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Adaptability of Membranes for Dairy Waste Management

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Abstract : Membranes produce a higher quality effluent than achieved using conventional filtration as a final polishing step in dairy Industry. Designed to simplify wastewater treatment, the membrane process replaces secondary clarifiers. Membranes are immersed directly in the bioreactor and operate at high levels of MLVSS (12,000-15,000 ppm) resulting in plant footprints up to 4 times smaller than conventional systems. This treatment process allows for long sludge retention times (up to 75 days), decreasing sludge production up to 70%. In addition the membranes are capable of being used with chemical treatment (phosphorus precipitation). The Membrane process offers the ideal solution for wastewater reuse applications, producing high quality effluent suitable for direct reuse in a single step process. The effluent is also ideally suited as an RO feed. Regardless of the feed water, membranes consistently produce an ideal RO feed, typically yielding a SDI < 3. This process provides significant advantages over conventional technologies where wastewater must be treated by a multi-step process prior to reuse. The development of electrically conducting membranes will control fouling and separation properties in the treatment of industrial effluent by adjusting surface charge. There is a real awareness that membrane technology will have a vital energy and environmental role to play in the dairy industry in the next ten years.
Key words : membrane, effluent treatment, dairy waste, zenon.

Introduction :

Dairy industry seeks cost-effective treatment technologies to remove organic matter and nitrogen from food processing wastewater containing high levels of suspended solids and nitrogenous compounds (Gadgil,1978). In the dairy industry re-use and multi-use cleaning-in-place (CIP) systems are operated by circulating chemicals and water without taking the equipment apart. The solutions, which become polluted due to the removal of fouling compounds, are drained periodically when they are considered to be too polluted. In the dairy industry re-use and multi-use cleaning-in-place (CIP) systems are operated by circulating chemicals and water without taking the equipment apart. The solutions, which become polluted due to the removal of fouling compounds, are drained periodically when they are considered to be too polluted. The large variations has occurred in composition (pollution, surface tension, etc) of the industrial caustic solutions coming from milk standardization and pasteurization plant CIP throughout their life time (7 days) and from 1 week to another. The work is also intended to show

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how nanofiltration [1 kg mol(-1) molecular weight cut-off] was robust and performed well, with good recovery of caustic solutions, even when faced with large variations of solutions composition: high caustic yield, permeation flux (J) in the range 42-110 l h(-1) m(-2), average chemical oxygen demand (COD) reduction equal to 0.58 and low surface tension change. Equations have been established for the prediction of J as a function of initial membrane hydraulic resistance (Rm) caustic concentration, volume reduction ratio (VRR) and initial soluble COD. When VRR increased, both J and pollution retention decreased despite the increase in irreversible fouling induced by the increase of soluble pollution concentration in retentate. The higher the initial soluble COD, the sharper is the decrease in J vs. VRR. Since irreversible fouling was usually small (0.1-3.4 × 10(13) m(-1), that is to say of the same order of magnitude as Rm), the membrane cleaning could be efficiently performed by using single phase sodium hypochlorite alternately with a more expensive acid-base cleaning sequence. The obtained permeate was a clear regenerated cleaning solution with low soluble COD (0.2-3.5 g/l) and surface tension (56-30 mJ m(-2)) which could be successfully exploited owing to its cleaning potential (Gesan-Guiziou *et al*., 2002).

Enforcement of wastewater discharge regulations and escalating sewage surcharges have forced the food processing industry to look for cost-effective technologies to provide pretreatment or complete treatment of their wastewater. Especially in the last five to ten years, because of increasing enforcement pressure to comply with wastewater discharge permits for constructing new and upgrading existing treatment plant. Regional pollution control authorities are applying more pressure on industries to reduce their organic BOD and chemical oxygen demand (COD) and solids loading to the sewers. Dairy and Food processing wastewaters are particularly targeted because of the high BOD concentrations typically contained, especially high-strength wastewaters with high levels of suspended solids, ammonia and protein compounds (Jones, 1974). Food processors are looking for cost-effective and application-specific treatment technologies to manage their wastewaters effectively.

The use of membranes for treatment of water and wastewater has increased in the last several years. This increase is because the membranes produce a higher quality effluent than achieved using sand filtration as a final polishing step. During this period, there have been improvements in membrane performance and reliability, as well as a decrease in the cost of membranes, which corresponds to an increase in the number of manufacturers. As fresh water becomes increasingly scarce, membranes will play a more important role in the production of water for subsequent use (*i.e.*, treatment of wastewater for reuse). This will help utilities continue to provide safe, clean, and affordable water for dairy and food Industry.

Table 1 : Wastewater Characteristics of Dairy

Parameter (Mg/lt)	Milk Processing	Integrated Dairy	Chilling Plant
BOD	657-1,016	1,634-4,953	55-5,034
COD	1,341-2,195	3,800-8,631	121-6,877
Suspended solids	538-657	89-4’953	36-899
Nitrogen	50.25	96.32	49.25-72.5
Fat	-	100-6,070	-
Phosphorus	2.6-4.8	0.3-0.8	0.14-0.2
Chloride	-	104	-
*p*H	6.6-6.9	5.6-6.8	2.9-10.7
Oil & Grease	-	280-2,207	5-176

Current Technologies :

The primary means of reducing BOD in food processing wastewaters is through biological treatment. Land applications including aerobic treatment such as ponds and lagoons are also used. Both aerobic and anaerobic technologies have been used, while anaerobic treatment of wastewater has emerged as an economical and viable alternative for conventional aerobic treatment particularly for high BOD wastewaters (Green, 1979). Aerobic technologies include trickling filter, activated sludge, rotating biological contactors, oxidation ditch, sequencing batch reactor and even controlled wetlands. Anaerobic technologies currently available are high-rate systems including continuous-flow stirred tank reactor, contact reactor, up flow sludge blanket, anaerobic filter (up flow and down flow), expanded or fluidized bed and two-stage systems that separate the acid-forming and the methane-forming phases of the anaerobic process. In many cases, aerobic and anaerobic processes are combined in one treatment system. Anaerobic treatment is used for removing organic matter in higher concentration streams, and aerobic treatment is used on lower concentration streams or as a polishing step to further remove residual organic matter and nutrients from the wastewater.

Existing bio-treatment processes have a number of outstanding difficulties listed below :

- Start up and restart problems with processes
- Biomass separation, sludge settlement, foaming and scum formation
- Inadequate process stability and resistance to shock
- Loads and toxins
- Odors associated with treatment
- Excessive biomass generation and sludge production
- Removal of nitrogen and phosphorus
- Biodegradation of fats, oils and grease

- Removal of specific types of pollutants, such as color bodies
- Destruction of disease-causing microorganisms that may be present in the wastewater

For most food processing wastes, biotreatability data are available for the design of the treatment plant without intermediate laboratory and pilot studies. Suppliers have already installed such plants at several similar factories using common design principles and manuals. However, there are still many wastes for which treatability data are not available or where the processing operations are significantly different (Khojare, 2002). Although the number of anaerobic installations has grown significantly over the past few years, the feedback of useful operating information is relatively slow.

Table 2 : Characteristics of Dairy Effluents

Parameter (mg/lt)	Concentration	
	Untreated effluent	Treated Effluent
pH	7.5	5.5-9.0
Total Solids	2010	-
Total dissolved solids	1360	<2100
Total Suspended solids	650	<100
BOD	1200	<30
COD	2000	<100
Oil & Grease	320	<10

Emerging Technologies :

Effective handling of high levels of suspended solids (>2%) in the wastewater is still a challenge for most of these current technologies.

a) Thermophilic Processing
b) Bioadditives
c) Biodenitrification
d) Hydrothermal Processing
e) Solvent Extraction
f) Membrane technology

Membrane (MBR) Technology :

Designed to simplify wastewater treatment, the MBR process replaces secondary clarifiers with membranes. The result is reduced capital and operating costs, increased reliability and high quality effluent at all times. Membranes are immersed directly in the bioreactor and operate at high levels of MLVSS (12,000-15,000 ppm) resulting in plant footprints up to 4 times smaller than conventional systems, as reported. The membranes form a physical barrier that prevents the passage of biomass and other impurities, even in the event of an upstream process upset. This treatment process allows for long sludge retention times (up to 75 days), decreasing sludge production up to 70%. Computer control systems ensure optimal plant operation, reducing operator intervention and chemical requirements. When a secondary treatment system already exists, membranes provide the ideal solution for effluent polishing by producing reliable, high quality permeates for discharge or reuse. The versatile membranes can be immersed in existing infrastructure or transportable tanks provided by 'ZENON'. Unlike conventional and other membrane filtration systems, membranes are tolerant to variable levels of suspended solids from upsets in the upstream biological process. In addition the membranes are capable of being used with chemical treatment (phosphorus precipitation).

Membranes can extend the life of current plant infrastructure, greatly reducing capital expenditures. (Khojare, 2003) Existing treatment plants can be converted to a MBR process by simply immersing membranes in existing biological reactors or clarifiers. This allows capacity to be immediately increased by several times, and upgrade the effluent to tertiary quality in a single step-process. The modular system can be easily expanded to match future plant waste flows by simply adding additional membranes in a just-in-time manner.

Reuse System :

The Membrane process offers the ideal solution for wastewater reuse applications, producing high quality effluent suitable for direct reuse in a single step process. The effluent is also ideally suited as an RO feed. Regardless of the feed water, membranes consistently produce an ideal RO feed, typically yielding a SDI <3. This process provides significant advantages over conventional technologies where wastewater must be treated by a multi-step process prior to reuse.

Conducting membranes :

Scientists of Waste Management and Pollution Control are working on more efficient treatment of wastewaters using advanced membranes. In particular, the development of electrically conducting membranes, which will control fouling and separation properties in the treatment of industrial effluent by adjusting surface charge. This research work seeks to develop conducting membranes fabricated from conducting polymers or from the application of conducting coatings to non-conducting substrates. It will look at synthesis and application of new substituted monomers in order to prepare co-polymers with appropriate properties.

Salient features :

- Conducting polymers based on polypyrrole suitable for membrane preparation can be readily synthesized and characterized using the facilities developed;

- Proof-of-concept at laboratory scale that conducting membranes can reduce fouling;
- Development of an innovative method for electrically charging the membrane;
- Selection of composite membrane structures for various applications; and
- Preparation of the control system for operating strategies.

A study recently sponsored by Beatrice Foods, Inc. and Conducted researchers at the University of Manitoba in Canada using Membrane System Specialists' Micro-Steel^{TM} stainless steel system proved the system can remove significant levels of fats proteins, and carbohydrates from waste cleaning materials generated during the processing of dairy products including fluid milk, ice cream, and cheese. According to the research findings published in the Journal of Dairy Science, The Micro-Steel^{TM} membrane system performed efficiently on samples from separator flushes, diluted flavored ice cream, and combined effluent, despite the much higher initial COD and suspended solids of these dairy effluents than of the controlled dairy products. While this dairy effluent is typically disposed of, the Canadian research team found that the use of the porous stainless steel micromembranes allow for up to an 89 percent recovery of the chemicals from the permeate stream. Membrane System Specialists' introduced the Mirco-Steel^{TM} system five years ago to offer industry leaders an effective process for meeting stricter regulations for waste management. The Micro-Steel^{TM} also produces both cost savings in chemical usage and a marketable by-product (MSS Fall 1996) http://www.mssincorporated.com/newsletters/vol6.html).

A wheat straw biofilter was evaluated for attenuating pollutants in dairy (milkhouse and milking parlor) wastewater. During the 14-day study, the biofilter was operated in a sequential aerobic-anaerobic mode in a temperature range of 8-14 degrees C. While the biofilter was very effective (89% removal) in attenuating total suspended solids and moderately effective (76% removal) in attenuating oil and grease, its effectiveness in attenuating chemical oxygen demand was low (37% removal). The biofilter was ineffective in attenuating nitrate, while its effectiveness in attenuating ammonium (20% removal) and total Kjeldahl nitrogen (15% removal) was low. The biofilter was not effective in attenuating ortho-phosphate, total phosphorus, and fecal coliform. Though microbial degradation accounted for some pollutant removal, filtration seemed to be the primary mechanism. Lower temperature of operation and high oil and grease concentration (that reduced nutrient transfer to the biofilm) decreased microbial activity, reducing pollutant attenuation. Biofilter performance could be enhanced by using residual heat in the wastewater to raise the operating temperature of the biofilter and by removing oil and grease prior to applying the wastewater to the biofilter (Shah *et al*., 2002).

Fouling experiments of nano-filtration (NF) and reverse osmosis (RO) are reported for treatment of the effluent of chemical-biological treatment plant and the original effluent of dairy industry respectively. In one study, a thin film composite type of spiral wound was used and fitted with flow-meters and pressure sensors (Turan *et al*, 2002). The feed water was stored into a feed tank and passed a fine filter and was pumped to membrane. Brine and permeate were recirculated back to the feed tank. Membrane fouling was investigated with 16 and 30% water recovery of a single membrane at different pressures and flow-rates for RO and NF membranes respectively. Fouling is evaluated with a relationship between relative flux (J/Jo) which is the ratio of the flux at any time during the fouling test to the initial flux and relative resistance (Rf/Rm) which is the ratio of fouling (cake) layer resistance to clean membrane resistance. Turbidity, conductivity, chemical oxygen demand (COD), total suspended solids (TSS) and total hardness were measured in the feed and permeate side of each membrane. The effluent total hardness concentrations of chemical-biological treatment plant were found greater than the influents. The results are presented in terms of the relative flux as a function of time related to hydrodynamic conditions and pollution characteristics of wastewater. The permeate water flux of RO membrane decreases more rapidly than NF membrane, the relative flux decreases with increasing the fouling layer resistance, Rf onto membrane surface. 50% the drop of permeate flux was observed for RO and NF membranes after 50 h and 80 h of operation, respectively. The fouling rate increases with an increase in the concentration of the wastewater constituents in the dairy industry. The relative flux decreased 10 and 20% with increasing chemical oxygen demand (COD) from 5,000 mgl-1 to 10,000 mgl-1 and from 45 mgl-1 to 450 mgl-1 for RO and NF membranes, respectively after 45 h of time. Fouling of membranes resulted in 100% increase of specific energy consumption as the relative permeate fluxes of NF and RO membranes decreased 30 and 40% respectively. The average of specific energy consumption was obtained at 6 and 10 kWhm-3; consequently, operational costs were estimated at U.S. $0.45 m-3 and U.S. $0.75 m-3 for NF and RO units respectively. Also, operational cost for chemical-biological treatment was found at U.S. $0.30 m-3 (Turan *et al*, 2002).

Conclusion :

There is a real awareness that membrane technology will have a vital energy and environmental role to play in the dairy industry in the next ten years. There is a demand for more investment and help in conducting this work.

In the dairy industry, greater use of membrane processes, as an alternative to conventional process will require:

- Development of cheaper and more efficient membranes with a longer life than the current average of seven years.
- Continued laboratory trials with ceramic layers and the development of novel ceramic supported polymer membranes.
- Development of high throughput ‘zeolite’ membranes and membranes for gas separation.
- Optimization of membrane supports and equipment in industrial trials.

- Development of new applications (mainly in waste treatment and food processing).
- Research into hybrid systems, eg a combination of solar evaporation and reverse osmosis.

Membrane technology replaces secondary clarifiers in the waste treatment plants with membranes. These are alternatives to biotreatment being used for BOD reduction in dairy wastewaters. Reverse osmosis has been installed at a dairy cheese plant to reduce BOD in the wastewater and allow direct discharge of the filtered water into a nearby creek. In this case the reduction of BOD is from 35-40 mg/ liter down to 8-9 mg/liter. The feed is evaporator condensate from a cheese-whey concentrator and is essentially 50% of the plant's discharge water. The result is reduced capital and operating costs, increased reliability and high quality effluent at all times. Membranes are immersed directly in the bioreactor resulting in plant footprints up to four times smaller than conventional systems. Membranes can extend the life of current plant infrastructure, greatly reducing capital expenditures and enhancing productivity.

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