suspended solids is considered as significant as BOD (Sawyer and McCarty, 1978).

### **2.3.3 Grease and oil**

Grease or oil is commonly measured by the Soxhlet extraction method. This involves the extraction of hydrolyzed fat materials using trichlorotrifluoroethane (Freon) (Sawyer and McCarty, 1978). Due to the pollution problems associated with Freon, alternative agents such as hexane and methyl-3-butyl ether or an 80:20 mixture of the above two chemicals have been used for the analysis (American Public Health Association, 1989). The analysis of grease or oil in waste water is paramount since studies have indicated that high levels of grease or oil have the potential of interfering with aerobic and anaerobic biological processes. Also, wastewater containing oil may cause surface films and shoreline deposits leading to environmental (lake, stream, and river) pollution (American Public Health Association, 1985).

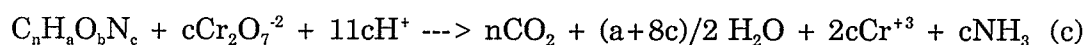
### **2.3.4 pH**

pH is important in the evaluation of wastewaters. Extreme pH values have been shown to upset the natural environment of living organisms (Sawyer and McCarty, 1978). Also, the efficiency of chemical coagulation and biological treatment

relies on proper pH control (Barnes and Wilson, 1983).

### 2.3.5 Chemical oxygen demand

Chemical oxygen demand (COD) is an alternative test for the quantification of organic matter in wastewater. It measures the oxygen equivalent of the organic matter content in a sample that is susceptible to oxidation by strong oxidizing agents under acidic conditions (Sawyer and McCarty, 1978). The equation



involves the oxidation of organic matter by potassium dichromate into water and carbon dioxide (Sawyer and McCarty, 1978). At the end of the digestion period, the excess amount of dichromate is measured either by a reducing agent such as ferrous ammonium sulfate (FAS) or by colorimetry and calculated as COD in mg/L (American Public Health Association, 1985 and Knechtel, 1978). When compared to BOD, COD is rapid, relatively cheap and reproducible. Due to these advantages, COD is believed to be the most suitable test for replacing BOD estimations of effluent strength (Staal, 1981).

### 2.3.6 BOD and COD Ratio

The identification of BOD:COD ratio for individual food plants is becoming a necessary aspect of water and waste analysis since it reduces the general testing period. As already indicated, the results of BOD analysis is obtained after 5 days while COD results can be obtained in 3 hours. Studies (Jones, 1974) have shown that a

correlation exists between BOD and COD of untreated dairy effluents, with BOD values ranging from 50% to 70% of the COD value. Percentages as high as 80 and as low as 20 have also been reported in some studies (Staal, 1981). The low BOD values have been attributed to inert organic material such as lignin which are not degradable by microorganisms used in BOD analysis. In contrast, lignin can be completely oxidized during COD analysis.

Variations in BOD:COD ratio have also been attributed to factors such as the differences in the BOD:COD ratio of individual milk constituents. For example, average values reported for casein, lactose and fat were 0.46, 0.53 and 1.26 respectively (Jones, 1974). Also, the BOD:COD ratio can be influenced by the concentration of effluent constituents. For example, the BOD:COD ratio of a 0.1% lactose solution was observed as 0.83. This is in contrast to the value of 0.5 reported for a 1% lactose solution (Staal, 1981). Factors leading to the poor reproducibility of BOD estimation may also lead to incorrect BOD:COD ratios. The presence of toxic substances, disinfectants or detergents in the effluent have been shown to affect BOD results and consequently, affects BOD:COD ratio (Jones, 1974). In consideration of the above points, a fairly constant correlation between BOD and COD of dairy effluent can be expected where the composition of effluent is relatively uniform. However, the BOD:COD ratio established in one plant cannot be transferred with sufficient reliability to another plant (Staal, 1981).

## **2.4 Water and Waste Management**

Untreated dairy effluent has a BOD value between 2,000 and 4,000 mg/L; about ten times the strength of domestic waste (250 mg/L BOD) (Campbell, 1994). The high

BOD observed in dairy effluents originates from cleaning operations, spillage, spoilage and as a residue of cheese, milk powder and other manufacturing processes. The primary organic constituents of dairy effluents consist of various proportions of fats, proteins and carbohydrates. Other organic compounds may result from products including fruit juices and ice cream additives such as fruits, nuts, coloring substances or sugar (Blanc and Navia, 1991). In general, the waste generating avenues in fluid milk processing include (1) washing, cleaning and the sanitation of pipes lines, pumps, processing equipment, tanks, tank trucks and filling machines; (2) start-up, product changeover and shut down of pasteurizer (HTST) and filling machines; (3) loss in filling operations through equipment jams and broken packages; and (4) lubrication of caser, stacker and conveyors (U.S. Environmental Protection Agency, 1971). To emphasize the impact of milk loss in processing, Carawan and Jones (1977) hypothesized that 1 kg BOD in the wastewater was equivalent to 9 kg of lost milk. This is based on the assumption that (1) 90% of the BOD in dairy wastewater is product related and (2) milk is the primary product, with a BOD of 100,000 mg/L.

Reports by U.S. Environmental Protection Agency (1971) indicated that the generation of dairy waste needs to be evaluated on a plant-by-plant basis, in order to provide information for the design and proper operation of waste treatment systems. Based on acquired information, Marshall (1984) reported that the majority of waste generated by a dairy plant can be avoided and easily corrected by proper management. In addition, Carawan and Jones (1977) suggested that every dairy processing plant should have someone completely responsible for the water and waste program. The detailed responsibilities of setting up a water and waste program includes (1) a survey of the plant - all water lines, meters, sewer lines, junctions, manholes and all other



parts of the system must be located; (2) the determination of the location and quantity of water used including the quantity of water brought into the plant from wells and municipal sources, as well as the quantity generated in the plant (by evaporators or other equipment); (3) the determination of the quantity and strength of waste generated, including flows from each section of the plant if possible; (4) the evaluation of the plant by determining why water is used and why waste is generated; (5) a plan to correct the problems; and (6) a water/waste education program. The most serious problems and/or the most easily corrected problems should be the first target. The education program is important as Marshall (1984) indicated a majority of the avoidable waste in dairy plants can be traced to staff that have been insufficiently trained, supervised and/or motivated.

Mans (1993) updated a list of water saving and waste reduction modifications applicable to the dairy industry with minimum capital expenditure. Similar lists were proposed by U.S. Environment Protection Agency (1971), and Carawan (1977). However, it was indicated that dairy plants are generally reluctant to adapt the corrective measures needed to reduce waste.

In the dairy industry, one universal problem area which was evaluated in this project is the utilization of sludge from separators. The sludge from a milk separator is defined as the discharged sediments and skim milk from a self-desludging separator at preset intervals during the HTST operation. The amount of milk sludge discharged is dependent on the duration of HTST operation, with as much as 600 liters being discharged a day (20 liters per discharge, 2 discharges per hour and 15 hours of processing per day). Treated as a clarifier, the separator removes dirt, somatic cells, red and white blood cells and microorganisms such as mastitis streptococci (35.2%),

tuberculosis bacteria (13.8%), Salmonella (1.9%), Micrococci, E. coli, Lactobacillus, Aspergillus, Mucor and Penicillium strains (International Dairy Federation, 1983). The composition of sludge has been quantified to be 64-73% water, 25-30% proteins, 1.4-3.3% fat and 2.6-3.5% ash.

## **2.5 Waste Pretreatment**

The most common waste pretreatment options in the dairy industry include aerobic and anaerobic treatment systems, coagulation/flocculation and membrane technology. The selection of an appropriate treatment is based on factors such as location of the plant, size of the plant, the composition, flow, and variation of the effluent, start-up cost of the treatment, running and maintenance cost of the treatment, and options for by-products (Carawan, 1992). A comparative study of the potential total waste treatment cost for a plant and the surcharge levied by publicly owned treatment works is an essential tool for deciding whether a pre-treatment is needed (Carawan, 1992).

### **2.5.1 Aerobic and Anaerobic Treatment Systems**

Twenty years ago, biological treatments were the preferred treatment method used by environmental consultants because of their efficiency in the removal of colloidal and dissolved organic matter from wastewater (U.S. Environmental Protection Agency, 1971). Biological oxidation is usually accomplished on fixed-bed units (trickling filters), fluid-bed systems (activated sludge), sequencing batch reactors and aerated lagoons (Eckenfelder and O'Connor, 1961; Mans, 1993). Under aerobic treatment conditions, wastewater is pumped into a treatment tank with different

configurations with the supply of microorganisms and oxygen (U.S. Environmental Protection Agency, 1971). The subsequent oxidation of organic matter (carbohydrates and proteins) results in the production of carbon dioxide, water and waste materials (sludge). Difficulties have been encountered in the biological treatment of whey due to the inability of microorganisms to degrade whey protein and the ability of these proteins to interact with the polysaccharide of the cell mass. In addition, the incorporation of whey or whey wash water in activated sludge treatment plants has been shown to result in excessive foaming (Jones, 1974). As such, it has been suggested that the whey and the wash water from cottage cheese operations should be excluded from aerobic treatment facilities (U.S. Environmental Protection Agency, 1971). Other reported problems generally associated with aerobic treatment include its sensitivity towards wide variation of flow and concentration and high waste strength, its problems in settling of sludge in activated sludge systems (bulking), additional nutrient requirements, quick development of anaerobic conditions in equalization basin, and odors resulting from the above mentioned anaerobic conditions (Ryder, 1984).

Unlike the aerobic treatment, anaerobic digestion is a bacterial fermentation where organic matter is broken down in the absence of oxygen to produce a mixture of carbon dioxide and methane. The first phase of decomposition, referred to as acid fermentation, involves the degradation of lactose to lactic acid, leading to a drop in pH. Fats and proteins are also decomposed to amino acids, organic acids, aldehydes, alcohols and other anaerobic intermediate compounds (Jones, 1974; Ryder, 1984). The second phase is referred to as methane fermentation and involves the conversion of organic acids to methane and carbon dioxide (Jones, 1974). The production of biogas

(methane) during an anaerobic treatment is an advantage over aerobic treatment since methane can be used as an energy source to produce steam or hot water. Other benefits encountered in anaerobic treatment include low and stable sludge production, and low odor and nutrient requirement (Ryder, 1984). The drawbacks of anaerobic digestion include high optimum operating temperatures (35 °C), lengthy start-up time (up to 8 to 12 weeks), sensitivity to chemicals, and heavy metals. The efficiency of COD removal in aerobic and anaerobic treatment have been shown to fluctuate from 50 to 99% and 70 to 99% respectively (Pico, 1986; 1987; 1988; Radick, 1989; 1991; 1993; Walsh et al., 1994). Generally, wastewater treatment facilities of this type are expensive to initiate (\$1,000 to \$4,000 for each lb of BOD produced per day) and operate (\$150 to \$600 per lb of BOD per day) (Anderson, 1992). In addition, they require precise process control (Martin and Zall, 1985). Carawan (1992) observed that 1 pound of BOD generates ca. 1 to 2.3 gallons of biomass, which typically cost about 10 cents per gallon to discard.

### **2.5.2 Coagulation**

Coagulation is a physicochemical treatment employed to remove colloidal matter, particularly fat and protein from dairy effluents by means of chemical or organic/natural coagulants (Green and Kramer, 1979). The operation involves the rapid mixing of coagulants and wastewater, followed by a slow mixing to promote flocculation. A separation process such as sedimentation, filtration or dissolved air floatation is then applied to separate the destabilized aggregates from the clarified liquid (Parsons, 1965). The use of natural/organic coagulants such as lignosulfonic acid (LSA), chitosan, modified carrageenan and carboxy methyl cellulose (CMC) have

the advantages of allowing the use of the resultant sludge for animal feed due to their feed or food grade status.

The soluble lactose content of dairy effluent, which contributes significantly to the BOD is relatively unaffected by this physical-chemical treatment (Jones, 1974). Traditional chemical coagulants (alum and lime, and ferric chloride) have a milk effluent BOD removal efficiency of approximately 70 to 75% (Blanc and Navia, 1991). Similar results were observed from an industrial dissolved air floatation system using CMC as the coagulant (Rusten et al, 1993). The application of LSA to milk models and industrial effluent was shown to be slightly inferior to alum and ferric sulphate in terms of COD removal (Karpati et al, 1990). The same study also suggested that the specific cost of COD removal by physico-chemical process is less than that the cost of using aerobic biological methods.

### **2.5.3 Membrane Technology**

#### **2.5.3.1 Background**

Cross flow membrane technology is based on the principle of selective permeability of one or more components of a liquid mixture through a membrane barrier (Jelen, 1991). Depending on the pore size, membrane processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), electrodialysis (ED) and reverse osmosis (RO) differ in their operating conditions (Table 1) and their ability to remove different food components (Cartwright, 1990).

Membrane technology has been defined as the future of pollution control due to its various advantages over other treatment options (Cartwright, 1990). As compared to other treatments, the membrane process is a continuous operation,

Table 1. Comparison of membrane separation processes (Cartwright, 1990).

Feature	Micro-filtration	Ultra-filtration	Reverse Osmosis	Electro-dialysis
Suspended solids removal	yes	yes	yes	no
Dissolved organic removal	no	yes	yes	no
Dissolved inorganic removal	no	no	yes	yes
Concentration capabilities	high	high	moderate	high
Permeate purity	high	high	high	moderate
Energy usage	low	low	moderate	moderate
Membrane stability	high	high	moderate	high
Operating cost (\$/1000 gallons feed rate)	0.50- 1.00	0.50- 1.00	1.00	1.00

utilizing little energy since no phase and temperature changes are taking place. In-plant treatment is possible since there are no significant size limitations on the modular design. It also has a minimum of moving parts with low maintenance requirements and no effect on form or chemistry of the contaminant (rejected materials) since the discrete membrane barrier ensures physical separation of contaminants.

### **2.5.3.2 Applications of UF, NF and RO in food industries**

In a study of red meat abattoir effluents in South Africa, membrane treatment was compared to other wastewater treatments (Cowan et al, 1992). In terms of the cattle unit (1 cu = 2 calves, 6 sheep/goats, and 2.5 pigs), the effluent production from large well-run abattoirs constituted 1.0 m<sup>3</sup>/cu effluent volume, 6.6 kg/cu total COD, 4.1 kg/cu soluble COD, 1.4 kg/cu suspended solids, 3.0 kg/cu total dissolved solids and 0.5 kg/cu protein. The addition of a protein coagulant followed by dissolved air flotation removed 60% of the organic load from the effluent. Aerobic biological treatment was observed to be expensive and generated large volumes of problematic sludge. Anaerobic digesters removed 70-80% of the soluble COD. However, UF membrane treatment consistently removed 90% of the total COD. Further RO treatment of the UF filtrate produced a high quality reusable water. The implementation of the process resulted in the reduction of potable water demand by 25%. The operating cost of a UF and RO membrane treatment (U.S. \$0.70/m<sup>3</sup> of effluent) was significantly less expensive than that of anaerobic digestion (U.S. \$1.17/m<sup>3</sup> of effluent).

Waste treatment applications of membrane technology in various food

industries was also performed at Osmonics Inc. (Paulson et al, 1984). The application of diafiltration using a UF membrane on the waste stream generated from corn wet-milling process produced a flavor improved, sulphur dioxide, lactic acid and ash free retentate. This retentate contained valuable proteins which could be dispensed as animal feed after drying. Also, the wash stream resulting from a soy protein extraction process contained 3 to 5% solids made up of proteins and sugars, and ca 1% sodium chloride. Reverse osmosis was applied to pre-concentrate this stream to greater than 20% solids prior to evaporation. This pre-concentration step saved 90% of the energy from the evaporator. The dried material was also used as animal feed. Further, fat and oils in the waste stream of a luncheon meat mold rinsing step were removed by a RO membrane. Ninety percent of the water was reclaimed for reuse.

Similar application involving UF was applied to the fractionation of proteins and oils from brine solution used in thawing frozen fish prior to further processing and smoking (Paulson et al, 1984). By recycling the ultrafiltered brine in the process, more than \$55,000 was saved on the salt costs. The cost of the membrane unit sized for the total brine flow was \$30,000. In terms of energy saving, product reuse and by-product quality improvement, the economically sound processes shown in the above membrane applications can also be found in the dairy industry.

First utilized in the treatment and disposal of whey, membrane technology (especially UF and RO) has been extensively used in the cheese manufacturing industry (Jelen, 1979). Bissett and Schmidtke (1984) conducted a study on the concentration of 35,000 kg of whey per day by hyperfiltration (reverse osmosis). Following an initial screening and fat separation, the whey was concentrated to a ratio of 4:1 with a 430 mg/L BOD discharge stream (permeate). With a mean system flux



of 12.1 L/m<sup>2</sup>h, the system operated at a pressure of 36 bars over a period of 11.2 hours per day. The authors calculated a payback period of 14 months with the assumption that the whey concentrate was given away free of charge. A saving of \$1.08 per kg of whey solids was achieved when this system was compared to activated sludge treatment.

The utilization of effluents by means of membrane technology was best demonstrated by Golden Cheese Company (Bush, 1991). Fat was separated by a clarifier from whey and made into whey butter. Whey protein concentrate, which was supplied to baby food, health food and pharmaceutical companies, was separated from lactose and minerals by UF. Lactose was concentrated from 4.8 to 10% solids by RO and further fermented to ethanol which was sold as fuel or solvent. Waste streams such as salted whey, buttermilk, heat treated excess yeast from the fermentation process and the distilled residual from CIP collected from the above processes were concentrated by RO before evaporation to use as an animal feed supplement. Permeate water collected from the reverse osmosis was used as boiler and CIP water.

Hayashi and Hatanaka (1984) used reverse osmosis to concentrate dairy effluents collected from milk, ice cream, yogurt, skim milk and cream powder operations from 3.4% to 18% solids. With a concentration ratio (representing the ratio of the initial feed volume to the volume remaining after membrane process) of 5.5, the treated effluent (permeate) was reduced in volume, BOD (72 to 90%) and COD (92 to 94%). The commercial applications of UF and NF to the fractionation of proteins, demineralization and concentration of whey are also commonly practised in the dairy industry (Kelly et al, 1991).

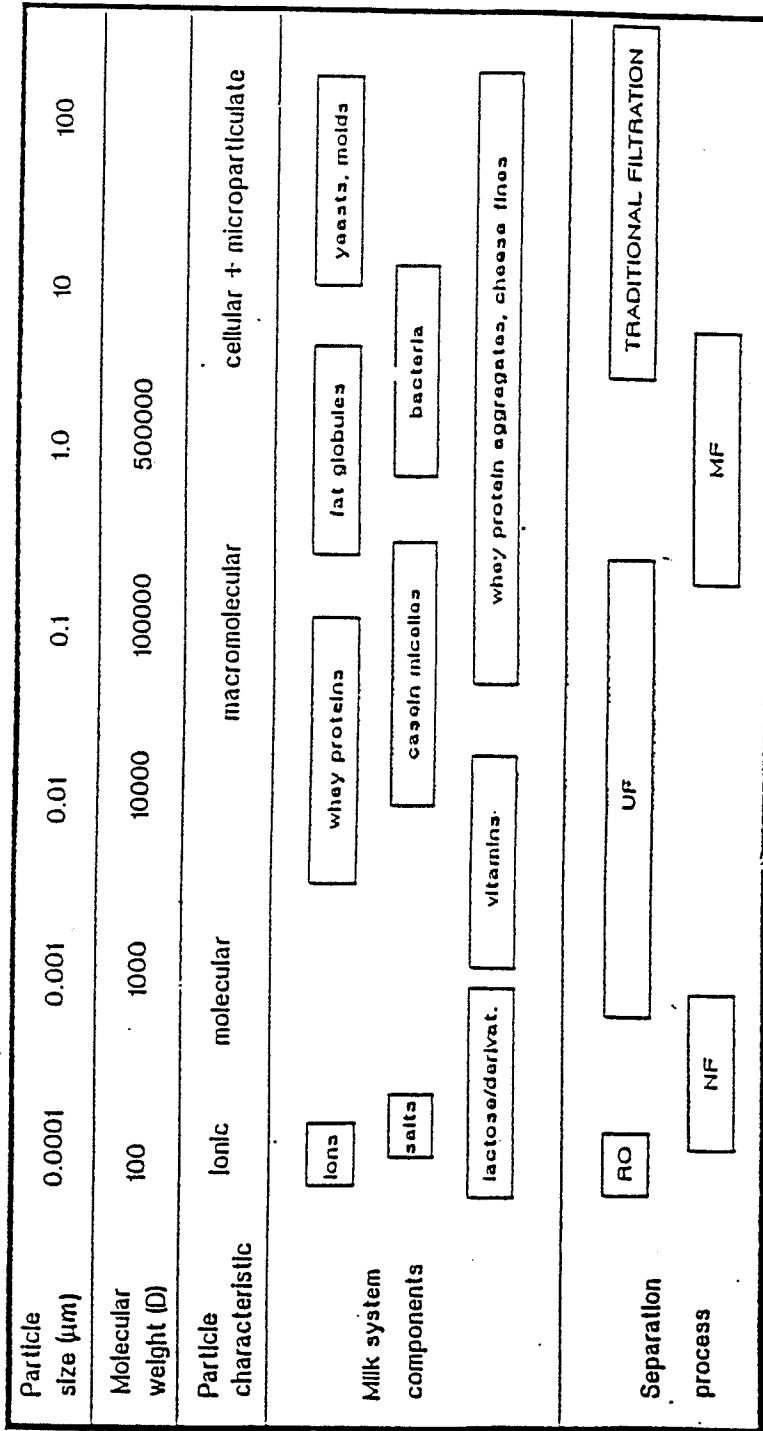
### 2.5.3.3 Microfiltration

With the cut-off sizes in the micron regions, the first adaptation of microfiltration was in the purification and sterilization of water and beverages (Merin and Daufin, 1990). As shown in Fig. 2, microfiltration, with a cut-off pore size of 0.1 to 0.2  $\mu\text{m}$ , allows the passage of minerals, lactose, some whey proteins and casein from milk. However, it retains fat globules, microorganisms and somatic cells (Jelen, 1991). In the dairy industry, the application of microfiltration is limited. Currently, it is only used for the removal of fat, casein fines and bacteria from whey prior to UF in order to improve UF flux and the quality of the concentrated proteins. It has also been applied to the clarification of cheese brine (Merin and Daufin, 1990). Applying microfiltration (1.2  $\mu\text{m}$ ) to whey resulted in the removal of 5 to 6% protein and 100% fat while reducing the bacterial count by a magnitude of 2 to 3 log cycles (Merin et al, 1983). The resultant whey was observed to obtain a 25 to 30% higher UF fluxes when compared to centrifuge clarified whey. However, Hanemaaijer (1985) observed that the efficiency of fat removal using different microfiltration membranes was only 20 to 60% when whey was pre-concentrated to a 25% solid content by reverse osmosis or evaporation.

Merin et al. (1983) studied the clarification of soft and hard cheese brine by microfiltration with various membrane sizes (0.2, 0.65, 0.8 and 1.2  $\mu\text{m}$ ). Results obtained indicated that 50 to 4,000 cfu/mL of yeast and mold were completely removed by all membrane sizes. The bacteria population ( $10^4$  to  $10^5$  cfu/mL initially) was reduced to less than 10 cfu/mL by the 0.2 and 0.65  $\mu\text{m}$  membranes and by 2 to 3 log cycles by the 0.8 and 1.2  $\mu\text{m}$  membranes. As such, the microfiltration process allowed for the conservation of energy and the improvement of the quality of brine compared

Figure 2. Spectrum of application of membrane separation processes in the dairy industry (Jelen, 1991).

RO = reverse osmosis  
NF = nanofiltration  
UF = ultrafiltration  
MF = microfiltration



to those obtained through the alternative process of pasteurization at 100 °C or greater for 30 to 60 minutes.

#### **2.5.3.3.1 Porous Stainless Steel (Microsteel) MF System**

Most membranes are made of synthetic polymers such as polysulphones, polyimide or polytetrafluoroethylene (PTEE) (Cheryan, 1986). As such, they are subject to limited operating conditions with respect to temperature, pressure and pH. They can also encounter problems such as fouling due to adsorption and adhesion of particles to surfaces, concentration polarization and pore blocking (Merin and Daufin, 1990). A more durable membrane made of mineral (Zirconium IV oxide) and ceramic has recently been developed (Pedersen, 1991). However, the most rugged and durable material currently being used for the development of microfiltration membrane is porous stainless steel. Porous stainless steel can withstand an extreme temperature of 250 °F., and extreme pH values (1-14) characteristic of cleaning agents used in CIP systems (Membrane System Specialists, 1993). In addition, the flux rate of this system can achieve values of 195 L/m<sup>2</sup>hr as compared to 60-80 L/m<sup>2</sup>hr range generally employed by synthetic polymeric membrane systems (Membrane System Specialists, 1993; Defrise and Gekas, 1988). The adaptation of backflushing to the stainless steel membrane overcomes the problems of membrane fouling and pore blocking usually associated with MF membranes (Membrane System Specialists, 1993; Cheryan, 1986). With the above mentioned advantages, the porous stainless steel (Microsteel) MF system has been proposed to the dairy industry as a means of chemical recovery.

### Caustic Recovery

Cleaning agents such as sodium hydroxide function by dissolving carbohydrates, saponifying fat, and peptizing proteins which have been deposited on the surface of processing equipment (Ecolab Chemical Company, 1990). The chemical reaction between sodium hydroxide and different food materials (soils) leads to the disintegration of soils into smaller particles that may be soluble or suspended in cleaning solutions (Wright, 1990). The Microsteel system is designed to remove suspended solids and soil from the evaporator and processing equipment CIP solutions. In addition, despite the lack of complete removal of soluble solids, the microfiltration system is capable of removing all microorganisms, and the suspended soil. These abilities can lead to the recycling of the CIP solutions. A study conducted by Pedersen (1991) indicated that greater than 98% of bacterial spores and 99% of total plate count could be removed from skim milk by a ceramic microfiltration membrane system with a pore size of 1  $\mu\text{m}$  (Table 2). The caustics recovered from this system are claimed to have the same strength and pH as the feed material (Membrane System Specialists, 1993). A concentration factor as high as 8-9:1 could be achieved without the occurrence of fouling since the porous stainless steel system features an automatic air backflushing to prevent the accumulation of deposits on the membrane.

A study conducted by Turpie et al. (1992) on Zirconium (IV) oxide membrane (pore size of 2-7  $\mu\text{m}$ ) indicated that the removal of grease and dissolved organics (66%), sand and dirt (100%), color (92-96%), turbidity (99%) and COD (89%) and the retention of detergent (94%) led to the recycling of the wash water from wool processing. An existing Microsteel system installed at Alto Dairy in Waupun, Wisconsin filters more than 11.4 kL of caustic solutions during an 8 hour time period with an average

Table 2. Bacteria retention of skim milk in a ceramic alumina microfiltration membrane system with uniform transmembrane pressure (Pedersen, 1991).

Type of bacteria	Initial population (cfu/mL)	Bacteria retention (%)
Total counts	6,000-15,000	99.10-99.90
Bacillus cereus spores	> 15,000	> 99.95
Lactate fermenting bacteria spores	> 1,100	> 98.40

recovery of 80%. Due to the dissolved solids being retained in the treated caustic solutions, a new batch of caustic solution is changed every 2 weeks (Wagner, 1994). Beatrice Foods in St. George, Ontario utilizes the Microsteel system fully for 20 hours a day. With an average of 80% recovery, the treated caustic solution collected from different sites of the dairy operation is used directly for the cleaning of the evaporator, HTST and pasteurized CIP system (Weaver, 1994). The latter system above operates at temperatures of 125 to 140 °F (52 - 60 °C), inlet pressures of 60 to 70 psi (4.22 - 4.92 kg/cm<sup>2</sup>), back pressure of 55 psi (3.87 kg/cm<sup>2</sup>) and permeate flow rate of 2 L/min.

### **Waste Pretreatment by Microfiltration**

Among all crossflow membrane processes, microfiltration has the largest pore size range and requires the least energy (Table 1). As such, microfiltration has often been used as the pre-concentration step prior to other dehydration processes (Merin and Daufin, 1990). Little literature is found on the utilization of microfiltration alone in effluent pretreatment. This is due to the fact that microfiltration may be insufficient for the reduction of enough organic solids to levels of acceptable BOD limits (300 mg/L). However, if the Microsteel system cannot be utilized fully (20-22 hours a day) for the recycling of CIP solutions, it may be justifiable to use the system to treat high strength effluents to alleviate some of the burden caused by sewage surcharges.

The efficiency of this fairly new system, safety of the recovered chemicals and economic feasibilities of the porous stainless steel system on chemical recovery and effluent pre-treatment is yet to be investigated.



### **3 THE ESTABLISHMENT OF A WATER AND WASTE MANAGEMENT PROGRAM**

#### **3.1 Introduction**

A recent publication by Agriculture Canada, Environment Bureau states that most dairy processors in Canada have implemented some form of effluent treatment in the past twenty years in response to high municipal sewage treatment charges, environmental regulations for rural-based plants and markets for by-products (Campbell, 1994). However, some relatively small dairy plants, restricted by location and space (such as the study model) have not yet implemented changes and are subject to public pressure to protect the environment and high sewage surcharge penalty imposed by publicly owned treatment facilities. Carawan (1992) also reported that more than 5% of all the milk received by a typical plant is lost into the sewer; and that more than 90% of dairy wasteload comes from milk or milk products. These data suggest that dairy processors lose profits by losing milk during processing and are charged for discharging the same milk into the sewer. This double loss profit scheme has enlightened processors to engage in either a water and waste management program or waste pretreatment (Mans, 1993). Some researchers believe that water and waste management is the first logical and economical step in the effort to curb product loss and the increasing surcharges (Carawan, 1992).

In view of the above, **the main objective of this chapter is to set up a water and waste management program at the study model site.** This will be

achieved using the following steps:

- A. The determination of the amount of water used in the plant.
- B. The determination of the pollution strength of products.
- C. A survey and evaluation of the plant and the determination of the strength of waste generated at different sites of the plant followed by the determination of the problem areas for investigation.
- D. The study of the corrective measures for the selected problem areas.

The selected problem areas studied were: (a) product returns, (b) sludge collected from the self-desludging separator and (c) milk collected from the milko-tester in the milk pasteurization area.

## **3.2 Methods and Materials**

### **3.2.1 In-Plant Evaluation**

#### **3.2.1.1 The Determination of the Amount of Water Used in the Plant**

There are two sources of water at the study model: city water and well water. The water meter reading of both sources were recorded hourly between 6:40 am and 12:55 am. The number of readings noted varied from day to day. City water was measured for a total of five days between the period of January and July of 1993. Well water was only measured three times between February and July of 1993 because of the lower variability in daily usage. The quality of the well water with regards to the mineral content was analyzed by Ecolab Chemical Company (St. Paul, Minnesota).

#### **3.2.1.2 The Determination of the Pollution Strength of Products**

The products produced at the study model include skim, 1%, 2% and whole milk, 10% cereal cream, 18% table cream and 35% whip cream, 5% and 10% butterfat (BF) soft serve ice cream mix, 10% white and chocolate ice cream mix, and different varieties of juices. All of the above products were subjected to COD, BOD, pH and suspended solids testing.

**3.2.1.3 A Survey and Evaluation of the Plant and the Determination of the Strength of Waste Generated at Different Sites of the Plant Followed by the Determination of the Problem Areas for Investigation**

The study model is located in a residential area of the inner city of Winnipeg. The model is a three level building with the ice cream freezing operation located in the basement, the mix/cream pasteurization operation and the packaging operation located on the first floor, and the fluid milk pasteurization operation located on the second floor.

The sewage lines of the whole building were examined; however, due to the multi-storey operation, difficulties were encountered in the segregation of the sewage lines for each operation. After careful examination, three accessible sites designated as areas A, B, and C were selected as the sampling sites. Area A is a collective drain including drains from the pasteurized milk storage area, drains from the mix pasteurizer, ice cream tanks, and packaging (except 1 liter and 2 liter machines) areas, drains from the case room and CIP system. Sewage collected from area B primarily consisted of effluents discharging from 1 liter and 2 liter packaging machines and cooling water from the engineering room. Area C collects effluents from the milk pasteurization area. The flow rate of each waste stream was not measured as a proper flow meter was not available.

From January to March of 1993, four 16 to 17 hour sampling trials were conducted at these sites. At each sampling site, a Masterflex peristaltic pump (Cole-Parmer Instrument Company, Niles, Illinois) operated continuously at a flow rate of 250-320 mL per minute. The effluents were collected in a 20 liter plastic pail. A

composite sample was taken every hour. The samples were cooled immediately and kept at 4°C before analyses. Analyses, including chemical oxygen demand (COD), pH and suspended solids, were conducted on all samples while biochemical oxygen demand (BOD) analysis was performed on selected samples for the determination of BOD/COD ratio. During the sampling period, any spillage, machine malfunctioning, and abnormalities were reported for further interpretation of the chemical analyses.

### **3.2.1.4 The Study of the Corrective Measures for the Problem Areas**

#### **3.2.1.4.1 Product Returns**

This problem area was eliminated through the management department of the study model. The impact of the elimination was evaluated by the composite samples collected during the months of January, February, and March (mentioned previously in step 3).

#### **3.2.1.4.2 Sludge Collected from Self-Desludging Separator**

A preliminary study was conducted on separator flushes. Separator flush is defined as the periodic discharge of sediments which is accumulated in the separator. The sediments include dirt particles, somatic cells, red and white blood cells and bacteria. The separator flush was analyzed for total solids, settleable solids and COD. In regards to separation analysis, the separator flush sample was subjected to a screening test using Tyler Canadian Standard sieves (St. Catherines, Ontario) with 105  $\mu\text{m}$ , 75  $\mu\text{m}$  and 63  $\mu\text{m}$  screen sizes respectively. Settleable solid determination was performed on all filtrate samples.

In addition, a centrifugation analysis was conducted on the separator flush samples to measure the settleability of the sediment. This analysis was performed using a modified solubility index test of milk powder. A similar methodology was applied to skim milk for comparative purposes. The analytical method involved pouring several well mixed 50 mL samples into Kimble conical graduated centrifuge tubes (Canlab, Mississauga, Ontario). Samples were then centrifuged using a Sorvall GLC-1 bench top centrifuge (Newtown, Connecticut) at various speeds and time periods. The volume of settleable solids was recorded as mL per 50 mL sample. The supernatants of all trials were analyzed for total solids and protein content.

#### **3.2.1.4.3 Milk Collected from the Milko-Tester in the Milk Pasteurization Area**

##### **Reclaim system**

Warm milk collected in a plastic funnel located at the A/S N. Foss milko-tester (A/S N. Foss Electric, type: 17410, Hillerod, Denmark) of the milk HTST system, was pumped through a 50 foot 1/8" inside diameter Tygon food grade plastic tubing (Baxter, Mississauga, Ontario) using a Masterflex peristaltic pump (Cole-Parmer Instrument Company, Niles, Illinois). The plastic tubing was secured by fittings and partially covered by vinyl tubing with a diameter of 0.75 inches and directed to the balance tank. The recycled milk is defined as the reclaim milk.

##### **Sample Collection**

Samples were collected at four sites in the milk pasteurization area. Raw milk samples were collected from the balance tank before (balance tank with or BTW) and

after (balance tank without or BTWO) the reclaim milk was re-introduced to the balance tank. In-line milk samples were also taken before the milko-tester line system. This sample site was located at the outlet line of the separator (separator out or SO). Samples were also aseptically collected at the end of the reclaim line (hose out or HO). The temperature of the milk at these four sites was measured using a BCR digital thermometer (Baxter Diagnostics Corporation, Canlab Division, Mississauga, Ontario) with a platinum probe. Samples were collected on days 1, 6, 11, and 21 of operation of the reclaim system. They were immediately frozen and allowed to thaw out a few hours prior to analyses. The parameters involved in this analysis included Standard Plate Count and Coliforms determination using Standard Plate Agar and Violet Red Bile Agar respectively.

### **Hydrolytic Rancidity**

Hydrolytic rancidity testing was performed using the method presented in the Standard Methods for the Examination of Dairy Products, 14th edition (Marth, 1978). This analysis measures the amount of fat hydrolyzed by lipase into fatty acids. The result of the analysis, known as the acid degree value (ADV), is defined as the proportion of fat neutralized by a known normality of potassium hydroxide titrant. In order to assure that the reclaim system lacked any significant effect on the activity of lipase at the site of the incorporation into the balance tank, the raw milk samples collected from the balance tank before and after the incorporation of the reclaim milk were subjected to hydrolytic rancidity testing. Milk and cereal cream which had been packaged and stored in retail cartons at 5.5-7.5 °C until the expired date were also collected for lipase activity testing. All the samples were frozen after collection and

thawed prior to analysis.

### **Shelf Life of Packaged Products (2% Milk and 10% BF Cereal) With and Without Reclaimed Milk**

The quality control department of the study model regularly analyzed packaged products for Standard Plate Count after 7 days of storage at a temperature range of 5.5-7.5 °C. Records of the Standard Plate Count on 2% milk (2 L size package) and 10% cereal (1 L size package) containing or not-containing reclaim milk were gathered for statistical analyses.

#### **3.2.2 Analytical Methods**

The chemical oxygen demand (COD) of all samples was determined by the test tube method described by Knechtel (1978). Reagents such as potassium dichromate, silver sulphate, mercuric sulphate, and potassium acid phthalate were obtained from Fisher Scientific Company (Fairlawn, New Jersey). Concentrated sulphuric acid was obtained from Mallinckrodt (Pointe-Claire, Quebec).

The analyses of settleable solids, suspended solids and biochemical oxygen demand (BOD) of all samples followed the methods outlined in the Standard Methods for the Examination of Water and Wastewater, 16<sup>th</sup> edition (American Public Health Association, 1985). The dilution water for BOD determination was prepared by fortifying deionized water with nutrient pouches supplied by HACH Company (Loveland, Colorado). The initial and final dissolved oxygen of all samples was measured using Orion oxygen meter (model 820, Orion Research Inc., Boston, Massachusetts).



The protein content of the centrifuged supernatant samples was determined by the standard assay procedure of Coomassie Blue protein assay (Pierce Chemical Company, Rockford, Illinois).

Total solids determination and hydrolytic rancidity analyses were performed using the method indicated in the Standard Methods for the Examination of Dairy Products, 14<sup>th</sup> edition (Marth, 1978). The chemicals used in the hydrolytic rancidity testing include Triton X-100, n-propanol and phenolphthalein (J.T. Baker Chemical Company, Phillipsburg, New Jersey); sodium tetrphosphate and potassium hydroxide (Fisher Scientific Company, Fairlawn, New Jersey); and methanol and petroleum ether (Mallinckrodt, Pointe-Claire, Quebec).

### 3.3 Results and Discussion

#### 3.3.1 The Determination of the Amount of Water Used in the Plant

As initially indicated, two sources of water (city water and well water) were used in the various operations of the study model. Analyses performed by Ecolab Chemical Company (Table 3) indicated that the well water contained extremely high dissolved solids; suggesting a high inorganic content. Individually, the amounts of iron, chlorides and sulfate were observed to be above the critical limit for the causing of staining, corrosion and filming of the machines. Therefore, well water, without any pre-treatment, was not recommended for use. At the time of this thesis preparation, well water was restricted to use as the cooling water during the transportation of cream from the separator to the cream holding tank (Appendices 1-3). The flow rate of the well water for this purpose varied, depending on the operator and the amount of cream produced. The hourly usage of well water ranged from 0.5 kL to 10 kL.

City water is used in all other functions of the dairy processing such as cooling water for machines, and water for washing, rinsing and sanitizing. The regular quantity of city water used on a production day averaged approximately 379 kL. This is, in contrast to, 41 kL of well water used during the same time period (Appendix 4). The model's hours of production varied from day to day, starting from 6 am and finishing between 7 pm and 10 pm. The consumption of city water during processing also varied from hour to hour as shown in Appendices 5 to 9. In general, the consumption of city water during the first 12 hours of production equalled the amount

Table 3. The composition of inorganics in well water.

Parameters	Well #1 (ppm) <sup>1</sup>	Well #2 (ppm) <sup>1</sup>	Problems associated if exceed units below <sup>1</sup>
Total Dissolved Solids	2,560	8,506	300-500 ppm - look for trouble
Iron	0.79	0.77	0.3 ppm & above - staining
Chlorides	632	3,350	250 ppm & above - corrosion
Sulfate	250	510	250 ppm & above - filming

<sup>1</sup> The analyses and proposed problems are supplied by Ecolab Chemical Company.

used for the wash-up of the machines during the night.

### **3.3.2 The Determination of the Pollution Strength of Products Produced**

Dairy effluents contain high levels of organic matter. This is usually reflected in the suspended solids, COD and BOD values. The study model manufactured products such as juices, fluid milk and cream, and a variety of ice cream mixes. As mentioned in the literature review, the loss of these products during processing took place either in (1) rinsing of all pipelines, pumps, processing equipment, tanks, trucks and filling machines, (2) start-up, product changeover and shut-down of HTST pasteurizers and filling machines, or (3) filling operations through equipment jams and broken packages (Jones, 1974). Therefore, the pollution strength of the products produced played an important role in the final make-up of the effluents. Common parameters such as pH, suspended solids, COD, BOD, and BOD/COD ratio contributing to pollution strength of most of the products manufactured in the study model are given in Table 4.

All dairy products tested had pH values ranging from 6.25 to 6.73. The protein content of dairy products was observed to be relatively constant. As shown in Table 4, a trend of increasing suspended solids values was observed, and correlated to the fat content (ranging from 600 mg/L in skim milk (0.1% BF) to 255,000 mg/L in whip cream (34% BF)). Higher suspended solids were observed in all ice cream mixes compared to fluid milk and cream with the corresponding fat content. The addition of stabilizers, emulsifiers and flavoring such as chocolate powder in the mix products might have contributed to the increased suspended solid values. Also, the COD and

Table 4. The pollution strength of the products produced in the study model.

Product	pH	Suspended Solids (mg/L)	COD (mg/L)	BOD (mg/L)	BOD/COD Ratio
Iced Tea	3.12	200	114,000	81,000	0.71
Apple Juice	3.74	100	125,000	95,000	0.76
Beep (orange drink)	2.98	2,000	144,000	101,000	0.70
Orange Juice	3.73	4,000	140,000	91,000	0.65
Skim milk (0.1% BF)	6.66	600	109,000	78,000	0.72
Milk (1% BF)	6.73	3,800	132,000	86,000	0.65
Milk (2% BF)	6.72	6,200	157,000	109,000	0.69
Homogenized Milk (3.2% BF)	6.58	10,300	199,000	128,000	0.64
Chocolate Milk (1% BF)	6.72	20,500	200,000	124,000	0.62
Cereal Cream (10% BF)	6.72	45,500	401,000	220,000	0.55
Table Cream (18%)	6.72	46,900	566,000	310,000	0.55
Whip Cream (34%)	6.76	255,000	1,062,000	563,000	0.53
Milk Shake (3.6% BF)	6.53	29,500	400,000	266,000	0.67
Vanilla Soft Serve (5% BF)	6.46	24,500	530,000	255,000	0.48
Vanilla Soft Serve (10% BF)	6.49	57,000	675,000	469,000	0.69
Chocolate Soft Serve (8.7% BF)	6.64	85,000	667,000	406,000	0.61
Ice Cream Mix (10% BF)	6.25	104,000	627,000	430,000	0.69
Chocolate Ice Cream (8.7% BF)	6.86	110,000	681,000	430,000	0.63

BOD values of dairy products increased with increments in the fat content. As compared to the literature findings (U.S. Environmental Protection Agency, 1971), the BOD values of various dairy products obtained in this study were slightly higher. The microorganisms involved in the analysis of BOD and the composition of the dairy products may be the causes of this discrepancy.

The COD and BOD values of juices primarily originate from carbohydrates since they are the principle component in juices. Having similar soluble solid content, all the juice products had similar level of COD values ranging from 114,000 to 144,000 mg/L. Orange juice products (orange juice and Beep) have a higher suspended solids content than iced tea and apple juice. This can be attributed to the differences in composition of these products.

The poor reproducibility, high biological sensitivity and the lengthy time required for BOD analysis has led to the industrial acceptance of COD analysis as the preferred method for the routine testing of pollution strength (U.S. Environmental Protection Agency, 1971). However, city officials from the Waterworks, Waste, and Disposal department still utilize BOD as the official method of representing pollution strength. The BOD/COD ratio of pure products of the study model fell within the range of 0.48 to 0.72. This is similar to the results cited in the literature (U.S. Environmental Protection Agency, 1971; Jones, 1974; Staal, 1981).

In general, compared to the maximum suspended solids and BOD (350 and 300 mg/L) permitted by the city of Winnipeg, Waterworks, Waste and Disposal department, all the products manufactured in the model constituted an extremely high pollution strength (Author. of Council of City of Winnipeg, 1988). Although spilled products were usually diluted with large amounts of water before discharging into the

sewer, the impact of this practice cannot be overstated as seen by the results shown in Table 4.

### **3.3.3 A Survey and Evaluation of the Plant and the Determination of the Strength of Waste Generated at Different Sites of the Plant followed by the Determination of the Problem Areas for Investigation**

The analyses of dairy effluents collected in selected areas (A, B and C) over a four day period during the months of January, February and March of 1993 are presented in Appendices 10 to 12 (a to d). The analyses included pH, suspended solids, and chemical oxygen demand (COD). Biochemical oxygen demand (BOD) on selected samples are tabulated in Appendix 13 for the determination of BOD/COD ratio.

The pH values usually reflect the composition of the effluents. For example, pH values higher than the neutral range suggest that alkaline detergents were in the sample. The near neutral pHs (6-7) indicate that milk products or water are the main constituents of the effluents and pH values in the acid range indicate either the presence of juice products or acid detergents.

The production schedule varied from day to day at the study model. Therefore, pH values reported in Appendices 10 to 12 (a to d) varied from hour to hour and from day to day. In general, area A (Appendices 10 a to d) represented the area where the mix pasteurizer, ice cream storage and processing tanks, jug (4 liter) and hamber (114 and 175 ml) packaging machines were located. High pH values were observed at mid-day and late at night in area A, indicating a mid-day and regular night wash-up of the mix pasteurizer (Appendices 10 a to d).

Area B consisted of drains from 1 liter and 2 liter packaging areas. Low pH

values were usually observed in the morning due to the production of juice products. Milk and chocolate milk products which were packaged during the course of the day (8:30 am to 8:00 pm) exerted close to neutral pH values (Appendices 11 a to d). High pH values were observed late in the evening, representing the beginning of the wash-up process. An occasional low pH observed during the day in area B was probably due to the sanitizer (Oxonia Active) which contained hydrogen peroxide and peroxyacetic acid.

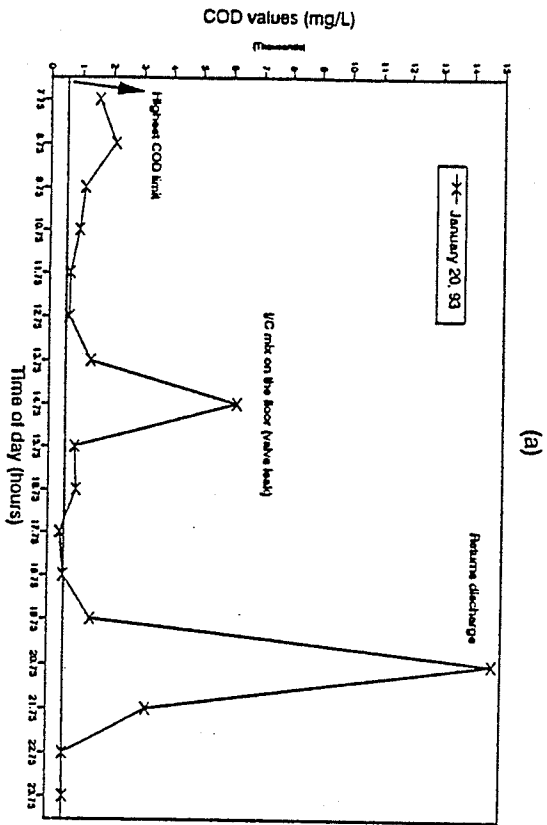
Area C covers the milk pasteurization area. Therefore, pH values of approximately 6 to 7 were mostly observed (Appendices 12 a to d). pH values ranging from 10-12 were observed when the pasteurizer was in wash-up at midday and after production.

Suspended solids of effluents in area A, B and C varied from hour to hour, and from day to day. Generally, the suspended solids values were positively correlated to the COD values. The suspended solid values in area C were higher than those observed in areas A and B with the same COD levels. This could be explained by the fact that the separator flush, contributing high suspended solids was discharged every 30 minutes in area C.

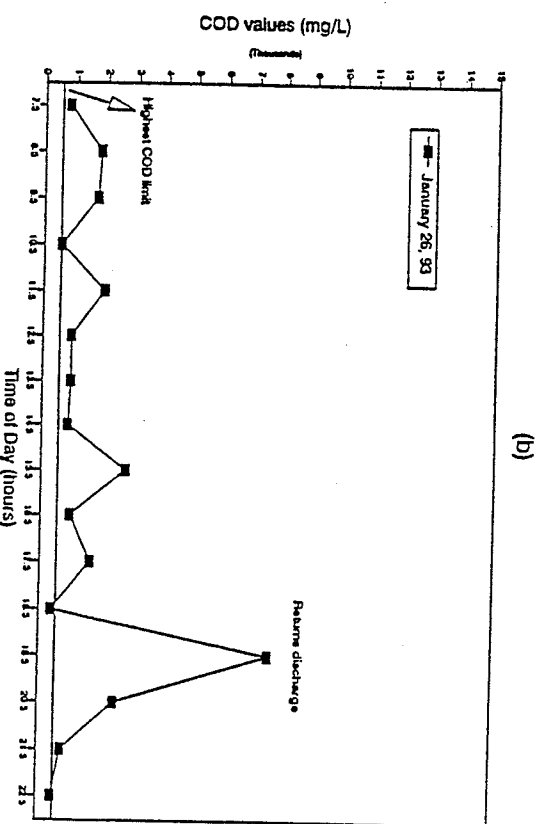
Chemical oxygen demand (COD) values of effluents reflected the severity of product spillage. Figs. 3 to 5 (a to d) illustrate the variation in COD values including the peaks attained due to accidents, machine breakdown or unnecessary practices. The COD loading showed variation from hour to hour, from day to day and from one sampling site to another. However, most of the effluents analyzed and presented in Figs. 3 to 5 (a to d) showed results exceeding the highest limit of 550 mg/L COD (equivalent to 300 mg/L BOD) allowed by the city of Winnipeg, Waterworks, Waste and



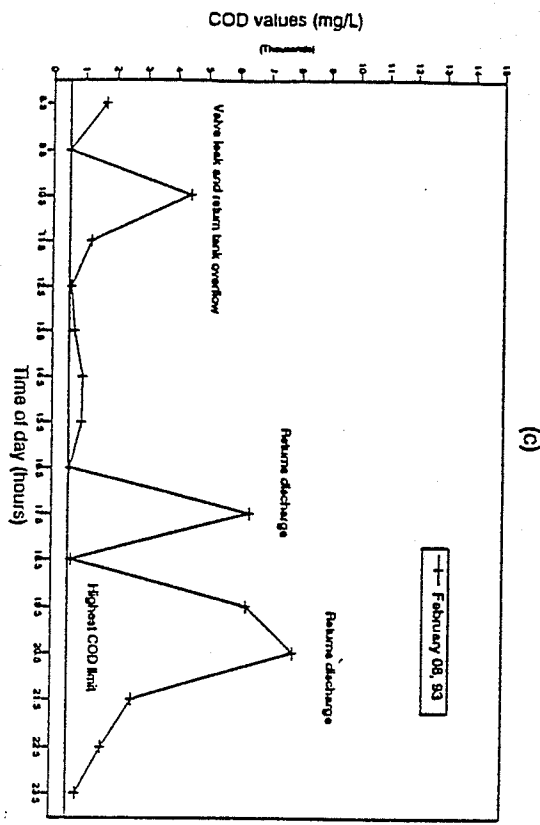
Figure 3. COD values of hourly effluent samples collected from area A which includes drains from pasteurized milk storage, mix pasteurizer, ice cream tank, packaging (except 1 liter and 2 liter machines), case room and CIP system areas on **(a) 20 January 1993, (b) 26 January 1993, (c) 08 February 1993** and **(d) 23 March 1993** and the possible source of operation for the peak COD values.



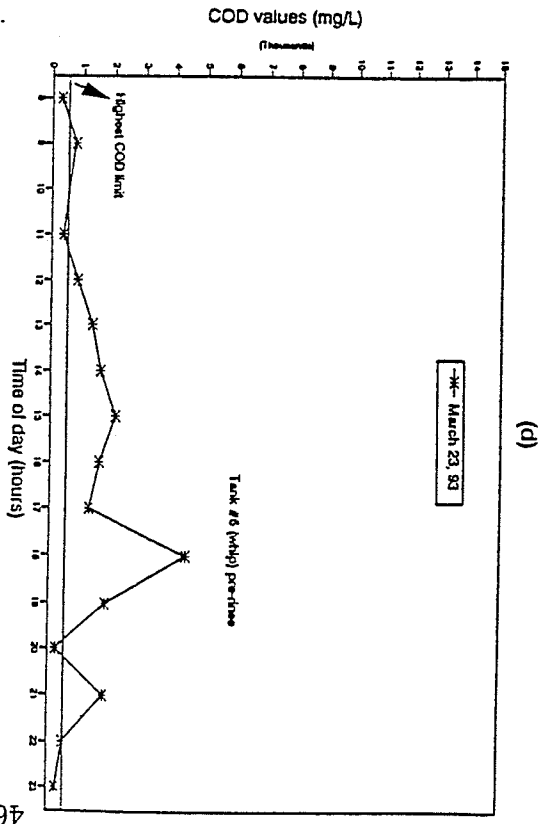
(a)



(b)



(c)



(d)

Figure 4. COD values of hourly effluent samples collected from area B which includes drains from 1 liter and 2 liter packaging machines and engineering room on (a) **20 January 1993**, (b) **26 January 1993**, (c) **08 February 1993** and (d) **23 March 1993** and the possible source of operation for the peak COD values.

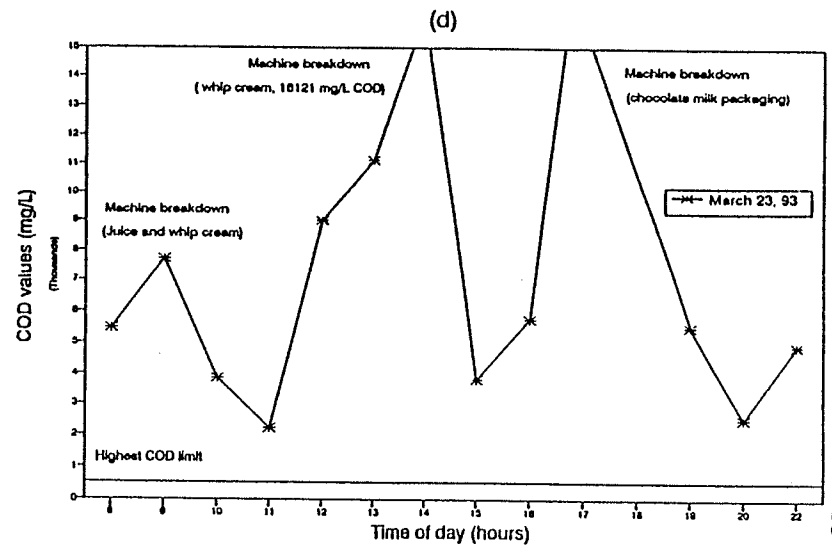
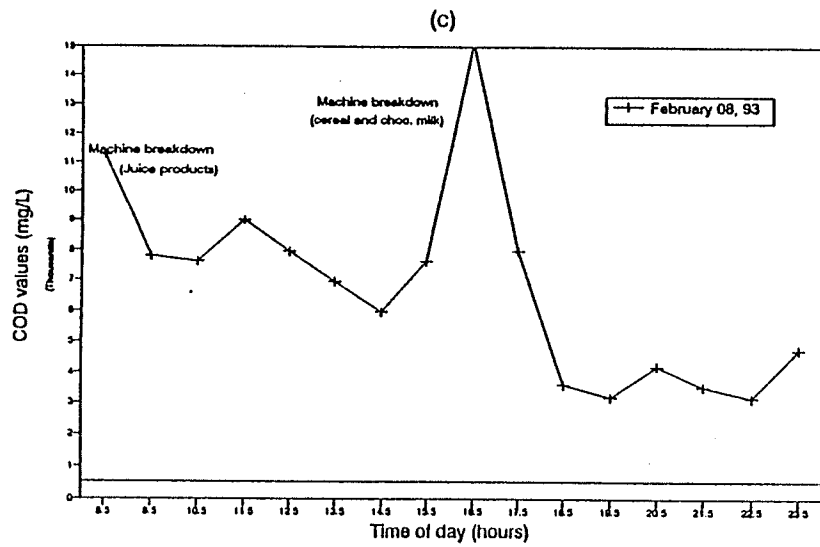
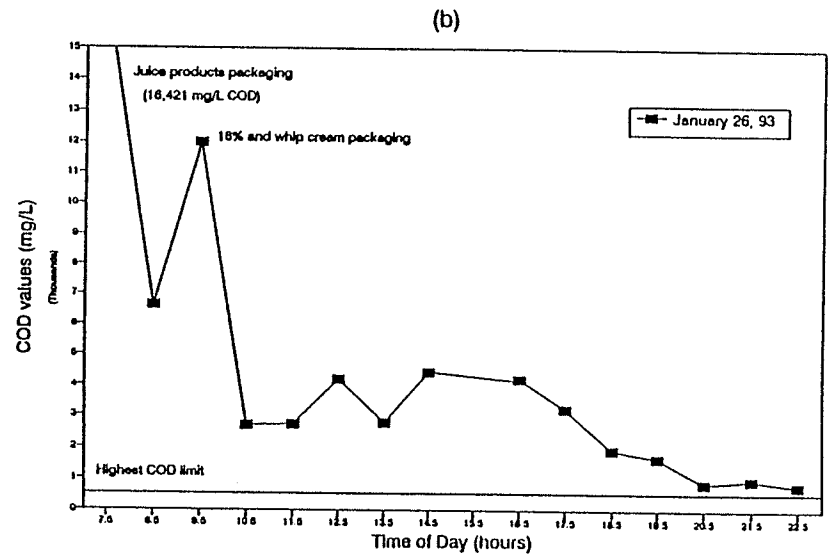
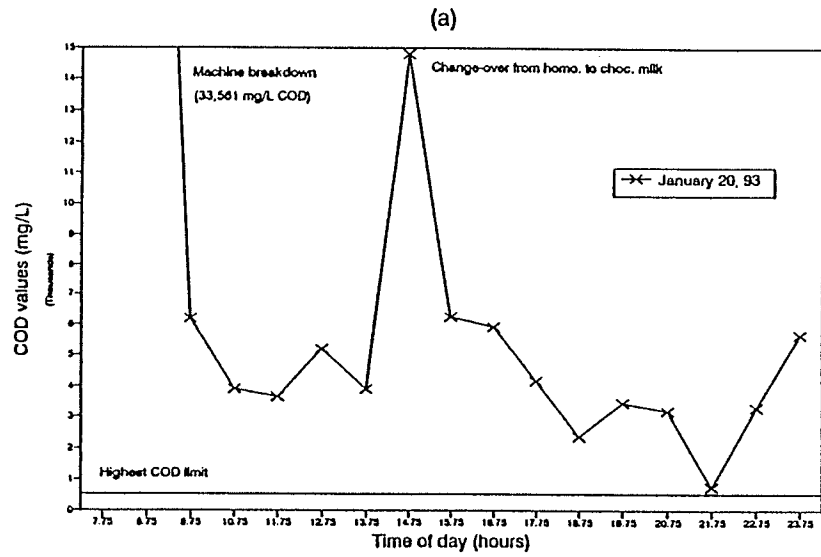
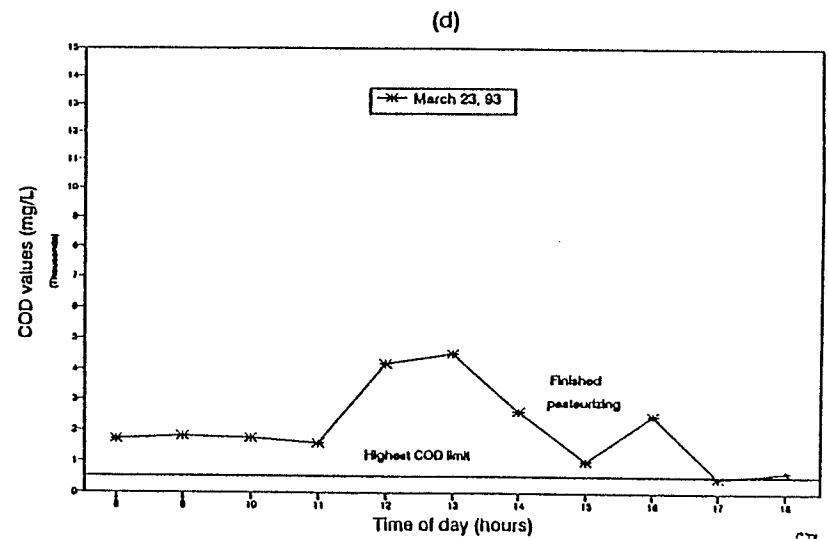
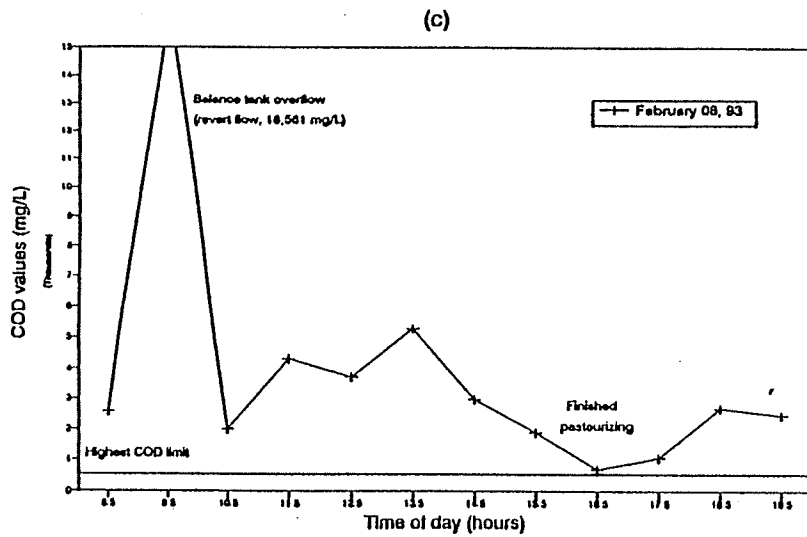
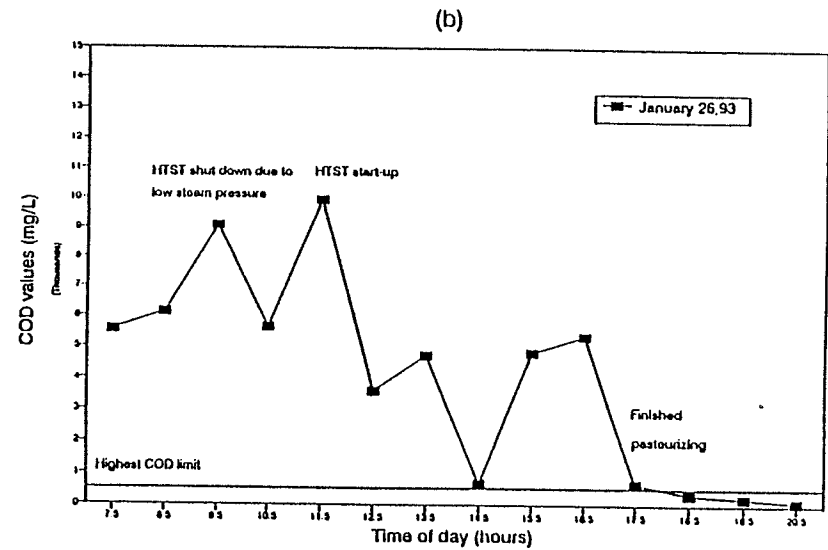
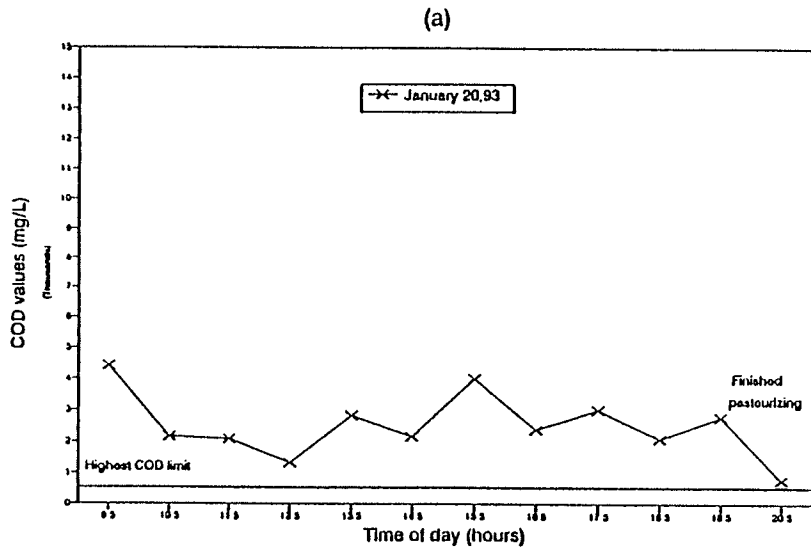


Figure 5. COD values of hourly effluent samples collected from area C which includes drains from the milk pasteurization area on **(a) 20 January 1993, (b) 26 January 1993, (c) 08 February 1993** and **(d) 23 March 1993** and the possible source of operation for the peak COD values.



Disposal department. This indicates a need for an improvement in the general practice of the dairy operation. Peaks indicating extremely high COD values were also identified. The cause of these peaks were investigated from the data collected during the sampling period.

The major problem area in area A was the expired products returned from the retailers. These products were discharged every day between 6:30 to 9:30 pm in the case receiving room. Peaks as high as 14,718 mg/L, 7,506 mg/L, and 7,784 mg/L were observed on January 20, January 26, and February 8 respectively (Appendices 10 a-c).

In area B, extreme high peaks were noted during the early morning hours when juices were packaged into 250 mL, 1 L and 2 L cartons. The normal practice for start-up and changeover of juice products was that the sanitizer-juice products were discharged into the sewer until the desired products was visually obtained. In addition, peaks were also found whenever there were machine break-downs. These were usually due to the spillage of products from the fillers.

In area C, random peaks were noted throughout the day. Spillage was mostly observed when the pasteurizer was in divert flow due to low temperature and pressure. The divert flow represents the milk which has not achieved the required heat temperature and time in the HTST is diverted back to balance tank for further pasteurizing. The discharge from the separator every half an hour and the discharge of excess milk from the milko-tester contributed to most of the COD and suspended solids observed in area C (Figs. 5 a-d).

The BOD values, the corresponding COD values and their ratios for selected samples are shown in Appendix 13. The BOD/COD ratio of the combined effluents exhibited a greater variability (0.28 to 1.04) than that of pure products. This

variability was reflected in the standard deviation value of 15.25. However, the average BOD/COD ratio obtained in this study (0.55) was within the range cited in the literature (U.S. Environmental Protection Agency, 1971; Jones, 1974; Staal, 1981).

### **3.3.4 The Study of the Corrective Measures for the Selected Problem Areas**

#### **3.3.4.1 Product Returns**

In area A, peaks were detected between 6:30 pm to 9:00 pm on January 20, 26 and February 8 of 1993 (Figs. 3a, b and c) when expired products were being discharged. These products, which were received everyday from the retailers, exhibited less than fresh qualities and were not suitable for reuse. An alternative route for their use was to dispense them to local farmers as animal feed. With implementation of this alternative, the COD loading dropped significantly (Fig 3d) with the highest COD value (1,811 mg/L) being obtained between 6:00 and 9:00 pm on March 23. This value was significantly lower than 14,718, 7506 and 7,784 mg/L observed on the days when returned products were discharged into the sewer.

The acceptability and digestibility of the expired products on the animals was not included in the scope of this study. No microbiological testing was performed on the expired products. In addition, the feeding program of these products adapted by the farmers was not known.

#### **3.3.4.2 Sludge Collected from Self-Desludging Separator**

The solids which collect in the sediment space of the separator of the HTST system consist of dirt particles, udder cells, white blood cells (leucocytes), red blood cells and bacteria (Teknisk Dokumentation, 1987). The self-cleaning separator is



equipped with an automatic ejection for accumulated sediments at 30 minute intervals. This discharge, with approximately 20 liters of skim milk contributes a COD value of 69,000 mg/L.

The separator flush was initially subjected to a screening test using Tyler Canadian standard sieves with three screen sizes (105, 75 and 63  $\mu\text{m}$ ) for sediment removal. This screening procedure was unsuccessful as the sediment was only partially removed by the finest screen size of 63  $\mu\text{m}$  (Table 5). In addition, the flow rate was reduced to zero shortly after the beginning of the process, suggesting that the screens were completely blocked by the sediment.

The separation of sediment using a laboratory scale centrifuge was also applied to the separator flush sample. As shown in Table 6, the removal of sediments reached a maximum at 1000 rpm after 15 minutes of operation. A centrifugation speed of 2,000 rpm for 5 minutes also resulted in a similar level of removal. After centrifugation at 1,000 rpm/15 mins and 2,000 rpm/5 mins, the supernatant constituted a total solid content of 9.13% and 9.15% respectively. This is comparable to that found in skim milk (9.09%) and as such, suggests a complete removal of sediments from the flush. The amount protein recovered from the above supernatant (2.85% and 2.88%) was found to be lower than that of skim milk (3.48%) (Table 6). This indicates that the centrifugation process might have forced some of the milk protein to deposit along with the dirt, blood cells and bacteria. Centrifugation at maximum speed and time (1,000 rpm/15 mins and 2,000 rpm/5 mins) had negligible effect on skim milk as their total solids and protein content remained constant.

Centrifugation proved to be better than screening for the removal of sediments from skim milk. The supernatant from centrifugation is equivalent to skim milk and

Table 5. The determination of settleable solids of separator flush after screening.

Mesh Number	Pore Size ( $\mu\text{m}$ )	Settleable Solids (mL/L)
No mesh	--	11
140	105	10
200	75	6
230	63	6

Table 6. Analyses of centrifugation separation of separator flush and skim milk.

Sample	Centrifugation parameter		Vol. of Sediment (mL/50 mL)	Total Solids	Protein
	Speed (rpm)	Time (min)		%	%
Separator Flush	--	--	--	9.77 (11.21) <sup>1</sup>	3.54 (4.07) <sup>1</sup>
	1000	0.5	4.25	8.79 (10.09)	3.16 (3.63)
	1000	2.5	4.75	8.50 (9.75)	2.97 (3.41)
	1000	5.0	5.25	8.39 (9.63)	2.63 (3.02)
	1000	10.0	7.25	8.09 (9.28)	2.57 (2.94)
	1000	15.0	7.25	7.96 (9.13)	2.48 (2.85)
	2000	2.0	4.00	8.20 (9.41)	2.53 (2.88)
	2000	5.0	7.00	7.97 (9.15)	2.51 (2.88)
Skim milk	--	--	--	9.09	3.48
	1000	15.0	Neg. <sup>2</sup>	9.14	3.48
	2000	5.0	Neg. <sup>2</sup>	9.10	3.47

<sup>1</sup> The total solids and protein (%) were adjusted with a dilution factor of 1.1475 (Cooling water at a flow rate of 300 mL/sec was collected simultaneously with the separator flush. The sampling time was recorded to be 1.5 second, representing 450 mL of cooling water was collected in a total volume of 3.5 L.).

<sup>2</sup> The volume of sediment observed was negligible.

as such may be recycled back to the balance tank as fluid milk. This can contribute up to 400 L in volume everyday. However, further studies on the protein content of the supernatant is required since the skim milk may be deficient in a particular milk protein.

#### **3.3.4.2.1 Economical Viability**

Various options such as a small scale continuous industrial decanter centrifuge, a small scale clarifier or a 20 L batch centrifuge can be considered as the apparatus for the recycling of skim milk for fluid milk processing. However, a initial study on the availability of the smallest scale continuous decanter centrifuge made by Tema Systems, Inc. which can handle a capacity of up to 13 L per minute seems to be too large for the operation. Further marketing research is needed as the annual savings of approximately \$127,000 on 400 liters of skim milk and the potential saving in surcharges should not be ignored (Table 7).

#### **3.3.4.3 Milk Collected from the Milko-tester in the Milk Pasteurization Area**

Warm milk heated to approximately 145°F (63°C) in the HTST regeneration section and standardized in the separator is pumped continuously through a dairy grade plastic hose (1/8" in diameter) to the milko-tester for butterfat testing. A small sample of milk is mixed with a diluent solution containing EDTA, Triton X-100 and an antifoaming agent for butterfat analysis. On completion of the analysis, this milk-diluent mixture is discarded. However, the chemical free surplus milk runs continuously into a collecting pail and is usually later discharged to the sewer. The

Table 7. Economics of the application of centrifuge method in the recirculation of separator flush.

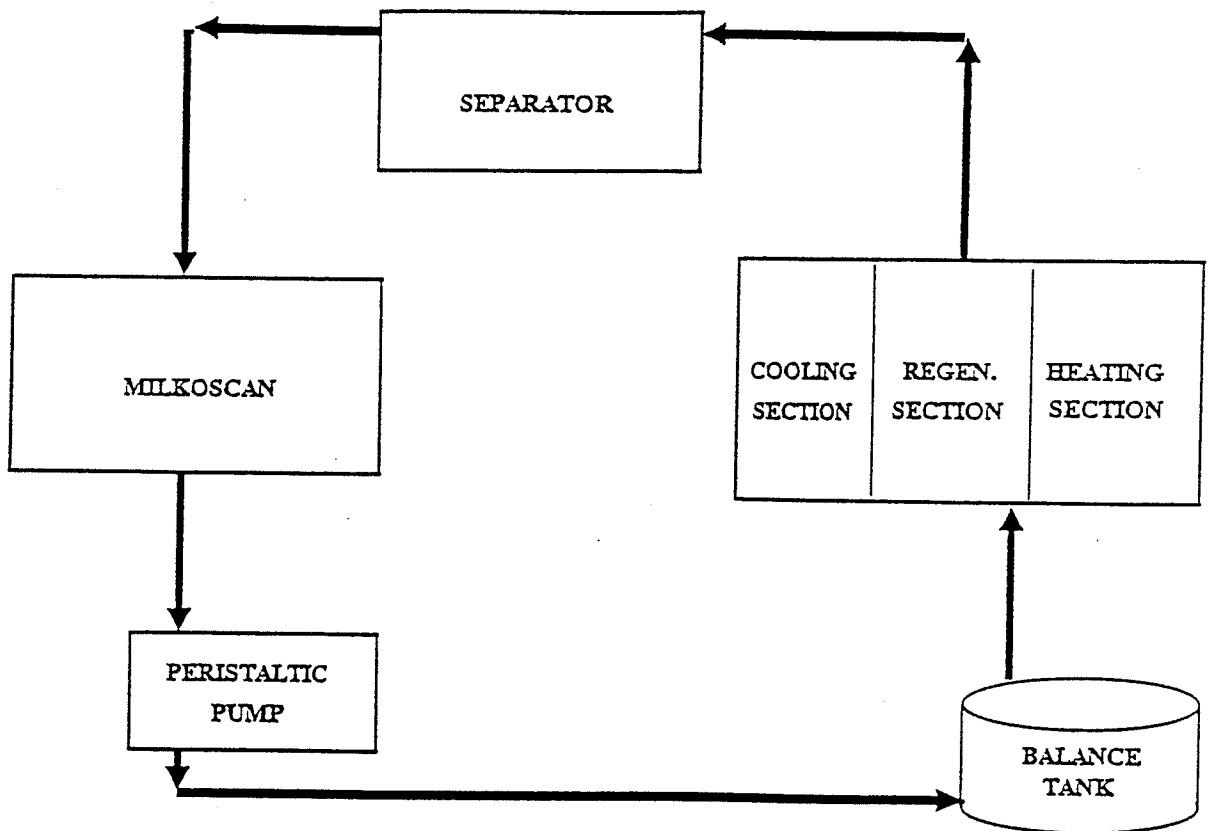
Parameter	\$
Cost:	
Centrifuge (eg. Tema decantor centrifuge, 3.5 gpm)	(U.S. 68,000) Can. 93,160
Savings (per year):	
Assumption: 400 L of skim milk per day	
1. Raw milk (raw skim milk was recycled and sold as product) Assumption: 3.7% BF Raw milk = \$58/100L BF = \$6/kg	36,660
2. Finished milk product (skim milk) Assumption: skim milk = \$0.9/L	90,720
Total savings annually:	127,380

amount of milk discharged through this system is about 60-70 liters per day.

Due to the elevated temperature of this milk sample (approximately 110 °F or 43°C), it is not desirable to store the sample for an extended period of time without refrigeration due to the possibility of accelerated microbial growth and enzymic changes. However, the immediate recirculation of the milk into the processing tank (i.e. milk balance tank) can serve to minimize the above changes. As shown in the schematic flow diagram (Fig 6), a reclaim system was set up to recirculate the chemical free surplus milk back to the balance tank through a 50 feet long dairy plastic tubing with the aid of a peristaltic pump.

The reclaim system is being cleaned with the HTST system during the clean-in-place (CIP) cycle. This included a pre-rinse with water and a pre-wash with 1% caustic (AC-101) solution at 140 °F (60 °C) for 30 minutes. This was followed by a rinse with water. The pre-wash cycle was usually performed at midday and at the end of production. The regular washing cycle, preceding the pre-wash cycle, was usually performed at speeds exceeding those used during the production. Active caustic (AC-101) along with Stabicip Therm at 1.7% and 0.7% concentrations were used in the washing cycle for a minimum time of 70 minutes at 183-185 °F (84-85 °C). This was followed by a 10 minute rinse at 140 °F (60 °C). After rinsing, the system was sanitized and soaked in 3000 ppm of Oxonia until the next operation. All the detergents mentioned in this section (4) were supplied by Ecolab Chemical Company (St Paul, Minnesota). Samples were periodically collected at the end of the reclaim line for microbiological analysis to ensure the safety of the reclaim line.

Figure 6. Schematic flow diagram of the reclaim system.



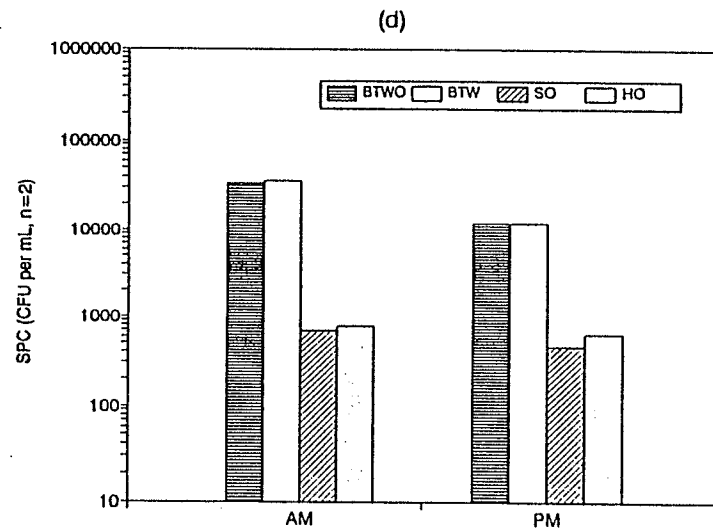
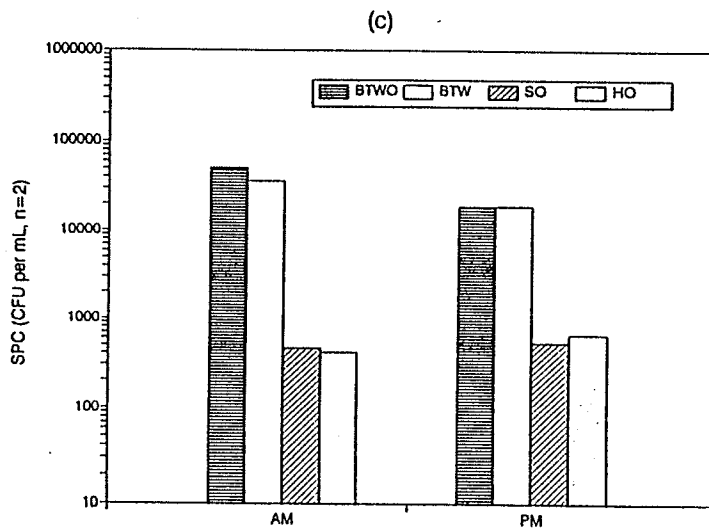
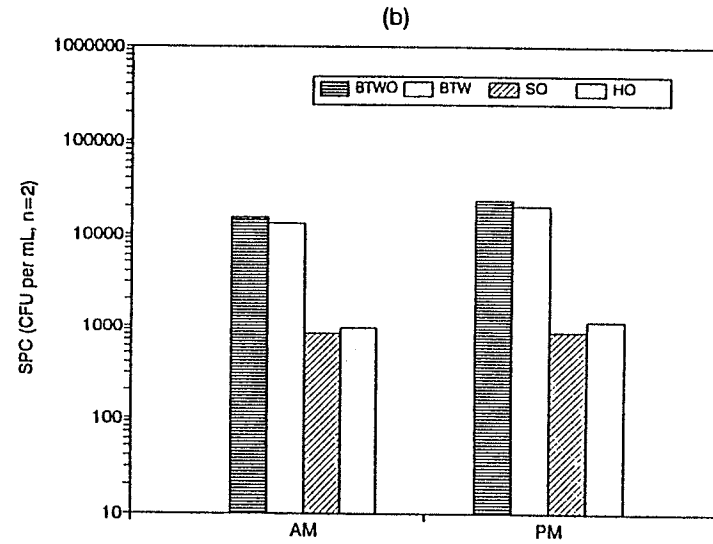
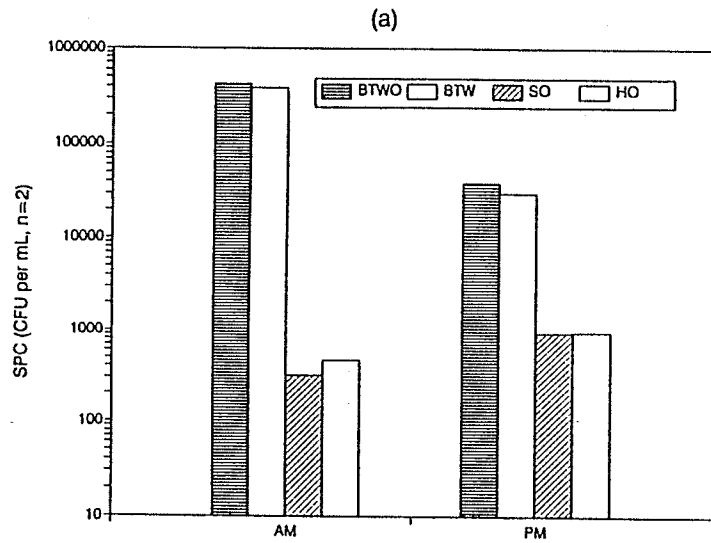


### 3.3.4.3.1 Microbiological Study

The microbiological analyses of the reclaim milk are tabulated in Appendices 14 (a to d). It was observed that the standard plate count (SPC) and coliforms count of all samples varied with the time and day of the experiment. The standard plate count of the balance tank samples either containing or not containing reclaim milk was in the range of  $10^4$  to  $10^5$  cfu/mL while the separator out and hose out samples, representing reclaim milk before and after the reclaim system, ranged at  $10^2$  to  $10^3$  cfu/mL. Based on the results shown in Figs. 7 (a-d) and 8, similar values were observed in SPC of balance tank samples either containing or not containing reclaim milk. The increase in SPC appeared to be negligible between the separator out and hose out samples. The coliform population of the balance tank samples was in the range of  $10^1$  to  $10^3$  cfu/mL. No coliform was detected in the separator out and hose out samples (Appendices 14 a to d). This indicated that all coliforms found in the balance tank samples were killed during the regeneration section of the HTST system. Similar values were shown in the coliform count between the balance tank with and without reclaim milk samples (Fig 8). A temperature drop of approximately 20 degree centigrade was noted when the milk was in the reclaim system with a residence time of about 1 minute (Appendix 15). The addition of the reclaim milk (40-45 °C) into the balance tank had no effect on the temperature of the resident milk (Appendices 14 a to d). This was probably due to the insignificant amount of reclaim milk being introduced into the balance tank.

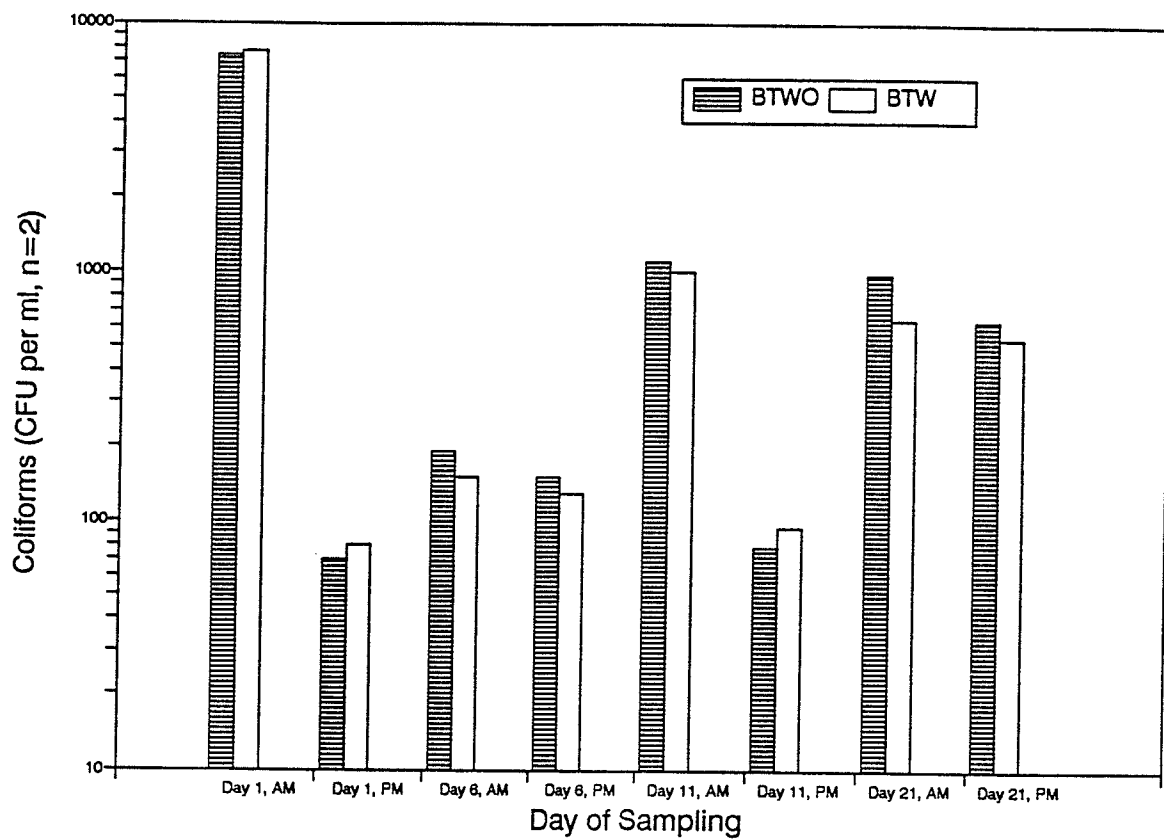
In view of these results, the lack of difference in the SPC and coliform count in the balance tank samples with and without reclaim milk indicates that the introduction of the reclaim milk from the milko-tester to the balance tank seemed to

Figure 7. Standard plate count of milk samples collected from the balance tank (with and without the incorporation of reclaim milk), the outlet of the separator and the end of the reclaim system on **(a) day 1, (b) day 6, (c) day 11** and **(d) day 21** of the operation of the reclaim system.



1. BTWO represented the sample collected from the balance tank without the attachment of the reclaim system.
2. BTW represented the sample collected from the balance tank with the attachment of the reclaim system.
3. SO represented the in-line sample collected from the outlet of the separator.
4. HO represented the sample collected at the end of the reclaim system.

Figure 8. The coliform count of milk samples collected from the balance tank with and without the incorporation of reclaim milk on day 1, 6, 11, and 21 of operation of the reclaim system.



1. BTWO represents the sample collected from the balance tank without the attachment of the reclaim system.
2. BTW represents the sample collected from the balance tank with the attachment of the reclaim system.

have no adverse microbiological effect on the milk. The absence of coliforms and the relatively constant standard plate count in the separator out and hose out samples suggested that no contamination occurred in the system. The relatively short residence time of approximately 1 minute aided in the efficiency of the recycling process and prevented microbial growth.

In regards to the 7 days shelf life study, a higher SPC was observed in 2% milk without the incorporation of reclaim milk. This trend was reversed in the case of 10% cereal cream. The high standard deviation reported in Table 8 was likely due to the nature of the dairy operation - susceptibility to human and machine variability. The findings from the shelf life studies of 7-day old samples of 2% (2 L cartons) and 10% cereal (500 ml and 1 L cartons) in Table 8 substantiates the statements that the introduction of the reclaim milk had no long term microbiological effects on either low or high fat milk products.

#### **3.3.4.3.2 Enzymatic Activity Study**

Lipase, a lipolytic enzyme naturally present in milk, is responsible for the hydrolysis of lipids into glycerol and free fatty acids. The hydrolysis of triglycerides carrying butyric acids results in the development of a rancid flavor. The lipolytic activity is facilitated by agitation and homogenization where fat is exposed through the destruction of the globular membrane (Riel, 1985). Also, the addition of warm milk to unpasteurized cold milk promotes lipolysis. This is supported by the hypothesis which states that when warm milk (at 30 °C) is cooled slowly, triglycerides which are susceptible for lipolysis tends to move towards the periphery.

Hydrolytic rancidity testing measures the amount of fat hydrolyzed by lipase

Table 8. Shelf life study (SPC) on 7 day 2% milk and 10% cereal samples.

Sample	Sample Size (n)	Sampling period	With/ without reclaim milk	SPC <sup>1</sup> (cfu/mL)
2% milk	37	Feb 22 - Apr. 15	Without	122.70 ±179.14
2% milk	37	Apr. 16 - Jun. 08	With	102.08 ±183.71
10% cereal	18	Feb. 22 - Apr. 15	Without	66.94 ±49.42
10% cereal	20	Apr. 19 - Jun. 28	With	77.50 ±50.21

<sup>1</sup> The SPC of each day was an average of two samples.

into fatty acids. According to the Standard Methods for the Examination of Dairy Products, 14<sup>th</sup> edition (Marth, 1978), the interpretation of results in terms of acid degree value (ADV, the amount of 1N base required to titrate 100 g of fat) is listed as follows:

less than 0.4 = Normal

0.7 - 1.1 = Borderline (indefinite)

1.2 = slight rancidity

1.5 and above = Unsatisfactory (extreme hydrolytic rancidity)

Balance tank samples containing and not containing reclaim milk collected during the microbiological study were also subjected to hydrolytic rancidity analysis. The average acid degree values (0.89 and 0.88) shown in Appendix 16 indicates negligible differences between samples in the presence and absence of the reclaim milk. The acid degree value of 2% milk and 10% cereal cream samples was measured on the date of expiration of the samples (Appendix 17). Similar values (0.70 and 0.71 respectively) were observed in the average ADV of the 2% milk samples and 10% cereal cream samples with and without the incorporation of the reclaim milk. The balance tank samples (Appendix 16) exhibited a higher lipase activity than the pasteurized samples (Appendix 17). This finding supports the statement cited in the literature that pasteurization inactivates lipase (Riel, 1985).

#### **3.3.4.3.3 Economics of the application of reclaim system**

In view of the above results, the reclaim system provided no adverse microbiological and enzymatic effect to the processed milk. The application was also economically sound since the savings obtained from it far exceeded the cost of



implementation in only one month (Table 9). A total of about \$23,000 could be saved annually on the cost of milk alone. Additional saving could be obtained from the reduction of sewage surcharges due to the application of this reclaim system.

Table 9. Economics of the application of reclaim system.

Parameter	\$
<b>Cost:</b>	
1. Start-up	
Masterflex peristaltic pump	750.00
Dairy grade tubing (1 package, 50 ft per package)	33.00
2. Monthly maintainence	
Dairy grade tubing	3.30
3. Monthly energy cost of pump (3.80 kwh/day, \$ 0.056/kwh)	4.46
<b>Total cost (first month):</b>	<b>790.76</b>
Savings (21 production days per month):	
Assumption: 65 L of 2% milk was saved per day	
1. Raw milk (Class 1, \$58/100L) Assumption: BF = \$6/kg	648.00
2. Finished 2% milk Assumption: 2% milk = \$1.0/L	1,365.00
<b>Total savings in a month:</b>	<b>2,013.00</b>

## **4 CHEMICAL RECOVERY AND PRETREATMENT OF DAIRY EFFLUENTS BY POROUS STAINLESS STEEL (MICROSTEEL) MEMBRANE SYSTEM**

### **4.1 Introduction**

Dairy plants spend large sums of money on chemicals and water for cleaning dairy equipment in an effort to avoid plant and product contamination. However, as the world strives to protect the environment and conserve water resources, governments are imposing higher costs on water and waste discharges and are also instituting more stringent restrictions on the presence of organic matter and chemicals in industrial wastewater. The most common chemicals (detergents and sanitizers) used in dairy industry include caustic soda (NaOH), sodium hypochlorite (NaOCl), phosphoric acid ( $H_3PO_4$ ) and nitric acid ( $HNO_3$ ). These chemicals exert several harmful effects to the environment. For example, their extreme pHs have been shown to offset the natural environment of living organisms as well as the efficiency of chemical coagulation and biological treatment (Sawyer and McCarty, 1978). The ratio of sodium to total cations in water is important in agriculture and human pathology. High sodium concentration in water has been shown to damage soil permeability and cause physiological problems in people with cardiac, renal or circulatory diseases (American Public Health Association, 1985).

As the dairy industry enlightens itself on water and waste conservation, a newly developed Microsteel membrane system has been proposed as a means of chemical

recovery. This system was developed using porous stainless steel materials (0.1-0.2  $\mu\text{m}$ ). Porous stainless steel can withstand an extreme temperature of 250 °F (121 °C), and the extreme pH values characteristic of the cleaning agents used in clean-in-place (CIP) systems (Membrane System Specialists, 1993). The overall objective of this investigation was to evaluate the strength of detergents (starting materials), permeate and retentate obtained from the use of the Microsteel membrane system. Also, recent literature has indicated the possibility of using membrane technology as an option for effluent pretreatment and solids recovery (Weber & Bowman, 1986). This possibility was also evaluated.

**The specific objectives of this study were to:**

- A. evaluate the efficacy of the Microsteel membrane system as a means of chemical recovery.
- B. investigate the use of Microsteel membrane system for COD reduction leading to a decrease in surcharges.
- C. evaluate the improvement of organic matter removal and pollution strength reduction with the use of a chemical coagulant in the microfiltration process.
- D. compare the removal of organic matter and the reduction of pollution strength by the Microsteel membrane system and a simulated ultrafiltration system.

## 4.2 Methods & Materials

### 4.2.1 Micro-Steel Membrane System

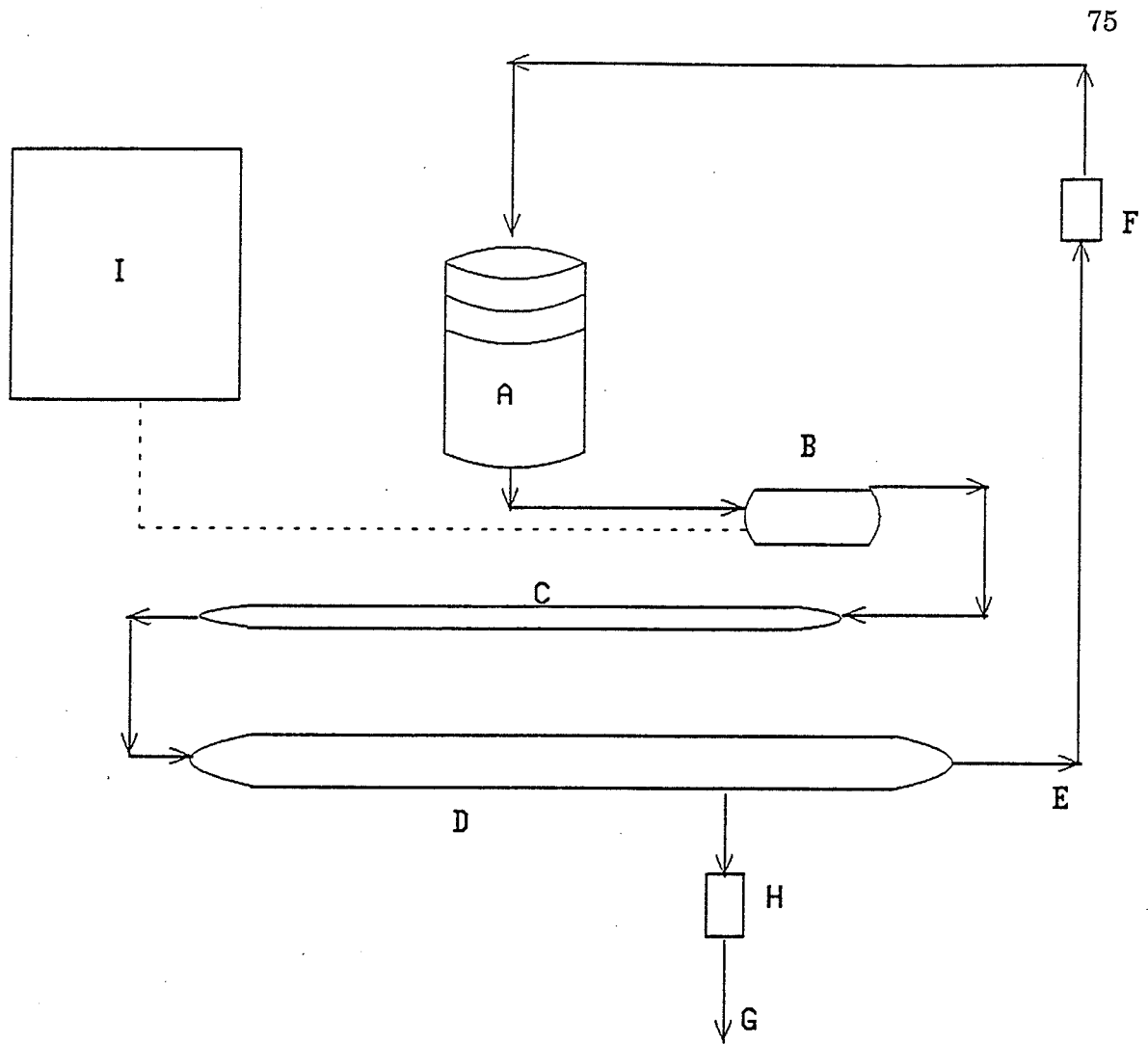
A micro-steel membrane system, supplied by Membrane System Specialists (Wisconsin Rapids, Wisconsin), was on loan between the period of September 20 to October 10, 1993. This system is a pilot unit containing a 4' by 2" stainless steel membrane vessel with four membrane tubes and a pore size of 0.1  $\mu\text{m}$ . As shown in the schematic flow diagram (Fig. 9), the unit is a self contained system complete with balance tank, pump, heat exchanger, pressure vessel, valves and gauges. Air supply is required for backflushing. The system operates at an infeed rate of 70 gallons (265 L) per minute at a pressure of up to 150 psi (10.55 kg/cm<sup>2</sup>).

All batches in this study were run at a frequency drive setting of 50; which is equivalent to 45-106 psi (3.16 - 7.45 kg/cm<sup>2</sup>) infeed pressure, 35-87 psi (2.46 - 6.12 kg/cm<sup>2</sup>) back pressure, 110-1,400 ml/min permeate flow rate and 32-58 gallons/min (121-220 L/min) concentrate flow rate. The variations in these parameters were due to the differences in solids content, viscosity and temperature of the samples.

#### 4.2.1.1 Chemical Recovery

During the loan period, 6 batches of spent CIP (clean in place) solution (100 kg in capacity each) which were collected after the wash cycle were used to assess the ability of the Microsteel membrane system to recover the different chemicals used in the dairy industry. The types of detergent, their recommended strength before use

Figure 9. Schematic flow diagram of Microsteel membrane system.



- A = balance tank
- B = centrifugal pump
- C = heat exchanger
- D = membrane tube
- E = retentate flow
- F = retentate pressure gauge
- G = permeate flow
- H = permeate pressure gauge
- I = control panel

and their suppliers are listed in Appendix 18.

In the study of chemical recovery, the permeate/retentate concentration ratio which indicates the volume ratio of the permeate and retentate portion, ranged from 4:1 to 8:1. Samples were collected from the starting materials, permeates and retentates. Also, a fresh sample which represents a detergent before the wash cycle was collected on one occasion. All samples were subjected to total alkalinity, acidity, active caustic, pH, and free stabicip testing analyses whenever applicable. Compositional analyses including total solids, ash, fat, protein and total carbohydrates as well as COD and suspended solids were also performed on starting material and permeate samples. The % removal of the above parameters was calculated using the formula described in Appendix 19.

#### **4.2.1.2 Effluent Pretreatment**

As listed in Table 10, various starting materials such as 2% milk, vanilla ice cream, 1% BF chocolate milk, and orange juice/iced tea were used in the study of effluent pretreatment. These starting materials were diluted to two strength COD values (1,000 and 3,000 mg/L COD) prior to each trial run. In addition, actual wastewater (diluted ice cream, separator flushes, effluents #1 and #2) obtained from the study model was applied to the Microsteel membrane system. Ice cream with various flavors (french cherry, strawberry and chocolate) obtained from a production day was collected, combined and diluted to a ratio of 1:9 prior to the microfiltration treatment. Separator flushes are skim milk flushing out regularly from the separator of the HTST system for the purpose of removing blood cells, somatic cells, udder cells, dirt and straw which were built up inside the separator (Teknisk Dokumentation,



Table 10. Various starting materials applied in the effluent pretreatment study.

Starting Materials	COD (mg/L)
<b>(1) Controlled Dairy Products</b>	
2% Milk	1,000 & 3,000
Vanilla ice cream	1,000 & 3,000
1% BF chocolate milk	1,000 & 3,000
<b>(2) Dairy Effluents</b>	
Separator flushes	90,938
Flavored ice cream (diluted)	52,799
Effluent #1	18,746
Effluent #2	18,615
<b>(3) Controlled Juices</b>	
Orange juice/iced tea	1,000 & 3,000

1987). Effluents #1 and #2 contained a combination of ice cream, rinse water from the storage tank, HTST, and packaging machine and cooling water from air compressors.

The permeate/retentate concentration ratio varied from 1:1 to 6:1. Samples were collected from the starting materials and permeates. All samples were analyzed for total solids, ash, suspended solids, chemical oxygen demand (COD), fat, protein and carbohydrates.

#### **4.2.1.3 Chemical Coagulation**

The chemical coagulant zinc chloride ( $ZnCl_2$ ) supplied by Mallinckrodt (Pointe-Claire, Quebec) was applied to diluted 2% milk (3,000 mg/L COD), and vanilla ice cream respectively (3,000 mg/L COD) prior to the microfiltration process. A dosage of 5% in volume of 5% strength zinc chloride was mixed with both samples in the balance tank of the Microsteel membrane system using a Lightnin mixer model #10 (Toronto, Canada) at level 5. The mixing rpm was later reduced to level 2. The solution was continually stirred for 5 minutes after the addition of 1N sodium hydroxide (NaOH; Millinckrodt, Point-Claire, Quebec) to adjust each sample to a final pH of 8-8.5. The microfiltration process proceeded after visual flocculation was identified. The starting material and permeate samples were analyzed for parameters similar to those of the effluent pretreatment study.

#### **4.2.1.4 Ultrafiltration System**

Microfiltered diluted 2% milk, vanilla ice cream, chocolate milk, and juice (permeate streams from the effluent pretreatment study, all at 3,000 mg/L COD) were

subjected to an ultrafiltration process. The ultrafiltration system consisted of an Amicon model# 8200 stirred ultrafiltration cell and a Diaflo ultrafiltration membrane (Danvers, Massachusetts) (62 mm dia.) with a pore size of 10,000 molecular weight cut-off.

The stirred ultrafiltration cell was placed on a Corning PC 351 stirrer (Mississauga, Ontario) and operated at 55 psi (3.87 kg/cm<sup>2</sup>) with a flow rate of 4.2 mL/min.. The microfiltered and ultrafiltered permeate samples were subjected to similar compositional and pollution strength analyses as the effluent pretreatment study.

#### 4.2.2 Analytical Methods

The acidity, active caustic and free stabcip testing of the chemical recovery samples followed the procedures and test kits provided by Ecolab Chemical Company (St Paul, Minnesota). The pH analysis was performed with Accumet pH meter model #910 (Fisher Scientific Company, Fairlawn, New Jersey).

The analyses of total alkalinity, total solids, ash, and suspended solids of all samples followed the methods outlined in the Standard Methods for the Examination of Water and Wastewater, 16<sup>th</sup> edition (American Public Health Association, 1985).

Soxhlet extraction method outlined in the standard methods (American Public Health Association, 1985) was used for the analysis of fat. However, in place of trichlorotrifluoroethane, hexane served as the extraction solvent. The determination of carbohydrates (primarily hexoses) was based on a colorimetric method using phenol and sulfuric acid (Benfield and Randall, 1976). The samples were first filtered through Whatman GF/C glass microfibre filter to remove all suspended solids.

carbohydrates using sep-pak C<sub>18</sub> cartridges (Waters Chromatography Division, Milford, Massachusetts).

The chemical oxygen demand of all samples was determined by the test tube method described by Knechtel (1978). Regents such as potassium dichromate, silver sulphate, mercuric sulphate and potassium acid phthalate were obtained from Fisher Scientific Company (Fairlawn, New Jersey) and concentrated sulphuric acid was obtained from Mallinckrodt (Pointe-Claire, Quebec).

The protein content of all samples was determined by the micro assay procedure of Coomassie Blue protein assay (Pierce Chemical Company, Rockford, Illinois). LKB Blochrom ultrospec II Spectrophotometer (Cambridge, England) was used to measure the absorbance of all test samples for carbohydrate (490 nm), COD (600 nm) and protein analyses (595 nm).

## 4.3 Results and Discussion

### 4.3.1 Chemical Recovery

In current food industry practice, used detergents are discharged either after every use or everyday. Reports have shown that such disposal of chemicals is economically unsound. Efforts to reduce these losses have led to the application of the Microsteel membrane technology to chemical recovery (Membrane System Specialists, 1993). The primary function of the Microsteel membrane system with respect to chemical recovery is the removal of all suspended solids and most of the "soil" from used detergents while maintaining the initial chemical strength of the detergents. However, in order to recycle and use the detergents for further cleaning, the suspended solids free permeate needs to be standardized for the lost chemical strength. As claimed in the literature (Membrane System Specialists, 1993), over 80% in volume of the original caustic solution can be recovered .

A routine cleaning system consists of four components: post soil rinse, detergent wash, post-detergent rinse and pre-soil sanitizer. The post soil rinse greatly contributes to the removal of milk components since most of the milk components remain unattached on the machine surface (Dunsmore et al, 1981). The function of the detergent wash is to remove milk components remaining after the post soil rinse including those which have been absorbed onto the machine surface. During this process, alkaline detergent components such as caustic (sodium hydroxide), and chlorinated alkali (Liquid Super Klenz), exert some cleaning actions by reacting with

fat and grease to form soaps (saponification), breaking down proteins into peptides (peptization), and reacting with carbohydrates to form simpler and more soluble fragments (hydrolysis). Acids are also used as detergents during washing. Acid detergents such as nitric acid and phosphoric acid (AC Special) are used to prevent or remove mineral deposits (Ecolab Chemical Company, 1990).

The chemical strength (such as % caustic, total, hydroxide and carbonate alkalinity, % acidity, % free Stabicip and pH) of the starting material, permeate and retentate of all batches is indicated in Tables 11a to 16a. Tables 11b to 16b present the composition and the pollution strength of the starting material and the permeate as well as the percent removal of these batches.

#### **4.3.1.1 AC 101 (Caustic)**

The primary detergent used for the cleaning of HTST systems is sodium hydroxide (caustic). The strength of sodium hydroxide is usually represented as % active caustic or total alkalinity. Percent active caustic indicates the % hydroxide ion (OH<sup>-</sup>) in the solution. Total alkalinity is a measurement of the acid neutralizing capacity of the detergent and accounts for anions such as hydroxides, carbonates and bicarbonates. Contributions from borates, phosphates, silicates or other bases may also be included in the measurement (American Public Health Association, 1985). However, the main cleaning parameter in total alkalinity is the hydroxide (OH<sup>-</sup>).

The % caustic in the starting material and permeate samples in Tables 11a and 12a were 2% and 0.8% respectively. These results were higher than the recommended strength for regular wash and prewash as listed in Appendix 18. This reflects inaccuracies during the preparation of fresh detergents by operators. However, despite

Table 11a. Chemical recovery study 1: Chemical strength of used CIP wash with stabicip (from mix pasteurizer).

Parameters	Starting Materials	<sup>1</sup> Permeate	Concentrate
Total Alkalinity (mg/L CaCO <sub>3</sub> )	25,227	25,250	25,180
OH <sup>-</sup> (mg/L)	22,501	22,250	23,010
Carbonate (mg/L)	2,726	3,000	2,170
Active Caustic (%)	2	2	2
Free Stabicip (%)	1.4	1.1	1.06
pH	13.27	13.27	13.20

Table 11b. Chemical recovery study 1: Composition and their respective % removal used CIP wash with stabicip (from mix pasteurizer).

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	31,679	31,094	13
Ash	18,073	19,208	6
Suspended Solids	78	52	41
COD	5,832	4,806	27
Fat	54.72	<1	>98.38
Protein	36.70	13.29	67.82
Carbohydrate	26.20	23.75	19.43

<sup>1</sup> The permeate/retentate concentration ratio was 8:1.

Table 12a. Chemical recovery study 2: Chemical strength of pre-wash solution from mix pasteurizer.

Parameters	Starting Materials	<sup>1</sup> Permeate	Concentrate
Total Alkalinity (mg/L CaCO <sub>3</sub> )	4,438	4,450	4,340
OH <sup>-</sup> (mg/L)	3,562	3,880	989
Carbonate (mg/L)	876	570	3,351
Active Caustic (%)	0.8	0.8	0.7
pH	12.14	12.16	12.10

Table 12b. Chemical recovery study 2: Composition and their respective % removal of pre-wash solution from mix pasteurizer.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	9,995	9,725	12
Ash	9,583	9,431	12
Suspended Solids	47	4	92
COD	345	284	27
Fat	22.37	<1	>96.02
Protein	14.79	2.98	82.07
Carbohydrate	14.77	8.55	48.48

<sup>1</sup> The permeate/retentate concentration ratio was 8:1.



Table 13a. Chemical recovery study 3: Chemical strength of used Super Klenz from CIP tank (September 23, 1993).

Parameters	Starting Materials	<sup>1</sup> Permeate	Concentrate
Total Alkalinity (mg/L CaCO <sub>3</sub> )	2,050	2,075	1,848
OH <sup>-</sup> (mg/L)	950	1,000	545
Carbonate (mg/L)	1,100	1,075	1,302
Free Chlorine (mg/L)	160	165	120
pH	11.97	11.99	11.94

Table 13b. Chemical recovery study 3: Composition and their respective % removal of used Super Klenz from CIP tank (September 23, 1993).

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	3,458	3,292	15
Ash	3,180	2,994	16
Suspended Solids	32	0	100
COD	523	393	33
Fat	22.67	3.75	85.28
Protein	7.66	<1	>88.38
Carbohydrate	20.50	20.47	11.13

<sup>1</sup> The permeate/retentate concentration ratio was 8:1.

Table 14a. Chemical recovery study 4: Chemical strength of used Super Klenz from tanker wash bay (September 24, 1993).

Parameters	Starting Materials	<sup>1</sup> Permeate	Concentrate
Total Alkalinity (mg/L CaCO <sub>3</sub> )	5,800	5,820	5,725
OH <sup>-</sup> (mg/L)	2,800	3,125	1,500
Carbonate (mg/L)	3,000	2,695	4,220
Free Chlorine (mg/L)	800	800	800
pH	12.29	12.29	12.29

Table 14b. Chemical recovery study 4: Composition and their respective % removal of used Super Klenz from tanker wash bay (September 24, 1993).

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	8,709	8,730	20
Ash	8,396	8,268	21
Suspended Solids	21	0	100
COD	1,006	901	28
Fat	68.29	<1	>98.83
Protein	20.27	<1	>96.05
Carbohydrate	85.31	<10	>90.62

<sup>1</sup> The permeate/retentate concentration ratio was 4:1.

Table 15a. Chemical recovery study 5: Chemical strength of used Super Klenz from CIP tank (October 1, 1993).

Parameters	Fresh Sample	Starting Materials	<sup>1</sup> Permeate	Concentrate
Total Alkalinity (mg/L CaCO <sub>3</sub> )	2,350	1,850	1,800	2,050
OH <sup>-</sup> (mg/L)	1,200	975	1,066	611
Carbonate (mg/L)	1,150	875	734	1,439
Free Chlorine (mg/L)	150	16	16	16
pH	11.97	11.91	11.93	11.79

Table 15b. Chemical recovery study 5: Composition and their respective % removal of used Super Klenz from CIP tank (October 1, 1993).

Parameters	Fresh Sample (mg/L)	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	3,562	3,067	2,767	28
Ash	2,804	2,093	1,774	32
Suspended Solids	0	31	2	95
COD	458	586	311	58
Fat	<1	8.25	<1	>96.97
Protein	<1	12.35	<1	>93.52
Carbohydrate	<10	46.90	43.20	26.31

<sup>1</sup> The permeate/retentate concentration ratio was 4:1.

Table 16a. Chemical recovery study 6: Chemical strength of used acid solution from tanker wash bay.

Parameters	Starting Materials	<sup>1</sup> Permeate	Concentrate
Acidity (mg/L CaCO <sub>3</sub> )	4,750	4,750	4,750
pH	1.60	1.62	1.46

Table 16b. Chemical recovery study 6: Composition and their respective % removal of used acid solution from tanker wash bay.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	2,436	1,790	41
Ash	1,846	1,116	52
Suspended Solids	42	6	89
COD	296	221	40
Fat	22.35	<1	>96.42
Protein	3.01	<1	>73.42
Carbohydrate	34.80	18.05	58.51

<sup>1</sup> The permeate/retentate concentration ratio was 4:1.

the variations in the chemical strengths of the starting materials, all parameters including the % caustic, total alkalinity and pH in both batches remain unchanged in the starting materials and permeates.

With respect to the compositional analyses of the starting material, the percent fat, protein and carbohydrate remaining in the permeate (Tables 11b-12b) were found to be relatively low. Comparatively, Table 12b showed a higher removal of suspended solids (92%), fat (96.02%) and protein (87.07%) than those observed in Table 11b. The slightly lower removal of solids in batch 1 (Table 11b) was probably due to the addition of Stabicip Therm to the detergent. Stabicip Therm defines a group of chemicals usually added to regular caustic wash. It consists of sequestrant and chelating agents which both bind calcium and magnesium in hard water and as such, prevent them from depositing on stainless steel surfaces in the presence of an alkaline solution (Ecolab Chemical Company, 1990). Furthermore, the addition of Stabicip Therm to an alkaline wash helps to enhance the solubilization and breakdown of soil including fat and protein (Ecolab Chemical Company, 1990). However, this enhancement of the detergent efficiency allows for the passage of soluble solids such as proteins into the permeate stream and consequently minimizes the efficiency of the treatment in terms of the removal of solids.

Ash content results from contribution from food, detergents and to a limited extent, water. Mineral soil from a food source is often chemically bound to other materials (protein and carbohydrates) and are referred to as "complex soil" (Ecolab Chemical Company, 1990). Complex soils usually develop during CIP cleaning at high temperatures. These modifications of the food components make for improbable analysis of the actual composition of the used detergents. The high ash content

reported in Tables 11b and 12b indicates that majority of the ash content resulted from make up chemicals of the detergents. Despite the fact that the inorganic content remained unchanged in the permeate, the amount of retentate which was discharged to the sewer could be reduced by 88% to 94%.

The post-soil rinse (which was previously discussed) often removes a high proportion of carbohydrates from the surface of the machines due to their high solubility in water. Some carbohydrates have been shown to remain complexed with other food components i.e. proteins and minerals. On such occasions, the solubility of the carbohydrates is reduced. However, upon chemical reaction during cleaning, carbohydrates (bound and unbound) may be hydrolysed and eventually dissolve in solution (Ecolab Chemical Company, 1990). In this study, it was established that the Microsteel membrane system was inadequate for the removal of carbohydrates. As shown in Tables 11b and 12b, the percent removal of carbohydrate was observed as 19.43% and 48.48% respectively.

#### **4.3.1.2 Liquid Super Klenz (chlorinated alkaline detergent)**

Tables 13a, 14a and 15a indicate the results collected from diluted Liquid Super Klenz solutions. Liquid Super Klenz, which is measured in terms of total alkalinity, is a chlorinated alkali detergent used in the cleaning of storage tanks, silos, pipe lines and packaging machines. Chlorine is used extensively in alkaline cleaning agents to break up peptide linkages in protein molecules so that they can be easily solubilized or dispersed in the cleaning solution. As the total alkalinity remained constant in starting materials and permeates in all three batches, the Microsteel membrane system in all batches (Tables 13a-15a) demonstrated an ability to concentrate the

hydroxide ions in the permeate portion and eliminate carbonate and bicarbonate ions by retaining them in the concentrate portion. This is beneficial in terms of detergency since the hydroxide ion is the primary component in the cleaning process. The pH and chlorine concentration remained unchanged in the permeates of all batches. The detergent strength (Table 13a-15a) varied from batch to batch; but was found to be lower than the recommended level in all batches. This indicates that more fresh detergent is needed to compensate for the lost strength if the recycled detergent is to be reused. The compensation varied from 0.15% (in volume) in Table 14a to 0.65% (in volume) in Table 15a.

A fresh detergent sample was also collected prior to the CIP washing cycle. Its chemical strength and composition are shown in Tables 15a and 15b respectively. The difference of all parameters in the fresh sample and the starting material represents the utilization of chemicals and the removal of soil from the machine surface during washing.

Despite the fact that the composition and the pollution strength of the starting materials varied from batch to batch, the Microsteel treatment system was proven to be effective (Tables 13b-15b). This was concluded as a result of the fact that the % removal of suspended solids, fat and protein in all batches was above 85%. With the exception of some dissolved carbohydrates remaining in the solution, the SuperKlenz solution in the permeates was almost free of soil.

The ash content, which is in proportion to the total alkalinity, is reflective of the chemical strength of the SuperKlenz solution. The ash content in the Superklenz solution was not as high as that observed in the caustic solution (AC 101). This is probably due to the lower concentration of sodium ions in the Superklenz solution.

#### **4.3.1.3 AC Special (Acid Detergent)**

In various food industries, acid cleaners (nitric and phosphoric acids) are commonly used in conjunction with alkaline detergents for the solubilization of complex soils where minerals are bound to carbohydrate and/or protein soils (Ecolab Chemical Company, 1990). The % acidity, or more commonly pH is used to represent the chemical strength of an acid detergent. The pH and % acidity of the starting materials and permeate of the acid detergent as shown in Table 16a was approximately the same. However, the pH values were higher than the recommended strength for CIP cleaning.

The removal of soil from the starting material of the acid detergent using the Microsteel membrane system was found to be effective since no fat or protein was detected in the permeate. The percent removal of ash from the acid detergent was noted as the highest (52%) among all types of detergents; as most of the ash content in acid detergents (Table 16b) accounts for the mineral deposits which have been removed from the machine surface.

#### **4.3.1.4 Microbiology**

Dunsmore et al (1981) reported that very high proportions (up to 99.8%) of bacteria could be removed by cleaning. He also stated that detergency was quantitatively more important than sanitizing. However, Davis (1968) reported that alkaline detergents never completely eliminate viable bacteria. The micromembrane system may prevent the accumulation of microorganisms and subsequently the contamination of processing equipment if detergents are recycled. This is supported by results (Pedersen, 1991), indicating a 99.7% reduction of bacteria in skim milk with



an initial population of 30,000 cfu per ml by means of microfiltration (ceramic alumina membrane with a pore size of 1.4  $\mu\text{m}$ ). A pore size of 0.1  $\mu\text{m}$  employed in the Microsteel membrane system ensures the elimination of all microorganisms from the starting solutions.

In general, the Microsteel membrane system proved to be effective in removing "milk stone" (soil from dairy products) from various detergents such as caustic, chlorinated alkali, and nitric and phosphoric acids while maintaining the chemical strength of these detergents. With the exception of the caustic solution containing Stabicip Therm, the permeate of all other detergents was found to be almost free of suspended solids, protein and fat. The removal of carbohydrates by the Microsteel membrane system was limited in all batches. However, the dissolved carbohydrate components would not hamper the performance of the recycled detergents or contaminate the equipment. The recycled detergents should be free of microorganisms. Further testing is needed to confirm the performance of this treatment system on caustic with Stabicip Therm and to confirm literature data on removal of bacteria. The evaluation of the effects of the accumulation of carbohydrates in continued recycling of various detergents is also recommended.

#### **4.3.2 Effluent Pretreatment**

Jelen (1991) indicated that with a cut-off pore size of 0.1-0.2  $\mu\text{m}$ , microfiltration allows for the passage of minerals, lactose, some whey proteins and casein while retaining fat globules, microorganisms and somatic cells. In this study, the results shown in Tables 17-28 followed patterns cited in the above literature.

Table 17. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **2% milk** at **1,000 mg/L COD** value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	897	359	66
Ash	138	58	64
Suspended Solids	53	0	100
COD	1,104	318	75
Fat	157.22	3.15	98.28
Protein	1215.30	<1	99.60
Carbohydrate	321.48	310.27	17.27

<sup>1</sup> The permeate/retentate concentration ratio was 6:1.

Table 18. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **2% milk** at **3,000 mg/L COD** value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	-- (2,037 <sup>2</sup> )	-- (1,245 <sup>2</sup> )	-- (59 <sup>2</sup> )
Ash	289	142	63
Suspended Solids	100	6	96
COD	2,983	818	79
Fat	370.21	5.26	98.93
Protein	544.63	33.23	95.42
Carbohydrate	-- (811.85 <sup>2</sup> )	-- (869.64 <sup>2</sup> )	--(28.23 <sup>2</sup> )

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

<sup>2</sup> Results obtained from a simulated experiment in duplicate (permeate/retentate concentrate ratio was 2:1).

Table 19. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **vanilla ice cream** at **1,000 mg/L** COD value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	1,035	576	58
Ash	85	78	31
Suspended Solids	160	0	100
COD	1,126	510	66
Fat	341.89	2.09	98.12
Protein	54.33	<1	>98.62
Carbohydrate	435.61	452.65	22.07

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

Table 20. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **vanilla ice cream** at **3,000 mg/L** COD value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	3,622	2,024	58
Ash	153	116	43
Suspended Solids	610	8	99
COD	4,084	2,243	59
Fat	1,228.01	4.88	99.70
Protein	179.26	8.35	96.51
Carbohydrate	1,485.15	1,552.47	21.60

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

Table 21. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **chocolate milk** at **1,000 mg/L** COD value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	953	568	55
Ash	157	78	63
Suspended Solids	130	0	100
COD	1,158	583	62
Fat	52.39	2.30	96.71
Protein	124.36	1.97	98.81
Carbohydrate	450.73	437.68	27.17

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

Table 22. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **chocolate milk** at **3,000 mg/L** COD value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	2,557	1,757	48
Ash	326	137	68
Suspended Solids	450	30	94
COD	3,438	1,996	56
Fat	165.25	5.05	97.71
Protein	355.30	24.50	94.83
Carbohydrate	1,429.87	1,252.87	34.28

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

Table 23. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **separator flushes** as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	72,700	31,076	79
Ash	10,946	7,203	67
Suspended Solids	12,700	560	98
COD	90,938	31,299	83
Fat	2,644.90	37.68	99.29
Protein	27,858.95	1,147.03	97.94
Carbohydrate	30,798.69	22,649.83	63.23

<sup>1</sup> The permeate/retentate concentration ratio was 1:1.

Table 24. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **diluted flavored ice cream** (flavors: french cherry, strawberry and chocolate) as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	42,914	21,737	75
Ash	1,159	752	68
Suspended Solids	9,333	620	97
COD	52,799	27,916	74
Fat	12,512.32	16.47	99.93
Protein	5,419.88	185.08	98.29
Carbohydrate	14,342.31	18,002.31	37.24

<sup>1</sup> The permeate/retentate concentration ratio was 1:1.

Table 25. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **combined effluents #1** (A combination of ice cream, rinse water from storage tank and packaging machine) as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	11,451	5,342	65
Ash	583	517	33
Suspended Solids	6,900	14	99
COD	18,746	6,440	74
Fat	3,387.66	7.25	99.84
Protein	1,514.79	12.80	99.37
Carbohydrate	5,783.35	4,787.19	37.92

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

Table 26. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **combined effluents #2** (A combination of ice cream including chocolate flavor, and rinse water from storage tanks and packaging machines) as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	11,878	5,299	67
Ash	632	475	44
Suspended Solids	7,000	7	100
COD	18,615	5,436	78
Fat	3,989.73	6.97	99.87
Protein	1,593.31	13.77	99.35
Carbohydrate	5,603.78	4,735.97	36.61

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

Table 27. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **juice** (orange/ice tea) at **1,000 mg/L** COD value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	787	768	27
Ash	88	96	18
Suspended Solids	12	0	100
COD	879	854	27
Fat	2.58	<1	>70.93
Protein	4.81	2.86	55.41
Carbohydrate	557.11	551.01	25.82

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

Table 28. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **juice** (orange/ice tea) at **3,000 mg/L** COD value as the starting material.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	1,991	1,911	28
Ash	194	214	17
Suspended Solids	21	17	39
COD	2,477	2,210	33
Fat	7.20	2.2	77.08
Protein	18.04	8.29	65.53
Carbohydrate	1,545.75	1,625.71	21.12

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.



#### 4.3.2.1 Controlled Dairy Products

Controlled dairy products defines dairy products (2% milk, vanilla ice cream and chocolate milk) which were diluted to 1,000 and 3,000 mg/L COD values respectively. In studies with these products, the removal of suspended solids (94%-100%), fat (96.71%-99.93%) and protein (94.83%-99.60%) using the Microsteel membrane system was very effective despite the concentration of the initial solutions (Tables 17-22).

The percent COD removal for 2% milk, vanilla ice cream, and chocolate milk with initial COD values of 1,000 mg/L and 3,000 mg/L were 75%, 66%, and 62%, and 79%, 59%, and 56% respectively (Tables 17-22). The descending trend observed above seems to follow results of the ratio of fat and protein to the total solids content of the samples. The ratio of fat and protein to the total solids was observed to be higher in 2% milk (42% and 45%), than in vanilla ice cream (38 % and 39%) and chocolate milk (19% and 20%).

The major mineral components of dairy products originate from milk and include soluble salts of calcium, potassium, magnesium and sodium (Riel, 1985). Due to the dissolved state and relative size of inorganic salts (Table 29), the removal of minerals by the membrane system of which the passage of particulate is primarily determined by molecular size was observed to be very ineffective. However, some of these mineral elements (calcium and magnesium) have been shown to complex to milk proteins (casein); resulting in an increase in the efficiency in their removal. In this study, the percent removal of ash ranged from 31% to 68% (Tables 17-22).

The removal of carbohydrates from the controlled dairy products was observed to be inefficient. As noted in Tables 17 to 22, the carbohydrate content in feed materials and permeates were fairly similar. The carbohydrate content of all samples

Table 29. Molecular sizes of milk components (Kessler, 1981).

Component	Molecular weight (D)	Diameter (nm)
Water	18	0.3
Chloride ion	35	0.4
Calcium ion	40	0.4
Lactose	342	0.8
$\alpha$ -lactalbumin	14,500	3
$\beta$ -lactoglobulin	36,000	4
Blood serum albumin	69,000	5
Casein micelles	$10^7 - 10^9$	25 - 130
Fat globules	--	2,000 - 10,000

included simple sugars such as lactose in milk, and glucose and sucrose in ice cream. The samples may also contain small amounts of gums such as carrageenan, carboxymethylcellulose and guar gum which act as stabilizers and emulsifiers in ice cream (Arbuckle, 1986). These gums may be separated from the permeate portion based on their sizes and solubility. In general and as previously discussed, the removal of carbohydrates by the microfiltration system is ineffective due to its dissolved state and small size (Table 29).

As indicated in Figure 2, with a membrane pore size of  $0.1 \mu\text{m}$ , a majority of casein micelles and most whey proteins should readily pass through the Microsteel membrane system into the permeate. However, the results presented in this (controlled dairy product) study indicates that over 94% of the proteins were removed by the membrane system (Tables 17-22). Several theories may serve to explain this contradiction. There is a possibility that the milk component spectrum in Figure 2 is misrepresentative of the fact. According to Fox (1989) and supported by other researchers (Horne, 1984), 95% of casein molecules have a mean diameter of  $0.1 \mu\text{m}$  (range:  $50\text{-}500 \mu\text{m}$ ) and a molecular weight of approximately  $10^8$  daltons. This value exceeds the  $0.1 \mu\text{m}$  ( $10^5$  daltons) spectrum of the membrane system. Whey proteins constitute about 20% of the total milk proteins and range in size from  $<10,000$  daltons for non-protein nitrogen substances to  $180,000$  daltons for immunoglobulins (Riel, 1985). Fox (1989) noted that only 10% of the total whey proteins exceed  $0.1 \mu\text{m}$  particle size range. As such, about 95.5% of total milk proteins with a molecular size greater than  $0.1 \mu\text{m}$  could be separated from the original milk system by the Microsteel membrane system.

Also, the possibility of developing concentration polarization during the

microfiltration treatment may serve to explain the contradiction of the results obtained from this experiment and those of Fig 2. Concentration polarization is defined as the phenomenon that occurs when the transport of solutes to the membrane surface must be balanced by an equal and opposite transport of solutes by diffusion from the membrane surface; and in the process generate a concentration gradient of solutes from the membrane surface to the bulk stream. As the solute concentration reaches a maximum, the size of solute molecule that can be accommodated is reduced due to restricted mobility. Eventually and under a high concentration, this could trigger the solute to precipitate and foul the membrane (Renner and Abd El-Salam, 1991; Cheryan, 1986). This phenomenon occurs readily in small size membrane processes such as ultrafiltration and reverse osmosis. The onset of concentration polarization is often indicated by a gradual decrease of flux rate. In this study (Tables 17-22), a relatively constant increase in permeate and retentate flow rate was noted. Therefore, the possibility of concentration polarization being responsible for the casein retention is highly speculative.

The processing temperatures in this study gradually increased with time and ranged from 19 °C to 62.8 °C. It is unlikely that heat induced coagulation of proteins under such conditions will be observed, since casein is an extremely heat stable protein (Fox, 1989). Although whey proteins are much more heat sensitive, heat coagulation of whey proteins occurs between 65 and 75 °C and is dependent on the time of exposure (Jelen, 1979).

#### 4.3.2.2 Dairy Effluents

The Microsteel membrane system performed efficiently on samples from separator flushes, diluted flavored ice cream, and effluent #1 and #2 (Tables 23-26). A nearly complete exclusion of suspended solids (94%-100%), fat (99.29%-99.93%) and protein (97.94%-99.37%) was achieved in all batches. Also, a range of 74% to 83% of the initial COD was removed in these batches (Tables 23-26).

Despite the combination of various dairy products resulting in much higher initial concentration, the composition of effluent #1 and #2 was similar to those of the controlled vanilla ice cream trials. As such, the percent removal of all parameters of effluent #1 and #2 was closely comparable to those of the controlled vanilla ice cream trials (Tables 19, 20, 25 and 26).

Compared to vanilla ice cream at controlled COD values (1,000 and 3,000 mg/L), results (Table 24) indicate that a higher removal of total solids (75%) and ash (68%) was observed in diluted flavored ice cream. This can be attributed to the easy removal of small fruit pieces and cocoa powder which contribute to the total solids and occasionally to the ash content of the flavored ice cream.

Compared to controlled dairy products, a higher level of exclusion of total solids (79%), ash (67%) and carbohydrates (63.23%) was observed in the separator flush trial. This may be attributed to the fact that the separator flush, consists of high density solid impurities that are readily separated by the membrane system. As a result of the higher removal of all components, the overall COD in the separator flush trial was highly reduced (83%).

The high suspended solids in trials such as separator flushes and diluted flavored ice cream resulted in a low permeate/retentate concentration ratio (1:1)

(Tables 23 and 24). During the microfiltration process of the above two batches, the permeate flow rate was relatively low. This suggests that the solid particles had partially blocked the membrane pores. The incorporation of air backflushing did little to affect the flow rate. As such, the microfiltration treatment of these two batches was terminated prematurely. However, despite the low flow rate, the Microsteel membrane system is more advantageous than other separation methods such as screening and filtration. Attempts to use a screening procedure was unsuccessful since milk solids quickly blocked the passage of fluids in screens with sizes ranging from 105  $\mu\text{m}$  to 63  $\mu\text{m}$ .

#### **4.3.2.3 Controlled Juice Products**

Controlled juice products are defined as a combination of iced tea and orange juice in equal proportion which were diluted to 1,000 and 3,000 mg/l COD values. Juice contains mainly water, and carbohydrate (Young, 1975). As shown in Tables 27 and 28, the carbohydrate content of juices represents over 71% of the total solids. The initial suspended solids, fat and protein content of juice products represent only 1% of the total solids. Tables 27 and 28 also indicate that the percent removal of all parameters was much lower in comparison to values obtained from the controlled dairy products and actual effluents. This may be attributed to the composition of the different samples.

The mineral content of fruit juice is relatively low. The major minerals in concentrated frozen orange juice are potassium, calcium, magnesium and sodium (Young, 1975). Existing primarily as salts of organic acids, most of these minerals remained dissolved in the permeate. Compared to dairy products, the lowest percent

removal of ash was observed in fruit juices.

The carbohydrate content of orange juice/iced tea is primarily made up of simple sugars, including glucose, fructose and sucrose. Small amounts of polysaccharides such as cellulose, hemicellulose and pectic substances constituting the indigestible fiber may also be present (Young, 1975). The simple dissolved sugars are too small to be separated by the microfiltration treatment and as such, remain in the permeate. In contrast, all of the polysaccharides are retained by the microfilter in the retentate. As observed in Tables 27 and 28, the carbohydrate content in starting materials and permeates are relatively constant.

Among all the parameters analyzed, the Microsteel membrane system effectively removed suspended solids, fat and protein. The inefficiency of the removal of ash and carbohydrates is primarily due to their dissolved state. The level of reduction of COD depends on the composition of the products. A relatively higher ratio of carbohydrate content than that of protein and fat to the total solids (eg. juices) results in a lower COD reduction. As the concentration of the solid material increases, the percent removal of these solids materials remains fairly constant as shown in the separator flush, flavored ice cream, and effluent #1 and #2 trials.

#### **4.3.3 Coagulation**

Coagulation studies were also performed on 2% milk and vanilla ice cream at 3,000 mg/L COD (Tables 30 and 31). The samples were coagulated using zinc chloride prior to the microfiltration process. Zinc chloride was chosen as the coagulant in this study was based on its success in the removal of egg proteins in egg processing

Table 30. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using **2% milk** at **3,000 mg/L** COD value as the starting material with the incorporation of a coagulant prior to the membrane process.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	2,657	1,523	57
Ash	848	586	48
Suspended Solids	165	0	100
COD	3,371	1,104	75
Fat	390.74	7.86	98.49
Protein	484.04	<1	>99.85
Carbohydrate	854.61	828.48	27.29

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.



Table 31. The % removal of the pollution strength and compositional parameters of the Microsteel membrane system study using ice cream at 3,000 mg/L COD value as the starting material with the incorporation of a coagulant prior to the membrane process.

Parameters	Starting Materials (mg/L)	<sup>1</sup> Permeate (mg/L)	Removal (%)
Total Solids	3,484	2,021	56
Ash	486	380	41
Suspended Solids	705	0	100
COD	4,281	2,436	57
Fat	1,119.64	6.46	99.41
Protein	163.26	<1	>99.57
Carbohydrate	1,567.86	1,642.97	21.91

<sup>1</sup> The permeate/retentate concentration ratio was 3:1.

effluents (Carvalho, 1992). A preliminary study of using zinc chloride in the coagulation of controlled dairy products (2% milk and vanilla ice cream) resulted in a 70-75% of COD reduction. In the study of the assessment of various components of dairy effluents in relation to their COD, zinc chloride was used for the precipitation of soluble protein (Palmer, 1984).

The results of the treatments presented in Figs. 10 and 11 indicate similar trends with respect to all parameters for both the milk and the ice cream. A slight improvement in the removal of suspended solids and protein was observed with the aid of the coagulant. This could be attributed to the fact that the primary action of coagulants such as aluminium sulphate and zinc chloride is the binding of proteins and suspended solids (Parsons, 1965). The difference in the carbohydrate content of the samples with and without coagulant was insufficient to draw conclusions. The ash content in the coagulation trials were higher than those observed in other trials due to the fact that the samples were taken after the addition of zinc chloride and sodium hydroxide into the sample. Excess coagulants and sodium ions which remained in the permeate resulted in the low ash removal observed in these trials.

Pretreatment of brine water in oil recovery facilities by the addition of chemical coagulants prior to membrane processes has been employed in an effort to enhance rejection and sustain high flux (Zaidi et al., 1992). It was hypothesized that hydroxide floc produced during coagulation coats the surface of the membrane, preventing small particles from clogging the ceramic membrane pores. However, with respect to COD reduction, no improvement was observed with the use of the coagulant. Since improvement in the permeate flow rate of the coagulation trials and the control were not noted, the incorporation of coagulation to the Microsteel membrane system results

Figure 10. A comparison of % removal of the pollution strength and the compositional parameters of 2% milk trial (3,000 mg/L initial COD value) with and without the incorporation of a coagulant.

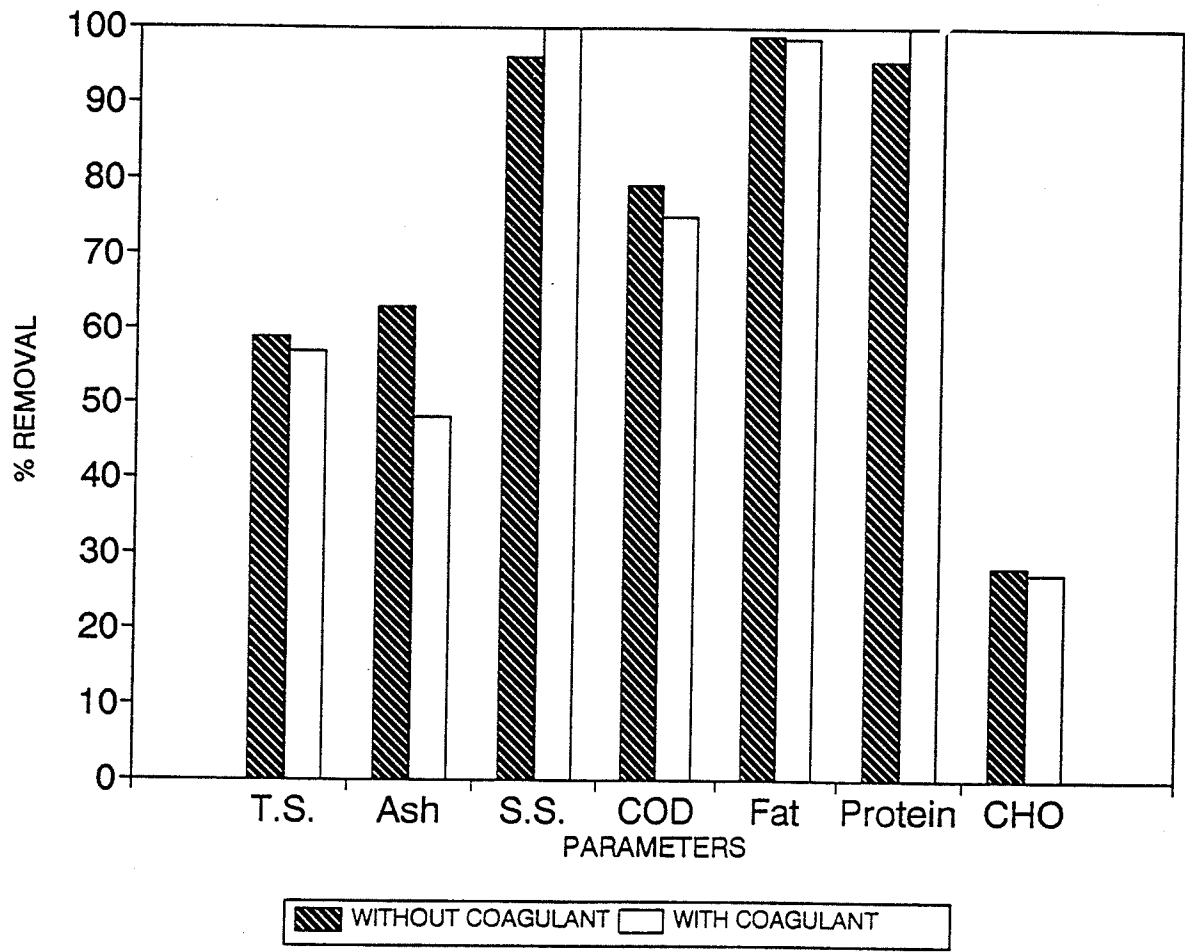
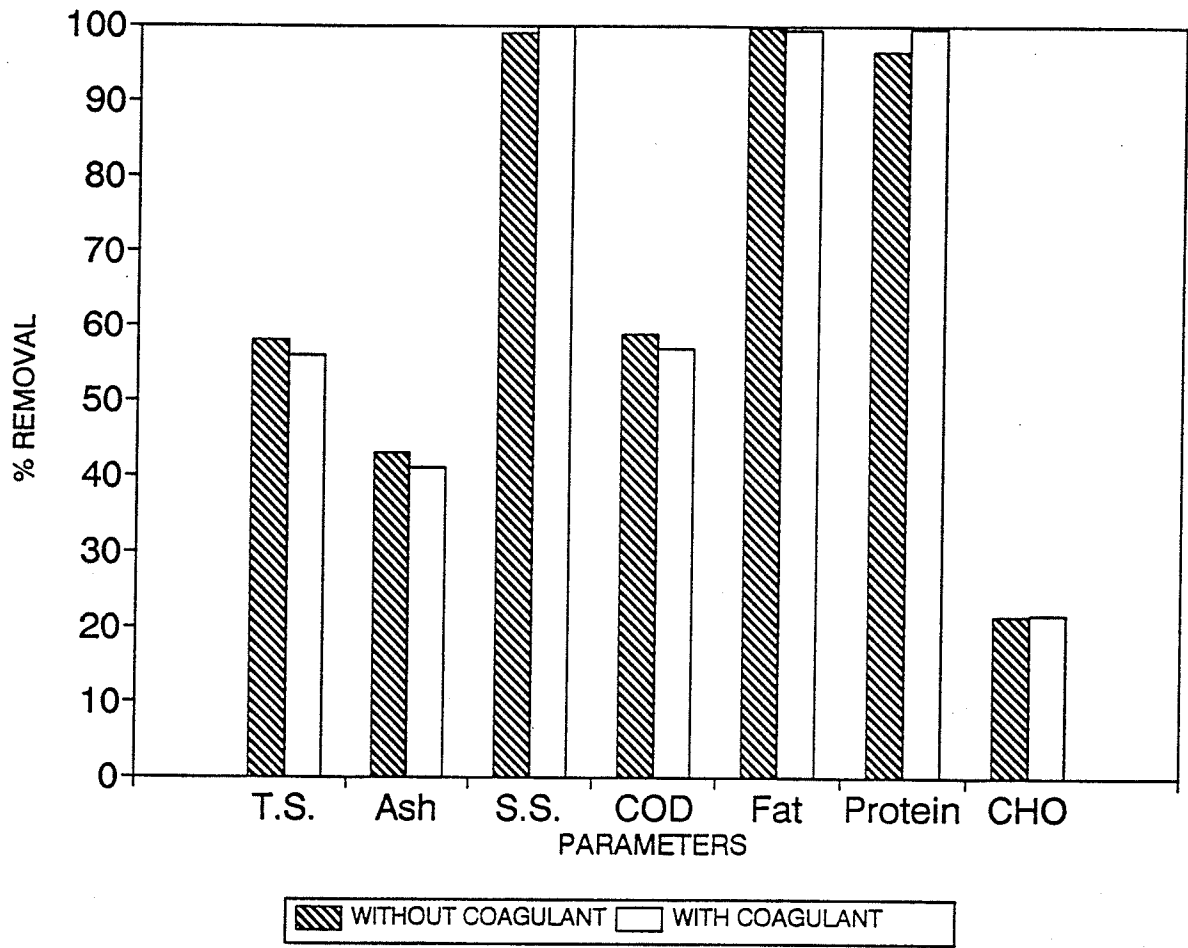


Figure 11. A comparison of % removal of the pollution strength and compositional parameters in vanilla ice cream (3,000 mg/L initial COD value) trial with and without the incorporation of a coagulant.



in no benefits in terms of COD removal and surcharge reduction.

#### 4.3.4 Ultrafiltration

Ultrafiltration is a membrane process that has been utilized in the dairy industry for protein purification in whey. The membrane pores are defined in molecular weight cut off sizes, typically 10,000-75,000 daltons. Due to its small pore size, the ultrafiltration process is capable of separating individual milk proteins from lactose and minerals. Large particles such as bacteria or fat globules can also be retained (Jelen, 1991).

In general, a majority of the remaining suspended solids, protein and fat from the microfiltered permeate were removed when subjected to an ultrafiltration treatment (Tables 32-35). However, this only accounted for the reduction of 7-30 mg/L in suspended solids, 7.94-52.50 mg/L in proteins and 2.60-8.32 mg/L in fat.

A slight improvement in the removal of ash was observed; with values ranging from 5% in ice cream and chocolate milk to 10% in juices (Table 36). However, the carbohydrate content of the controlled dairy products before and after ultrafiltration remained fairly constant. A difference of 1.5% to 2.5% was noted in Table 36. No improvement was observed in juices since all the sugar remained dissolved in the permeate.

The percent COD removal for 2% milk, vanilla ice cream, chocolate milk and juice at 3,000 mg/L were 16, 13, 8 and -2% respectively (Tables 32-35). However, with respect to the original concentration in the starting materials, no significant improvement was observed (Table 36). It was shown that only a 3% and 4% COD was removed by further ultrafiltration treatment of chocolate milk and vanilla ice cream

Table 32. The % removal of the pollution strength and compositional parameters of an ultrafiltration treatment using **microfiltered 2% milk** sample as the starting material.

Parameters	<sup>1</sup> Permeate		Removal (%)
	Microfiltration Treatment (mg/L)	Ultrafiltration Treatment (mg/L)	
Total Solids	1,245	1,117	12
Ash	115	117	0
Suspended Solids	13	0	100
COD	1,048	895	16
Fat	8.32	<1	>88.18
Protein	52.50	0.75	98.60
Carbohydrate	869.64	857.47	3.04

<sup>1</sup> The permeate/retentate concentration ratio was 60:1.



Table 33. The % removal of the pollution strength and compositional parameters of an ultrafiltration treatment using **microfiltered ice cream** sample as the starting material.

Parameters	<sup>1</sup> Permeate		Removal (%)
	Microfiltration Treatment (mg/L)	Ultrafiltration Treatment (mg/L)	
Total Solids	2,032	1,993	4
Ash	116	107	9
Suspended Solids	7	0	100
COD	2,308	2,042	13
Fat	4.50	<1	>78.14
Protein	7.94	<1	87.62
Carbohydrate	1,570.29	1,546.88	3.13

<sup>1</sup> The permeate/retentate concentration ratio was 60:1.

Table 34. The % removal of pollution strength and compositional parameters of an ultrafiltration treatment using **microfiltered chocolate milk** sample as the starting material.

Parameters	<sup>1</sup> Permeate		Removal (%)
	Microfiltration Treatment (mg/L)	Ultrafiltration Treatment (mg/L)	
Total Solids	1,808	1,787	3
Ash	131	118	11
Suspended Solids	30	0	100
COD	2,049	1,916	8
Fat	4.90	<1	>79.93
Protein	24.50	<1	>95.99
Carbohydrate	750.06	745.17	2.28

<sup>1</sup> The permeate/retentate concentration ratio was 60:1.

Table 35. The % removal of the pollution strength and compositional parameters of an ultrafiltration treatment using **microfiltered orange juice/ice tea** sample as the starting material.

Parameters	<sup>1</sup> Permeate		Removal (%)
	Microfiltration Treatment (mg/L)	Ultrafiltration Treatment (mg/L)	
Total Solids	2,003	2,051	0
Ash	194	191	5
Suspended Solids	17	0	100
COD	2,249	2,332	-2
Fat	2.60	<1	>62.17
Protein	8.59	4.68	46.43
Carbohydrate	1,677.74	1,726.89	-1.21

<sup>1</sup> The permeate/retentate concentration ratio was 60:1.

Table 36. Percent removal of parameters with respect to the original concentration in the starting materials of 2% milk, ice cream, chocolate milk and juices (all at 3,000 mg/L COD) by microsteel membrane system and ultrafiltration treatment.

Parameters	Removal (%)							
	2% Milk		Ice Cream		Choco. Milk		Juices	
	Micro. <sup>1</sup>	Ultra. <sup>2</sup>	Micro.	Ultra.	Micro.	Ultra.	Micro.	Ultra.
Total Solids	59	64	58	59	48	48	28	24
Ash	63	70	43	48	68	73	17	27
Susp. Solids	96	100	99	100	94	100	39	100
COD	79	78	59	63	56	59	33	31
Fat	98.93	>99.80	99.70	>99.94	97.71	>99.55	77.08	>89.75
Protein	95.42	99.90	96.51	>99.59	94.83	>99.79	65.53	80.86
CHO	28.23	30.74	21.60	23.16	30.28	32.12	21.12	17.58

<sup>1</sup> % removal from the starting material derived from the microfiltration treatment (Microsteel membrane system, 0.1  $\mu\text{m}$  cut-off).

<sup>2</sup> % removal from the starting material derived from the ultrafiltration treatment (Amicon model #8,200 UF cell, 10,000 molecular cut-off).

respectively while a decrease in COD was observed in 2% milk and juices (Table 36).

The amount of solids materials (ash, fat, protein and carbohydrate) which fall in the size between 10,000 molecular weight and 0.1  $\mu\text{m}$  in dairy products and juices is very little. As such, no significant improvement in the removal of COD and suspended solids was observed in all products tested. Therefore, further membrane treatment (ultrafiltration) of microfiltered samples is not justified. However, if the finished product contains certain valuable proteins (such as  $\alpha$ -lactalbumin,  $\beta$ -lactoglobulin and serum albumin) (Table 29) which can be separated and purified (Kessler, 1981; Maubois and Olliver, 1991), ultrafiltration treatment may serve a beneficial purpose in this process.

#### 4.3.5 Reduction of Surcharges

According to the City of Winnipeg, Waterworks, Waste and Disposal Department, the BOD, suspended solids, grease, and pH values of the study model ranged from 820-2,400 mg/l, 109-659 mg/l, 190-790 mg/l and 7.8-11.0 respectively in the last three years (Anonymous, 1994). The average consumption of water for a 3 month period at the study model was noted as approximately 31,000 kiloliters. As the total surcharge is determined by the surcharge rate and the consumption of water, the study model has been subjected to surcharges ranging from \$11,238 to \$33,251 for 3 month periods in the past three years.

The high pH (7.8-11) of the dairy effluents reflects that a significant amount of alkaline detergents was found in the composite effluent samples. This is apparent since on average, 98% of the total city water used in the plant is employed for purposes other than incorporation into products and is eventually discharged as

effluent. In the study of chemical recovery, it has been established that as much as 89% of the detergent solution used can be recycled. The incorporation of the Microsteel membrane system in the study of chemical recovery serves three functions: (1) It saves approximately 9,600 L of water, 19 L of Liquid SuperKlenz and 73.6 L of caustic (AC 101) used in the production of the detergent solution everyday (Appendices 20, 21 and 22); (2) it lowers the pH of the overall effluents and reduces the surcharge due to the reduction of the amount of city water used and (3) it minimizes the detrimental effect on the environment due to the discharge of less chemicals.

As established in the present study, the incorporation of the Microsteel membrane system for processing dairy effluent results in the reduction of BOD, suspended solids and grease. This subsequently leads to the reduction of surcharges. The results presented in Tables 25 and 26 illustrate that higher than 99% of grease (fat) and suspended solids of the original dairy effluent could be removed by means of the Microsteel membrane system.

Removal of more than 65% of the original COD in the permeate was shown in the same effluent study (Tables 25 and 26). The level of BOD removal in the effluents of the study model is expected to be similar to the COD removal. The U.S. Environmental Protection Agency (1971) established that the ratio of BOD of dairy components such as lactose, fat and proteins to the amount of these components (measured in lbs) were 0.65, 0.89 and 1.03 respectively. Using effluents 1 and 2 (Tables 25 and 26) as examples of typical dairy effluents discharged from the study model, the theoretical percent removal of BOD was calculated to be 74.75 and 73.69% (Appendices 23 and 24). As such, with an initial BOD of 820-2,400 mg/l, the BOD of

the effluents after the Microsteel membrane treatment could be reduced to 216-631 mg/l. Conservatively, the cost saving of surcharges in the pretreatment of effluents is estimated to be as high as \$27,000 for a 3 month period or \$108,000 annually (Table 37).

The retentate collected from the membrane treatment represents about 10-20% of the original total volume of effluent. This retentate contains fat and protein which are of great value as by-product ingredients or animal feed. The establishment of the disposal program of the liquid retentate as animal feed is important in the viability of the Microsteel membrane system.

#### **4.3.6 Economic Viability**

A suitable Microsteel system (CRS-100) selected for the study model is capable of operating 8 to 16 gallons per minute (30-60.6 L/min) of permeate. This system requires approximately 2.4 hours to operate 7.92 kL of chemical solution (AC 101 caustic and Liquid Super Klensz). However, it seems to be too excessive to collect all effluents for pretreatment since the average daily usage of city water is 379 kL. As such, the quantity of effluent collected for pretreatment must be reduced. Optic sensors which automatically divert high strength effluent for pretreatment can be installed in segregated drain pipes. These devices greatly reduce the quantity of effluent needed to be treated. Based on the available information (Appendix 25), the cost of the Microsteel membrane system can be justified in approximately 1 year.

Table 37. Reduction of city sewage surcharge by the Microsteel membrane system.

	Range of BOD (mg/l)	Range of suspended solids (mg/l)	Range of surcharges \$
Before Treatment	820-2,400	109-659	11,238 - 33,251
After Treatment	216 - 631	1 - 7	0 - 6,351
Potential savings on surcharges:			
	per a 3-month period:	\$11,000-27,000	
	per a year:	\$44,000-108,000	



## 5 CONCLUSIONS AND RECOMMENDATIONS

Upon the establishment of the water and waste management program in the study model, numerous problem areas which led to excessive product spillage were recognised. The study of the selected problem areas provided simple but economically sound solutions to reduce the loss of raw materials and subsequently increase product yield. Other areas which have been addressed to the study model included the installation of automatic shut-off nozzles on all water hoses, the reuse of post-detergent rinse of CIP system for pre-detergent rinse of the next cycle, the collection of juices at start-up and changeover for reuse, and the utilization of left over flavored ice cream mix which cannot be reused for animal feed. The above areas were not included in the scope of this thesis preparation because of the time limitation.

Further marketing research on an appropriate centrifuge, the study of the composition of the recycled milk and an approval of the process by the government regulatory agency are required for the recycling of the milk discharged from the separator.

A maintenance program of the milk reclaim system was recommended to the study model to ensure the safety of the system. The program included the regular microbiological testing of the reclaim milk collected from the end of the reclaim system, the replacement of new plastic tubing every two weeks, and the maintenance of the pump.

Despite the elimination of the major problem areas, the pollution strength of

effluents in the study model indicates that the effluents obtained from general operational practice still exceeded the maximum limit allowed by the city of Winnipeg, Waterworks, Waste and Disposal Department. This indicates a need for the improvement of the general operational practice of the model plant. If an economical solution could not be found, a pre-treatment on the general effluents emitted from the study model might be the next step to counteract the high sewage surcharges. More importantly, the water and waste management program in a food industry should be a long term on-going process.

In view of the study on the Microsteel membrane system, the results show significant benefits in the areas of chemical recovery and effluent pretreatment. A projected reduction of over 30% of Liquid Super Klenz and 80% of caustic (AC 101) and water used in the preparation of detergents can be obtained daily with the application of the Microsteel membrane system. The microfiltration process does not alter the strength of the detergents since the starting materials and permeate were shown to have similar values. However, further study on the chemical removal of detergent solution containing Free Stabicip is recommended.

A nearly complete elimination of grease and suspended solids as well as about 70% reduction of BOD loading in the effluent after the Microsteel membrane treatment would lower the sewage surcharge significantly despite the initial pollution strength. The incorporation of chemical coagulant and ultrafiltration to the Microsteel membrane system results in no significant improvement in terms of COD reduction. The application of the Microsteel membrane system serves two functions to the study model, (a) reduce sewage surcharge, (2) reduce the amount of chemicals and organic matter discharged into the environment.

## 6 REFERENCES

- American Public Health Association. 1985. Standard Methods for the Examination of Water and Wastewater. 16<sup>th</sup> edition. American Public Health Association, American Water Works Association and Water Pollution Control Federation. Washington, D.C. pp 92-100, 128, 245, 265-273, 525-538.
- American Public Health Association. 1989. Standard Methods for the Examination of Water and Wastewater. 17<sup>th</sup> edition. American Public Health Association, American Water Works Association and Water Pollution Control Federation. Washington, D.C. pp. 523-541.
- Anderson, A. 1992. Private communication. Mead and Hunt Inc. Madison, Wisconsin, U.S. Quoted in Mans, J. 1992. Clear Solutions. Dairy Foods. 94(3):49-54.
- Anonymous, 1992. Statistics in Surcharges. Wasteworks, Waste and Disposal Department, City of Winnipeg.
- Anonymous, 1994. Information on Sewage Surcharges. Beatrice Foods. Winnipeg, Manitoba.
- Arbuckle, W.S. 1986. Energy Value and Nutrients of Ice Cream. In "Ice Cream", 4th Ed. The AVI publishing Company, Inc. Westport, Connecticut. pp. 9-17.
- Authority of the Council of the City of Winnipeg. 1988. City of Winnipeg By-law #5058/88, Part 5 and 7. City of Winnipeg.
- Barnes, D. and Wilson, F. 1983. Colloids, Coagulation and Flocculation. In "Chemistry and Unit Operations in Water Treatment". Applied Science Publishers. Essex, England. pp. 85-121.
- Benefield, L.D. and Randall, C.W. 1976. The Phenol-Sulfuric Acid Test - Effective Alternative for Carbohydrate Analysis. Waters and Sewage Works. 1976: February.
- Bissett, D.W. and Schmidtke, N.W. 1984. Concentrating Whey by Hyperfiltration at a Small Canadian Cheese Plant. Int. Dairy Fed. #184:96-97.
- Blanc, F.C. and Navia, R. 1991. Treatment of Dairy Wastewater by Chemical Coagulation. 45<sup>th</sup> Purdue Ind. Waste Conf. Proc. 45:681-689.
- Bush, P. 1991. Gold to the Last Drop. Dairy Foods. 92(11):70-73.

- Campbell, I. 1994. Water Quality and Competitiveness in Dairy Processing. Environ. Bureau, Adaptation and Grain Policy Directorate, Policy Branch, Agriculture and Agri-Food Canada. Ottawa, Ontario.
- Carawan, R.E. and Jones, V.A. 1977. Water and Waste Management Educational Program for Dairy Processing. *J. of Dairy Sci.* 60:1192-1197.
- Carawan, R.E. 1992. Wastewater Pretreatment in Dairy Plants. Does it Save Money? Food or Drain. North Carolina Cooperative Extension Service, North Carolina. pp. 1-4.
- Cartwright, P.S. 1990. The Opportunities for Membrane Technologies in Pollution Control Applications. 44<sup>th</sup> Purdue Ind. Waste Conf. Proc. 44:343-351.
- Cartwright, P.S. 1992. Industrial Wastewater Treatment with Membranes - A United States Perspective. *Water Sci. Technol.* 25(10):373-390.
- Carvalho, L. 1992. Private communication. Export Packers. Winnipeg, Manitoba, Canada.
- Cheryan, M. 1986. Modelling of Ultrafiltration Process. In "Ultrafiltration Handbook". pp. 73-125. Technomic Publishing Company, Inc. Lancaster, Pennsylvania.
- Cowan, J.A.C., MacTavish, F., Brouckaert, C.J. and Jacobs, E.P. 1992. Membrane Treatment Strategies for Red Meat Abattoir Effluents. *Water Sci. Technol.* 25(10):137-148.
- Davis, J.G. 1968. Chemical Sterilization. *Progress in Ind. Microbiol.* 8:141- 208.
- Defrise, D. and Gekas, V. 1988. Microfiltration Membranes and the Problem of Microbial Adhesion. A Literature Survey. *Process Biochem.* 23(4):105-116.
- Dunsmore, D.G. Twomey, A., Whittlstone, W.G. and Morgan, H.W. 1981. Design and Performance of Systems for Cleaning Product - Contact Surfaces of Food Equipment: A Review. *J. of Food Protection.* 44:220-240.
- Eckenfelder, W.W. and O'Connor, D.J. 1961. Principles of Biological Oxidation. In "Biological Waste Treatment". Pergamon Press Ltd. USA. pp.14-75.
- Ecolab Chemical Company, 1990. Klensade Training Manual. Klensade, Division of Ecolab Ltd. Minnesota.
- Fox, P.F. 1989. The Milk Protein System. In "Developments in Dairy Chemistry". pp. 1-54. Elsevier Science Publishers Ltd., Essex, England.
- Green, J.H. and Kramer, A. 1979. Waste Management. In "Food Processing Waste Management". The AVI Publishing Company, Inc. Westport, Connecticut.

- Hanemaaijer, J.H. 1985. Microfiltration in Whey Processing. *Desalination*. 53:143-155.
- Hayashi, H. and Hatanaka, K. 1984. Treatment of Dairy Effluent by Using Reverse Osmosis and a Sludge Dryer. *Int. Dairy Fed.* #184:23-24.
- Horne, D.S. 1984. Determination of the Size Distribution of Bovine Casein Micelles Using Photon Correlation Spectroscopy. *J. of Colloid and Interface Sci.* 98(2):537-550.
- International Dairy Federation. 1983. Sludge from Milk Separators. *Int. Dairy Fed.* #156:22-24.
- Jelen, P. 1979. Physico-Chemical Properties of Milk and Whey in Membrane Processing. *J. of Dairy Sci.* 62:1343-1351.
- Jelen, P. 1991. Pressure-driven Membrane Processes: Principles and Definitions. In "New Applications of Membrane Processes". International Dairy Federation, Belgium. pp. 7-14.
- Jones, H.R. 1974. Waste Production by the Industry, and In-Plant Control to Reduce Wastes. In "Pollution Control in the Dairy Industry". Noyes Data Corporation. Park Ridge, New Jersey. pp. 44-66, and 116-138.
- Karpati, A., Bencze, L., and Borszeki, J. 1990. New Process for Physico-Chemical Pretreatment of Dairy Effluents with Agricultural Use of Sludge Produced. *Water Sci. Technol.* 22:9:93-100.
- Kelly, P.M., Horton, B.S. and Burling, H. 1991. Partial Demineralization of Whey by Nanofiltration. In "New Applications of Membrane Processes". International Dairy Federation, Belgium. pp. 130-140.
- Kessler, H.G. 1981. *Food Engineering and Dairy Technology*. Verlag A. Kessler, Freising, FRG. pp.86. Quoted in Glover, F.A. 1986. Modifications to the Composition of Milk. pp.236. In "Modern Dairy Technology". Elsevier Applied Science Publishers, London, New York.
- Knechtel, J.R. 1978. A More Economical Method for the Determination of Chemical Oxygen Demand. *Water and Pollut. Control.* 22:25-28.
- Mans, J. 1993. Clear Solutions. *Dairy Foods.* 94:3:49-54.
- Marshall, K.R. 1984. Waste Elimination in Dairy Plants. *Int. Dairy Fed.* #184:43-46.
- Martin, J.H. and Zall, R.R. 1985. Dairy Processing Wastewater Bioaugmentation - An Evaluation of Effectiveness. 40<sup>th</sup> Purdue Univ. Ind. Waste Conf. Extension Service. 40:351-360.

- Marth, E.H. (ed) 1978. Standard Methods for the Examination of Dairy Products. 14<sup>th</sup> edition. American Public Health Association, Washington, DC.
- Maubois, J.L. & Ollivier, G. 1991. Milk Protein Fractionation. In "New Application of Membrane Processes". pp. 15-20. International Dairy Federation, Belgium.
- Membrane System Specialists. 1993. Micro-Steel, Caustic Recovery System. Wisconsin Rapids, Wisconsin. pp. 2-4.
- Merin, U. and Daufin, G. 1990. Crossflow Microfiltration in the Dairy Industry: State-of-the-Art. Lait. 70:281-291.
- Merin, U., Gordin, S. and Tanny, G.B. 1983. Microfiltration of Cheese Brine. J. of Dairy Res. 50:503-509.
- Moore, J.A. and Buxton, B.M. 1977. The Treatment and Disposal of Wastewater from Dairy Processing Plants. Environ. Protection Technol. Ser. Proc. 8<sup>th</sup> Natl. Symp. on Food Processing Wastes. 8:427-442.
- Palmer, J. 1984. Assessment of Dairy Waste Strength and Composition. Int. Dairy Fed. #184:55-56.
- Parsons, W.A. 1965. Coagulation. In "Chemical Treatment of Sewage and Industrial Wastes". National Lime Association. Washington, D.C. pp. 1-22.
- Paulson, D.J., Wilson, R.L., and Spatz, D.D. 1984. Crossflow Membrane Technology and Its Applications. Food Technol. 38:12:77-87.
- Pedersen, P.J. 1991. Microfiltration for the Reduction of Bacteria in Milk and Brine. In "New Applications of Membrane Processes". International Dairy Federation, Belgium. pp. 33-49.
- Permut, A.H. 1993. Personal Communications. City of Winnipeg, Waterworks, Waste and Disposal Department.
- Pico, R.F. 1986. Dairy Wastes. Water Pollut. Control Fed. 58(6):556-557.
- Pico, R.F. 1987. Dairy Wastes. Water Pollut. Control Fed. 59(6):448-449.
- Pico, R.F. 1988. Dairy Wastes. Water Pollut. Control Fed. 60(6):874-875.
- Radick, K.A. 1989. Dairy Wastes. Water Pollut. Control Fed. 61(6):862-863.
- Radick, K.A. 1991. Dairy Wastes. Water Pollut. Control Fed. 63(4):450-451.
- Radick, K.A. 1993. Dairy Wastes. Water Pollut. Control Fed. 65(4):399.

- Renner, E. & Abd El-Salam, M.H. Basic Principles. 1991. In "Application of Ultrafiltration in the Dairy Industry". pp. 7-29. Elsevier Science Publishers Ltd., Essex, England.
- Riel, R. 1985. Composition and Physico-chemical Structure of Milk. In "Dairy Science and Technology". pp.1-51. La Fondation de Technologie Laitiere du Quebec Inc.
- Rusten, B. Lundar, A., Eide, O., and Ødegaard, H. 1993. Chemical Pretreatment of Dairy Wastewater. *Water Sci. Technol.* 28(2):67-76.
- Ryder, D.N. 1984. Anaerobic Digestion. *Int. Dairy Fed.* #184:127-131.
- Sawyer, C.N. and McCarty, P. 1978. Water and Wastewater Analysis. In "Chemistry for Environmental Engineering" pp. 416-439. McGraw-Hill, Inc., New York.
- Schexnayder, K. 1991. The Waste of the '90s. *Dairy Foods.* 92(5):47-48.
- Sperber, B. 1993. Green Tide Rising. *Food Processing.* 54:9:15-26.
- Staal, 1981. Relationships between BOD, COD and TOCC in Dairy Effluents. *Bulletin, Int. Dairy Fed.,* #184:15-16.
- Teknisk Dokumentation AB. 1987. General Milk Treatment. In "Dairy Handbook". Alfa-Laval. Lund, Sweden.
- Turpie, D.W.F., Steenkamp, C.J. and Townsend, R.B. 1992. Industrial Application of Formed-In-Place Membrane Ultrafiltration and Automated Membrane-Forming in the Treatment and Recycle of Rinse-Water During the Scouring of Raw Wool. *Water Sci. Technol.* 25(10):127-136.
- U.S. Environmental Protection Agency. 1971. Dairy Food Plant Waste and Waste Treatment Practices. U.S. EPA, Washington, D.C. pp. 171-180, 195, 215-343.
- Wagner, R. 1994. Private Communication. Alto Dairy. Waupun, Wisconsin, U.S.A.
- Walsh, J.L. Jr., Ross, C.C. and Valentine, G.E. Jr. 1994. Food Processing Waste: Dairy. *Water Pollut. Control Fed.* 66(4):411.
- Weaver, T. 1994. Private Communication. Beatrice Foods. St. George, Ontario, Canada.
- Weber, W.F. and Bowman, W., 1986. Membranes Replacing Other Separation Technologies. *Chemical Engineering Progress.* 82:11-23.
- Wright, W.A. 1990. The Chemistry of Detergents. In "CIP:Cleaning In Place" pp.17-29. The Society of Dairy Technology, Huntingdon, Cambridgeshire.

- Young, C.T. 1975. Composition and Nutritive Value of Raw and Processed Fruits. In "Commercial Fruit Processing". pp. 539-579. The Avi publishing company, Inc. Westport, Connecticut.
- Zaidi, A., Simms, K. and Kok, S. 1992. The use of Micro/Ultrafiltration for the Removal of Oil and Suspended Solids from Oilfield Brines. Water Sci. Technol. 25(10):163-176.



## Appendix 1. Consumption of well water (08 February 1993, Monday).

Time of Day	Water Meter Reading	Hourly Well Water Usage (M <sup>3</sup> )
8:25	79269	-
9:35	79273	4
10:35	79274	1
11:35	79276	2
12:35 pm	79278	2
1:35	79281	3
2:35	79285	4
3:35	79289	4
4:35	79289	0
5:35	79289	0
6:35	79289	0

## Appendix 2. Consumption of Well Water (23 March 1993, Tuesday)

Time of Day	Water Meter Reading	Hourly Well Water Usage (M <sup>3</sup> )
7:30	80907	--
8:00	80909	2
9:00	80912	3
10:00	80915	3
11:00	80916.5	1.5
12:00 pm	80917	0.5
1:00	80922	5
2:00	80925	3
3:00	80928	3
4:00	80928	0

## Appendix 3. Consumption of Well Water (14 July 1993, Thursday)

Time of Day	Water Meter Reading	Hourly Well Water Usage (M <sup>3</sup> )
8:00	95998	--
9:00	96008	10
10:00	96018	10
11:00	96028	10
12:00 pm	96030	2
1:00	96032	2
2:00	96032	0
3:00	96035	1
4:00	96036	2
5:00	96036	1
6:00	96036	0
7:00	96036	0

Appendix 4. The Consumption of City and Well Water (Anonymous, 1994)

Month	Total City Water used (kL)	Total City W. used for Prod. (kL)	City W. used on Production Day (kL/day)	Total Well Water used (kL)	Well Water used on Production Day (kL/day)
Aug., 93	10,389	N/A <sup>1</sup>	404.90 (21 day) <sup>2</sup>	1,182	54.67 (21 day) <sup>2</sup>
Sept.	8,348	119	347.29 (21)	1,227	57.62 (21)
Oct.	8,239	117	338.65 (20)	1,107	53.10 (20)
Nov.	9,039	110	368.52 (21)	888	40.67 (21)
Dec.	8,901	108	359.62 (21)	760	34.14 (21)
Jan., 94	9,338	98	369.24 (21)	733	33.76 (21)
Feb.	8,730	101	374.40 (20)	671	32.55 (20)
Mar.	9,866	212	375.39 (23)	927	38.39 (23)
Apr.	9,749	241	389.25 (20)	730	33.90 (20)
May	8,452	229	350.76 (21)	705	32.29 (21)
June	10,547	N/A <sup>1</sup>	422.86 (22)	936	40.86 (22)
July	10,788	N/A <sup>1</sup>	450.10 (20)	737	34.90 (20)

<sup>1</sup> The numbers were not available.

<sup>2</sup> The numbers of production days in a month.

## Appendix 5. Consumption of City Water (20 January 1993, Wednesday)

Time of Day	Water Meter Reading	Hourly Water Usage (M <sup>3</sup> )
8:55 am	45471	--
9:55	45487	16
10:55	45499	12
11:55	45517	18
12:55 pm	45529	12
1:55	45547	18
2:55	45569	22
3:55	45586	39
4:55	45605	19
5:55	45647	42
6:55	45666	19
7:55	N/A <sup>1</sup>	--
8:55	N/A <sup>1</sup>	--
9:55	45716	50 (3 hours)
10:55	45736	20
11:55	N/A <sup>1</sup>	--
12:55	45762	26 (2 hours)

<sup>1</sup> The readings were not available.

## Appendix 6. Consumption of City Water (26 January 1993, Tuesday)

Time of Day	Water Meter Reading	Hourly Water Usage (M <sup>3</sup> )
6:40 am	47105	--
7:40	47121	16
8:40	47134	13
9:40	47152	18
10:40	47169	17
11:40	47188	19
12:40 pm	47211	23
1:40	47227	14
2:40	47245	18
3:40	47258	13
4:40	47282	24
5:40	47299	17
6:40	47314	15
7:40	47327	13
8:40	47347	20
9:40	47364	17

## Appendix 7. Consumption of City Water (08 February 1993, Monday)

Time of Day	Water Meter Reading	Hourly Water Usage (M <sup>3</sup> )
7:35 am	50694	--
8:35	50707	13
9:35	50720	13
10:35	50736	16
11:35	50752	16
12:35 pm	50764	12
1:35	50787	23
2:35	50804	17
3:35	50822	18
4:35	50841	19
5:35	50858	17
6:35	50874	16
7:35	50889	15
8:35	50911	22
10:00	50950	39
11:35	50967	17
12:15	50979	12

## Appendix 8. Consumption of City Water (23 March 1993, Tuesday)

Time of Day	Water Meter Reading	Hourly Water Usage (M <sup>3</sup> )
7:15 am	62986	--
8:00	62993	7
9:00	63004	11
10:00	63015	11
11:00	63030	15
12:00 pm	63039	9
1:00	63050	11
2:00	63069	19
3:00	63083	14
4:00	63105	22
5:00	63129	24
6:00	63149	20
7:00	63165	16
8:00	63183	18
9:00	63200	17
10:00	63215	15
11:00	63231	16
12:00	63246	15



## Appendix 9. Consumption of City Water (14 July 1993, Thursday)

Time of Day	Water Meter Reading	Hourly Water Usage (M <sup>3</sup> )
8:00 am	209948	--
9:00	209963	15
10:00	209978	15
11:00	209996	18
12:00 pm	210011	15
1:00	210027	16
2:00	210048	21
3:00	210070	22
4:00	210089	19
5:00	210111	22
6:00	210127	16
7:00	210141	14
8:00	210158	17
9:00	210181	23
10:00	210195	14

## Appendix 10a.

Dairy effluent analysis of hourly samples collected from Area A which includes drains from the milk storage, mix pasteurizer, ice cream tank, packaging (except 1 liter and 2 liter machines), case room and CIP system areas on **20 January 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
6:45-7:45 am	7.35	80	1,560
7:45-8:45	7.08	170	2,091
8:45-9:45	7.03	100	1,119
9:45-10:45	8.03	160	935
10:45-11:45	8.07	100	655
11:45-12:45 pm	8.44	100	617
12:45-1:45	11.15	300	1,339
1:45-2:45	9.85	660	6,180
2:45-3:45	7.50	180	838
3:45-4:45	7.85	150	882
4:45-5:45	8.84	120	382
5:45-6:45	9.67	80	493
6:45-7:45	10.86	120	1,318
7:45-8:45	4.87	1,420	14,718
8:45-9:45	10.80	90	3,196
9:45-10:45	10.00	70	522
10:45-11:45	10.34	80	536

Appendix 10b. Dairy effluent analysis of hourly samples collected from **Area A** which includes drains from the milk storage, mix pasteurizer, ice cream tank, packaging (except 1 liter and 2 liter machines), case room and CIP system areas on **26 January 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
6:30-7:30 am	6.85	10	769
7:30-8:30	7.25	220	1,796
8:30-9:30	7.85	200	1,722
9:30-10:30	7.02	40	537
10:30-11:30	10.07	50	1,980
11:30-12:30 pm	11.82	100	916
12:30-1:30	10.69	110	916
1:30-2:30	8.41	90	835
2:30-3:30	9.42	250	2,740
3:30-4:30	9.60	100	941
4:30-5:30	9.71	100	1,613
5:30-6:30	9.40	20	386
6:30-7:30	8.87	450	7,506
7:30-8:30	10.92	130	2,444
8:30-9:30	9.14	48	736
9:30-10:30	11.20	0	454

Appendix 10c. Dairy effluent analysis of hourly samples collected from **Area A** which includes drains from the milk storage, mix pasteurizer, ice cream tank, packaging (except 1 liter and 2 liter machines), case room and CIP system areas on **08 February 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
7:30-8:30 am	7.14	240	1,656
8:30-9:30	9.37	60	513
9:30-10:30	9.60	400	4,438
10:30-11:30	9.20	120	1,225
11:30-12:30 pm	8.79	90	596
12:30-1:30	8.90	100	712
1:30-2:30	11.10	190	961
2:30-3:30	7.42	90	928
3:30-4:30	11.24	50	580
4:30-5:30	8.22	1,000	6,358
5:30-6:30	9.13	120	629
6:30-7:30	9.40	300	6,294
7:30-8:30	7.01	1,640	7,784
8:30-9:30	6.36	300	2,583
9:30-10:30	9.75	240	1,623
10:30-11:30	10.30	95	828

Appendix 10d. Dairy effluent analysis of hourly samples collected from **Area A** which includes drains from the milk storage, mix pasteurizer, ice cream tank, packaging (except 1 liter and 2 liter machines), case room and CIP system areas on **23 March 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
7:15-8:00 am	6.75	50	303
8:00-9:00	8.99	224	769
9:00-10:00	N/A <sup>1</sup>	N/A <sup>1</sup>	N/A <sup>1</sup>
10:00-11:00	7.38	50	368
11:00-12:00 pm	10.04	72	867
12:00-1:00	9.15	140	1,320
1:00-2:00	10.98	460	1,612
2:00-3:00	11.04	210	2,098
3:00-4:00	6.09	220	1,568
4:00-5:00	9.70	128	1,276
5:00-6:00	9.76	430	4,367
6:00-7:00	10.61	210	1,811
7:00-8:00	10.98	152	239
8:00-9:00	10.26	460	1,774
9:00-10:00	11.03	105	484
10:00-11:00	9.26	104	258

<sup>1</sup> The sample was not available for analysis.

Appendix 11a. Dairy Effluent Analysis of hourly samples collected from **area B** which includes drains from 1 liter and 2 liter packaging machines and the engineering room on **20 January 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
6:45-7:45 am	4.73	600	19,295
7:45-8:45	4.23	1,200	33,561
8:45-9:45	7.40	150	6,187
9:45-10:45	7.87	60	3,903
10:45-11:45	7.98	70	3,653
11:45-12:45 pm	7.88	120	5,185
12:45-1:45	7.95	70	3,903
1:45-2:45	7.55	1,110	14,801
2:45-3:45	7.84	190	6,261
3:45-4:45	7.47	320	5,922
4:45-5:45	10.23	60	4,154
5:45-6:45	2.46	370	2,371
6:45-7:45	10.50	40	3,425
7:45-8:45	7.06	200	3,181
8:45-9:45	10.65	220	751
9:45-10:45	2.25	290	3,284
10:45-11:45	8.09	60	5,627

Appendix 11b. Dairy Effluent Analysis of hourly samples collected from **area B** which includes drains from 1 liter and 2 liter packaging machines and the engineering room on **26 January 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
7:00-7:30 am	4.42	0	16,422
7:30-8:30	4.76	350	6,659
8:30-9:30	6.86	2,050	12,001
9:30-10:30	6.93	60	2,710
10:30-11:30	6.91	130	2,722
11:30-12:30 pm	7.42	350	4,183
12:30-1:30	7.30	0	2,776
1:30-2:30	7.57	350	4,404
2:30-3:30	N/A <sup>1</sup>	N/A <sup>1</sup>	N/A <sup>1</sup>
3:30-4:30	7.48	290	4,191
4:30-5:30	6.85	200	3,196
5:30-6:30	3.34	90	1,930
6:30-7:30	6.54	30	1,678
7:30-8:30	11.50	24	861
8:30-9:30	2.60	30	964
9:30-10:30	7.23	0	764

<sup>1</sup> The sample was not available for analysis.

Appendix 11c. Dairy Effluent Analysis of hourly samples collected from **area B** which includes drains from 1 liter and 2 liter packaging machines and the engineering room on **08 February 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
7:30-8:30 am	4.10	900	11,262
8:30-9:30	6.40	320	7,784
9:30-10:30	5.94	280	7,620
10:30-11:30	6.01	230	9,008
11:30-12:30 pm	6.37	560	7,951
12:30-1:30	6.44	320	6,958
1:30-2:30	6.23	600	5,964
2:30-3:30	6.42	560	7,620
3:30-4:30	6.47	880	15,236
4:30-5:30	6.41	600	7,949
5:30-6:30	6.37	300	3,610
6:30-7:30	6.04	170	3,179
7:30-8:30	6.32	300	4,173
8:30-9:30	6.46	220	3,511
9:30-10:30	6.30	160	3,148
10:30-11:30	11.60	95	4,703



Appendix 11d. Dairy Effluent Analysis of hourly samples collected from **area B** which includes drains from 1 liter and 2 liter packaging machines and the engineering room on **23 March 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
7:20-8:00 am	6.15	840	5,469
8:00-9:00	5.94	1,240	7,706
9:00-10:00	5.36	880	3,847
10:00-11:00	6.60	760	2,226
11:00-12:00 pm	6.63	920	8,990
12:00-1:00	6.58	1,000	11,140
1:00-2:00	6.54	1,920	16,121
2:00-3:00	6.52	1,840	3,804
3:00-4:00	6.26	2,080	5,749
4:00-5:00	1.95	3,200	20,335
5:00-6:00	N/A <sup>1</sup>	N/A <sup>1</sup>	N/A <sup>1</sup>
6:00-7:00	5.99	260	5,502
7:00-8:00	7.03	1,280	2,508
8:00-10:00	10.15	230	4,886

<sup>1</sup> The sample was not available for analysis.

Appendix 12a. Dairy Effluent Analysis of hourly samples collected from **area C** which includes drains from the milk pasteurizer area on **20 January 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
8:30-9:30 am	6.68	210	4,419
9:30-10:30	6.98	240	2,179
10:30-11:30	12.12	200	2,091
11:30-12:30 pm	11.83	90	1,324
12:30-1:30	12.55	290	2,828
1:30-2:30	9.90	210	2,164
2:30-3:30	10.60	220	3,977
3:30-4:30	7.24	170	2,385
4:30-5:30	7.65	480	3,019
5:30-6:30	8.20	210	2,077
6:30-7:30	12.24	486	2,777
7:30-8:30	12.29	30	781

Appendix 12b. Dairy Effluent Analysis of hourly samples collected from **area C** which includes drains from the milk pasteurizer area on **26 January 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
6:30-7:30 am	6.75	1,000	5,554
7:30-8:30	6.72	650	6,143
8:30-9:30	6.75	1,180	9,091
9:30-10:30	6.80	150	5,627
10:30-11:30	6.68	2,320	9,938
11:30-12:30 pm	11.39	550	3,586
12:30-1:30	7.30	620	4,729
1:30-2:30	9.40	80	688
2:30-3:30	8.90	560	4,803
3:30-4:30	6.49	170	5,333
4:30-5:30	7.65	120	677
5:30-6:30	11.89	100	323
6:30-7:30	11.31	16	206
7:30-8:30	8.20	0	88

Appendix 12c. Dairy Effluent Analysis of hourly samples collected from **area C** which includes drains from the milk pasteurizer area on **08 February 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
7:15-8:30 am	6.86	2,130	2,583
8:30-9:30	6.78	2,100	16,561
9:30-10:30	12.17	320	1,987
10:30-11:30	11.31	2,010	4,305
11:30-12:30 pm	7.23	2,430	3,709
12:30-1:30	7.07	400	5,266
1:30-2:30	6.94	250	2,981
2:30-3:30	6.90	190	1,888
3:30-4:30	11.40	400	696
4:30-5:30	8.22	160	1,060
5:30-6:30	8.60	220	2,683
6:30-7:30	7.95	225	2,451

Appendix 12d. Dairy Effluent Analysis of hourly samples collected from **area C** which includes drains from the milk pasteurizer area on **23 March 1993**.

Time	pH	Suspended Solids (mg/L)	COD (mg/L)
7:10-8:00 am	7.13	180	1,730
8:00-9:00	7.05	170	1,807
9:00-10:00	7.12	190	1,762
10:00-11:00	11.64	160	1,584
11:00-12:00 pm	7.13	640	4,171
12:00-1:00	7.20	680	4,495
1:00-2:00	7.08	320	2,617
2:00-3:00	7.18	140	996
3:00-4:00	11.52	400	2,475
4:00-5:00	10.30	52	466
5:00-6:00	8.14	100	660

Appendix 13. The determination of BOD/COD ratio from samples obtained from area A, B, and C.

Area	BOD (mg/L)	COD (mg/L)	BOD/COD Ratio
A	850	1,560	0.54
	550	935	0.59
	2,670	6,180	0.43
	487	838	0.58
	400	882	0.45
	930	1,383	0.67
	715	1,656	0.43
	265	513	0.52
	320	596	0.54
	313	712	0.44
	2,970	6,358	0.47
	267	629	0.42
	687	867	0.79
	646	1,320	0.49
	957	1,612	0.59
	1,275	2,098	0.61
	1,030	1,568	0.66
	870	1,276	0.68
	4,550	4,367	1.04
	750	1,811	0.41
B	3,200	6,187	0.52
	2,310	3,903	0.59
	2,340	3,653	0.64
	2,980	5,185	0.57
	7,740	14,801	0.52

Appendix 13 continued. The determination of BOD/COD ratio from samples obtained from area A, B, and C.

Area	BOD (mg/L)	COD (mg/L)	BOD/COD Ratio
B	3,270	6,261	0.52
	3,070	5,922	0.52
	800	2,371	0.34
	1,500	3,181	0.47
	6,640	11,262	0.59
	4,550	7,784	0.58
	4,430	7,951	0.56
	3,330	6,958	0.48
	3,700	7,949	0.47
	1,815	3,610	0.50
	3,130	5,469	0.57
	4,403	7,706	0.57
	2,218	2,226	1.00
	3,337	8,990	0.37
	3,767	11,140	0.34
	5,700	16,121	0.35
	4,850	5,749	0.84
7,250	20,335	0.36	
2,600	5,502	0.47	
C	2,817	4,419	0.64
	985	2,385	0.41
	975	2,583	0.38
	8,300	16,561	0.50
	1,850	3,709	0.50
	3,015	5,266	0.57
	480	1,060	0.45

Appendix 13 continued. The determination of BOD/COD ratio from samples obtained from area A, B, and C.

Area	BOD (mg/L)	COD (mg/L)	BOD/COD Ratio	
C	1,100	2,683	0.41	
	1,383	1,730	0.80	
	1,421	1,762	0.81	
	1,221	1,584	0.77	
	1,985	4,171	0.48	
	1,275	4,495	0.28	
	1,475	2,617	0.56	
	870	996	0.87	
	1,425	2,476	0.58	
	315	466	0.68	
	345	660	0.52	
		Average: (n=62)		0.55 ±0.15



Appendix 14a. Standard plate count (SPC), coliform, and temperature of samples collected on day 1 of operation of the reclaim system.

Day, Time of Operation	Site	SPC (cfu/mL) <sup>1</sup>	Coliforms (cfu/mL) <sup>1</sup>	Temp. °C
1, A.M.	Balance tank without reclaim milk	$4.3 \times 10^5$	$7.4 \times 10^3$	3.6
	Balance tank with reclaim milk	$3.8 \times 10^5$	$7.7 \times 10^3$	3.6
	Separator out	$3.1 \times 10^2$	< 1	60.1
	Hose out	$4.6 \times 10^2$	< 1	40.1
1, P.M.	Balance tank without reclaim milk	$3.9 \times 10^4$	$7.0 \times 10^1$	5.3
	Balance tank with reclaim milk	$3.0 \times 10^4$	$8.0 \times 10^1$	5.3
	Separator out	$9.2 \times 10^2$	< 1	63.5
	Hose out	$9.3 \times 10^2$	< 1	44.4

<sup>1</sup> Results were the mean of duplicate samples.

Appendix 14b. Standard plate count (SPC), coliform, and temperature of samples collected on day 6 of operation of the reclaim system.

Day, Time of Operation	Site	SPC (cfu/mL) <sup>1</sup>	Coliforms (cfu/mL) <sup>1</sup>	Temp. °C
6, A.M.	Balance tank without reclaim milk	$1.5 \times 10^4$	$1.9 \times 10^2$	2.8
	Balance tank with reclaim milk	$1.3 \times 10^4$	$1.5 \times 10^2$	3.2
	Separator out	$8.1 \times 10^2$	< 1	64.1
	Hose out	$9.4 \times 10^2$	< 1	43.9
6, P.M.	Balance tank without reclaim milk	$2.3 \times 10^4$	$1.5 \times 10^2$	2.8
	Balance tank with reclaim milk	$2.0 \times 10^4$	$1.3 \times 10^2$	2.8
	Separator out	$8.4 \times 10^2$	< 1	56.1
	Hose out	$1.1 \times 10^3$	< 1	41.7

<sup>1</sup> Results were the mean of duplicate samples.

Appendix 14c. Standard plate count (SPC), coliform, and temperature of samples collected on day 11 of operation of the reclaim system.

Day, Time of Operation	Site	SPC (cfu/mL) <sup>1</sup>	Coliforms (cfu/mL) <sup>1</sup>	Temp. °C
11, A.M.	Balance tank without reclaim milk	$5.1 \times 10^4$	$1.1 \times 10^3$	2.0
	Balance tank with reclaim milk	$3.6 \times 10^4$	$1.0 \times 10^3$	1.9
	Separator out	$4.6 \times 10^2$	< 1	61.6
	Hose out	$4.1 \times 10^2$	< 1	44.7
11, P.M.	Balance tank without reclaim milk	$1.9 \times 10^4$	$7.8 \times 10^1$	4.9
	Balance tank with reclaim milk	$1.9 \times 10^4$	$9.4 \times 10^1$	4.9
	Separator out	$5.3 \times 10^2$	< 1	61.8
	Hose out	$6.5 \times 10^2$	< 1	45.4

<sup>1</sup> Results were the mean of duplicate samples.

Appendix 14d. Standard plate count (SPC), coliform, and temperature of samples collected on day 21 of operation of the reclaim system.

Day, Time of Operation	Site	SPC (cfu/mL) <sup>1</sup>	Coliforms (cfu/mL) <sup>1</sup>	Temp. °C
21, A.M.	Balance tank without reclaim milk	$3.4 \times 10^4$	$9.7 \times 10^2$	2.6
	Balance tank with reclaim milk	$3.6 \times 10^4$	$6.4 \times 10^2$	2.6
	Separator out	$6.9 \times 10^2$	< 1	61.7
	Hose out	$7.9 \times 10^2$	< 1	41.7
21, P.M.	Balance tank without reclaim milk	$1.2 \times 10^4$	$6.3 \times 10^2$	4.5
	Balance tank with reclaim milk	$1.2 \times 10^4$	$5.4 \times 10^2$	4.5
	Separator out	$4.5 \times 10^2$	< 1	60.9
	Hose out	$6.3 \times 10^2$	< 1	40.8

<sup>1</sup> Results were the mean of duplicate samples.

Appendix 15. Operational parameters (flow rate and residence time) of the reclaim system at various time and days of operation.

Day, time of operation	Flow rate <sup>1</sup> (mL/min)	Residence Time <sup>1</sup> (seconds)
1, am	120	61.32
1, pm	98	75.08
6, am	188	39.14
6, pm	132	55.74
11, am	116	63.43
11, pm	118	62.36
21, am	102	72.14
21, pm	112	65.70

<sup>1</sup> Results were the mean of duplicate samples.

Appendix 16. The acid degree value of the balance tank samples with and without the incorporation of reclaim milk.

Day, Time of Operation	Acid Degree Value	
	Balance tank without reclaim milk	Balance tank with reclaim milk
1, A.M.	1.07	0.90
1, P.M.	1.04	0.82
6, A.M.	0.86	1.16
6, P.M.	1.11	1.22
11, A.M.	0.78	0.72
11, P.M.	0.72	0.66
21, A.M.	0.81	0.82
21, P.M.	0.71	0.73
Average:	0.89 ± 0.16	0.88 ± 0.21

<sup>1</sup> Results were the mean of duplicate samples.

Appendix 17. Acid degree values of 2% milk and 10% cereal cream at expired date.

Sample	Code Date	With/without Reclaim Milk	Acid Degree Value
2% Milk	April 17, 93	Without	0.71
	April 24	Without	0.72
	May 01	Without	0.75
	March 14, 94	Without	0.69
	March 18	Without	0.68
		<b>Average:</b>	<b>0.71 ± 0.02</b>
2% Milk	May 15, 93	With	0.78
	May 21	With	0.78
	June 6, 94	With	0.65
	June 13	With	0.65
	September 23, 94	With	0.64
		<b>Average:</b>	<b>0.70 ± 0.07</b>
10% Cereal	March 15, 93	Without	0.62
	April 17	Without	0.75
	April 23	Without	0.69
	May 01	Without	0.68
			<b>Average:</b>
10% Cereal	May 15, 93	With	0.77
	May 24	With	0.75
	June 14	With	0.61
	September 24, 94	With	0.63
		<b>Average:</b>	<b>0.69 ± 0.07</b>

<sup>1</sup> The acid degree value was an average of 2 samples.

Appendix 18. Name, recommended strengths and supplier of the detergents used in the membrane study.

Trade Name	Chemicals for CIP	Recommended strength	Supplier
AC 101	Sodium Hydroxide	0.5% (prewash) 1.5% (regular)	Klenzade
Liquid Super Klenz	Sodium Hydroxide Sodium Hypochloride	7,000 ppm alk. (CIP) 10,000 ppm alk. (COP)	Klenzade
AC - Special	Phosphoric Acid Nitric Acid	2.5% (or pH 1.2)	Klenzade
Stabicip Therm (add to regular AC 101 wash)	Sequestrant Sodium Hydroxide Soap Organic Salt	0.75%	Klenzade



Appendix 19. Formulation for calculating % removal in micromembrane process.

$$\% \text{ Removal} = \frac{(\text{mg/L starting material} * 1) - (\text{mg/L permeate} * \text{permeate volume ratio} / (\text{permeate} + \text{retentate}))}{\text{mg/L starting material} * 1} * 100\%$$

Appendix 20. Theoretical reduction of water used in the preparation of detergents.

Regular usage of water in the preparation of detergents per day:

CIP tank (tanker wash bay)	760 litres
CIP tank (pasteurized side)	$1520 * 2 = 3,040$ litres
Raw silos wash-up	$492 * 8 = 4,000$ litres
Mix HTST (1 pre-wash and 2 regular wash)	$570 * 3 = 1,710$ litres
Milk HTST (1 pre-wash and 2 regular wash)	$836 * 3 = 2,508$ litres
<b>Total:</b>	<b>12,018 litres</b>

Total detergent solution recovered per day (Assumption: permeate/retentate concentration ratio is 4:1):

$$12,018 \text{ litres} * 4/5 = 9,614 \text{ litres}$$

## Appendix 21. Theoretical reduction of chemicals (Superkrenz).

Regular usage of Super Krenz : 7.49 mL/L of water  
(7,000 ppm alkalinity)

**1. Truck Wash-up (Tanker Wash Bay)**

Size of CIP tank:	760 liters
Strength of Super Krenz after treatment: (table 4a)	5,820 ppm
Strength to replenish:	$7,000 - 5,820 = 1,280$ ppm
Super Krenz required:	$(7.49 \text{ mL/L} * 1,280) / 7,000 * 760 \text{ L}$ = 1 Liter
Super Krenz required without treatment: (fresh)	$7.49 * 760 \text{ L}$ = 5.7 Liters

**2. CIP Tank (Pasterized side)**

Size of CIP tank (filled up twice daily):	1,520 Liters (2x)
Strength of Super Krenz after treatment: (table 2a)	1,800 ppm
Strength to replenish:	$7,000 - 1,800 = 5,200$ ppm
Super Krenz required:	$(7.49 \text{ mL/L} * 5,200) / 7,000 * 1,520 * 2$ = 17 Liters
Super Krenz required without treatment: (fresh)	$7.49 \text{ mL/L} * 1,520 * 2$ = 23 Liters

**3. Raw Silos Wash-up**

Regular usage:	8 batches * 492 Liters (130 gallons) = 4,000 Liters
Strength of Super Krenz after treatment: (table 2a)	1,800 ppm
Strength to replenish:	$7,000 - 1,800 = 5,200$ ppm
Super Krenz required:	$(7.49 \text{ mL/L} * 5,200) / 7,000 * 4,000 \text{ L}$ = 22 Liters
Super Krenz required without treatment: (fresh)	$7.49 \text{ mL/L} * 4,000 \text{ L}$ = 30 Liters

**Total Super Krenz required without treatment: 58.7 Liters**

**Total Super Krenz required with treatment: 40 Liters**

**Reduction of Super Krenz: 18.7 Liters**

## Appendix 22. Theoretical reduction caustic (AC 101).

Regular usage of caustic per day:

Mix HTST (1 pre-wash and 2 regular wash)	28 L
Milk HTST (1 pre-wash and 2 regular wash)	52 L
Total:	80 L

Total caustic recovered (Assumption: permeate/retentate concentration ratio is 4:1):

$$80 \text{ L} * 4/5 = 64 \text{ L}$$

## Appendix 23. Theoretical BOD calculation using effluent 1 as an example.

	Starting Materials	Permeate
From Table 42,		
Fat (mg/L)	3,387.66	7.25
Protein (mg/L)	1,514.79	12.80
Carbohydrate (mg/L)	5,783.35	4,287.19
lb of BOD of component ratio <sup>1</sup>		
Fat		0.89
Protein		1.03
Carbohydrate		0.65
Theoretical BOD (mg/L)	8,334.43	2,806.31
% Removal of BOD:	$\frac{(8,334.43 * 1 - 2,806.31 * 3/4)}{8,334.43 * 1} * 100\%$	
	= 74.75%	

<sup>1</sup> (U.S. Environmental Protection Agency, 1971)

## Appendix 24. Theoretical BOD calculation using effluent 2 as an example.

	Starting Materials	Permeate
From Table 43,		
Fat (mg/L)	3,989.73	6.97
Protein (mg/L)	1,593.31	13.77
Carbohydrate (mg/L)	5,603.78	4,735.97
lb of BOD of component ratio <sup>1</sup>		
Fat		0.89
Protein		1.03
Carbohydrate		0.65
Theoretical BOD (mg/L)	8,834.43	3,098.77
% Removal of BOD:	$\frac{(8,834.43 * 1 - 3,098.77 * 3/4)}{8,834.43 * 1} * 100\%$	
	= 73.69%	

<sup>1</sup> (U.S. Environmental Protection Agency, 1971)

## Appendix 25. Estimated economics of the application of reclaim system.

Parameter	\$
<b>Start-up Cost:</b>	
1. Microsteel system (CRS-100)	85,500 US 122,300 Can.
2. Energy Cost per Year (6.34 kw * 22 hrs/day * 240 working days * 0.056/kwh)	1,875
3. Optic sensor (estimation) 3 * \$700 each	2,100
First year estimated investment (without including plant modification):	126,275
<b>Savings:</b>	
1. Chemicals (64 L * \$1.08/L) + (19 L * \$1.34/L) * 240 working days	22,699
2. Surcharges	44,000 - 108,000
3. Water 9.6 kL * \$0.31/kL * 240 working days	714
Estimated Maximum Saving:	131,413