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Review Article

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Dairy Wastewater Treatment by Membrane Systems - A Review

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ABSTRACT

Among the food industries, dairy industry is most polluting in regards to its large water consumption because water has been a key processing medium. Environmental protection agencies have started a strict vigil for banning of wastewater discharge into the natural resources of water. This has made the water treatment more expensive thereby becoming a huge burden for the industries. Thus, water reuse has become an environmentally and economically feasible solution. But water reuse becomes more challenging by employing conventional treatment processes due to wide fluctuations in industrial effluent quality. It has been shown that membrane processes to be convenient to treat dairy wastewater for recovering of milk components and producing reusable water i.e. usable in the washing of floors, and replacing of water in cooling towers or boiler, etc. But the major problem facing by the membrane installers is fouling of membrane materials, however many of advanced techniques were developed for overcoming the fouling problems. Depending on the size of permeable particles, membranes are divided into four major types namely Microfiltration membranes (MF), Ultra filtration membranes (UF), Nano-filtration membranes (NF) and Reverse Osmosis membranes (RO). The applications of these membrane systems are discussed briefly in this review.

Key words: *Dairy waste water, Membrane systems, Water reuse*

INTRODUCTION

Water is the key processing utility in dairy industry. Water is used almost in every processing steps of dairy industry such as sanitization, heating, cooling and cleaning of dairy equipment namely silos, tanks, homogenizers, pipes and heat exchangers, etc[34]. The average quantity of dairy effluent generates about 2.0 to 2.5 liters of wastewater per liter of milk processed[22]. In the dairy industry, the water used during starting, equilibrating, stopping and rinsing of the processing units (flushing water, first rinse water, etc.) thereby dilution of rinse water with milk residues also contributes to the total waste water production[35].

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Moreover, the liquid effluent generated from the dairy processing lines consists of organic matter, fats, suspended solids and nutrients are the major sources of pollution[3]. Many problems have been reported during waste water treatment by the conventional systems include primary and secondary treatments[11, 28]. At the same time, environmental protection agencies have obligated more stringent regulatory prohibitions on the discharge of waste water into the natural water sources. This has resulted in a more expensive process by the conventional treatments to comply with the discharge quality standard itself, alternatively this has raises huge burden for the industries[34]. Thus, treatment of waste water to the level of reuse using membrane systems has become an environmentally and economically feasible solution for industries in nowadays. The practice of reusing effluents generated by membrane systems can improve the industry's image in terms of environmental impacts and raise its profits. Membrane treatment of dairy wastewaters could simultaneously lower the total water consumption by using in cooling towers or boilers and for good manufacturing practices such as washing the floors and external part of trucks and rinsing outside areas[5,41] and the effluent production of the dairy plant by recovering milk components like lactose, proteins, etc. present in wastewater.

Membrane processes

The membrane is a porous medium, generally made up of polymeric, ceramic or metal material. The physical and chemical properties are the basic criteria of fluid passage through the membrane. The separation operation of membrane environments or media depends on selective passage of particles through themselves. Membrane processes are very promising technologies in which product recovery is possible conjointly produce the high quality effluent suitable for direct reuse at various operations expect in products contact surfaces. General benefits using membrane processing for waste water treatments increase the standards of outlet wastewater, mass transfer reduction, reduced energy consumption, high effectiveness, ease of use and recovery of dairy residues and CIP solutions. Membrane systems can compete with more advanced technologies of wastewater treatment[16]. There are four types of pressure driven membrane processes, which are commonly used for wastewater treatment are Reverse Osmosis (RO), Ultra Filtration (UF), Nano Filtration (NF), and Micro Filtration (MF)

Reverse osmosis

RO is the process that ensures the standard water quality by reducing high levels of suspended solids and dissolved salts. Reverse osmosis is a process that uses semi permeable spiral wound membranes to separate and remove sub micron colloidal matter, pyrogens, organic, dissolved solids, color and nitrate from influent water[17].

Ultrafiltration

Ultrafiltration process is widely used in dairy and food industries. The pore size of UF membrane (0.001-0.01 µm) is lesser than NF and RO membrane. The pressure applied during UF is between 1-10 bar. The UF process membranes are especially characterized on the basis of molecular weight cut off (MWCO) rather than a pore size of membrane material. Even several membranes manufacturers treat MWCO as basic criteria for accessing the efficiency of membrane separation. MWCO ranges from 1-200 kDa for UF processes.

Nanofiltration

Nanofiltration process is in between ultrafiltration and reverse osmosis. It contains pores close to or lower than nanometer that the size is usually around 0.5 to 1.5 nm[16]. NF is widely used for wastewater treatment and water softening. NF concentrates, fractionates or purifies aqueous solutions of organic solutes with a molecular weight between 100 and 1000 Da and uses pressures ranged from 1 to 4 MPa[6, 32].

Micro filtration

The main concept of usage of microfiltration is to separate particles and bacteria from other smaller solutes. The pore size of MF membrane is generally in between 0.2-2.0 µm.

It can selectively separate particles with molecular weights of above 200 kDa. MF uses pressure lower than 0.2 MPa[6, 20].

Applications of membrane processes to treat or recycling of dairy waste water

Single membrane systems

Bennani *et al.*[10] investigated the treatment of dairy wastewater using UF of PES-5 membrane and process efficiency and permeate quality was improved by operating under optimum conditions of transmembrane pressure (TMP) and volume reduction factor (VRF). In this process, more than 99% of retention rate was observed for turbidity and BOD_5, above 80% for suspended matter and 95% for proteins with an optimal TMP fixed at 2.5 bar. A recovery of 58% of the dairy effluent was attained after UF treatment. It was also claimed that the permeate quality obtained in optimal TMP and VRF allows the industry to reject its effluents into the river without contamination risks and to reuse or recycle.

Koyuncu *et al.*[23] studied the two alternative membrane processes such as NF and RO for treatment of dairy waste water. NF membranes were used in different operating conditions. Successive batch runs had shown that around 90% of the treatment plant effluent was generated for reuse. It was observed that heavy metal removal also very high. In the second part of the study, two pass RO membranes were applied to the raw wastewater of the dairy industry. The RO experiments confirmed that two-pass RO can produce permeate of very good quality. Flux values decreased slightly during the each RO run however almost complete COD removals were achieved.

Treatment of the dairy wastewater was carried out by RO until 90-95% water recovery to attain a removal rate of above 99.8% for TOC and above 99.5% for lactose, 96% for nitrogenous matter and 95% for multivalent ions and 87% for monovalent ions. Finally demonstrated that quality of purified water was similar to vapour condensates from dairy processing and allowing this water to be reused for heating, cleaning and cooling purposes[39].

Low pollutant dairy condensate from flash coolers of a direct UHT plant in dairy industry was processed through a RO spiral wound membrane in order to produce high quality boiler water. Main parameters selected for evaluation of water quality were conductivity, chemical oxygen demand and pH of influent and effluent water. It was achieved that conductivity and chemical oxygen demand reductions up to 98.2% and 97.8%, respectively. It was claimed that post-treatment would be necessary to adjust permeate to the final pH for reuse purpose as boiler feed water[36].

Chollangi and Hossain[14] reported that treatment of dairy wastewater by UF at low transmembrane pressure resulted in a high permeate flux using regenerated cellulose membranes, but the permeate water quality was not sufficient for water reuse because it contained high lactose concentration.

Combined membrane systems

Nonetheless, one single membrane operation is insufficient for producing water of standards complying with the requirements for reuse purpose because of the high COD and BOD levels of the dairy process water. So many research workers have been worked up on combined membrane systems to get the standard quality water as an outlet.

A dairy effluent model solution was treated by RO and NF processes. The treatment of both the processes shown that lactose rejection was 99.9% for RO and 95-97% for NF membrane. Rejection of mineral salts was 62-63% for NF and 98-99% for RO, the low mineral content of RO permeate makes it possible to be reused in the dairy industry for washing floors and the outside of plant vehicles[24].

Luo *et al.*[27] demonstrated that the two stage UF and NF treatment of dairy wastewater was a viable and promising method to recycle water and nutrients for the production of bioenergy. In the first stage, Ultracel PLGC UF membrane was used for protein and lipid concentration and it could be used for algae cultivation to produce bio fuel and biodiesel. In the second stage, permeate obtained from UF was concentrated by the

NF270 membrane to obtain lactose in the retentate and reusable water in permeate. It was proven that this two-stage UF/NF process had a higher efficiency and less membrane fouling as compared with single NF process.

Dairy effluent model solution i.e. diluted skimmed milk (dilution of 1/3) was treated by NF and RO, the results showed that COD removal was 99 %, Lactose removal was 98.2-99.9%, divalent cations removal was 90 % and final water quality was close to vapour condensate issued from milk and whey drying steps. It was observed that only a two stage filtration treatment would be able to provide reuse of dairy waste[8].

Turan[38] investigated the performance of NF and RO membranes for dairy wastewater treatment by varying the filtration conditions, in which NF and RO membranes showed excellent performance by removing at 98% and 99.7% of the COD, respectively along with the performance evolution.

An effluent model solution (diluted skimmed milk) was treated by several NF and RO with dead-end filtration flow process. It was observed that for NF membranes, Desal5 DL and the new FilmTec NF had given the best COD rejection and for RO membranes Koch TFC HR and Desa13 SF gave the best rejection. The primarily selected membranes such as Desal5 DL and Koch TFC HR spiral-wound membranes were tested by cross flow filtration and the results obtained were agree very well with those obtained by dead-end filtration. But the effluent quality has not met the standards for reuse purpose. It was stated that to reach the goal for reuse of the purified water in the dairy plant, a finishing step (membrane, other) must be added[7].

Riera *et al.*[31] investigated the NF to treat UHT flash cooler condensates. The nanofiltration membrane (200 Da MWCO) used in this study allows permeates be obtained that can be reused in the industry with high permeate flow rates. Baskaran *et al.*[9] studied several Australian wastewaters from milk powder industries in order to reduce valuable organic products and reusing of permeates after treatment. Chmiel *et al.*[13] shown that low contaminated vapour condensate from milk processing treated by NF and RO can produce reusable water.

Treatment of dairy wastewater by a two stage membrane process with ultrafiltration (UF) and nanofiltration (NF) was investigated. Treatment of dairy wastewater by the UF and NF90 and NF270 processes were studied under the conditions of TMP with 0.2 and 1 MPa for UF and NF respectively. It was observed that protein rejection exceeded 99% by both UF and NF operation. Lactose rejections were 98.5 and 54% for UF and NF90 combination and UF and NF270 combination respectively[19]. In which lactose and protein rejection was excellent for UF and NF270, thereby it was declared that the final water content may meet the reuse water standards.

Combination of membrane systems with hybrid technologies

A combined UASB-MBR system was developed to treat dairy wastewater to join the advantages of the methanogenic and reusing of dairy waste water. The average total and soluble COD removal rate in final water were above 95% and 99% respectively with an average methane content of 73% biogas production[33].

Chen and Liu[12] investigated the possibility and applicability of MBR hybrid system with coagulation in reclaiming dairy wastewater. The results have shown that poly-aluminium chloride as the appropriate coagulant was effective for turbidity removal before membrane treatment application. The final water quality was as follows, the turbidity of 0.01–0.26 NTU, COD of 5.07–8.8 mg/L, aluminum of 0.03–0.07 mg/L and chloride of 16–22 mg/L.

Al-Shammari *et al.*[1] developed a system including biological treatment unit, powdered activated carbon and submerged membrane microfiltration system for dairy effluent treatment. The average removal efficiencies of the system for biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solid (TDS) were 98.8%, 92.5%, 96.7% respectively were obtained during the study. It was stated that the characteristics of water produced from the integrated system were better than the standard for water reusing in landscaping.

Andrade *et al.*[4] evaluated the application of membrane bioreactor (MBR) as secondary and nanofiltration (NF) as tertiary treatment for the reuse of dairy wastewater. The proposed treatment system (MBR+NF) showed overall removal efficiencies of 99.9% for COD and 93.1% for total solids. The final treated wastewater could be reused as water for cooling, steam generation, or washing of external areas and trucks.

László[25] examined the applicability of the membrane technique (NF) and the effect of pre-ozonation during dairy waste water treatment. The best degree of surfactant removal from model anionic surfactant solution was obtained at 20 ^{o}C and 40 bar by nanofiltration. Investigations on the effect of ozone treatment of the waste water indicated that pre-ozonation increased the COD and surfactant removal efficiency and decreased the flux. Pre ozone treatment of waste water enhanced the biodegradability of the retentate from 68.8% to 96.4%.

Fouling of membranes and remedies

The major membranes limitations are fouling of membranes due to blockage of membrane pores, deposition of protein and minerals, cake formation, adsorption of particles on the pores and depth fouling[30, 2] and bacterial biofilms[37]. That means fouling is caused by the accumulation of particles, bacteria and sediments present in milk leading to a remarkable loss in the membranes efficiency. From the last decades fouling of membrane remains the major concern in the dairy industry[18, 29]. The several factors affecting fouling of membranes are back pulsing, back washing, cross flushing, particle size, membrane surface chemistry and ionic strength[21]. The issue of fouling in membranes can be overcome by regular cleaning of membranes at appropriate time intervals, use of low fouling membranes, membrane modules with suitable channel heights, by applying high pressure, application of electric potential, ultrasound waves, microturbulence, uniform transmembrane pressure (UTP), ceramic membranes, use of turbulent flow of liquids, vibrating and rotating disc modules[15, 40] and also high frequency back pulsing method[26].

CONCLUSION

Water reclamation or reuse is the new challenge in the new millennium. Membrane processes are proved convenient to treat dairy wastewater for recovering of milk components present in dairy wastewater and producing reusable water. The significant improvements in reliability and cost effectiveness of membrane technology have increased the reuse probability and recycling extent of dairy wastewater. In contrast, reuse of treated effluent should be encouraged for replacing the water in cooling towers or boilers and for good manufacturing practices such as washing the floors and external part of trucks and rinsing outside areas in dairy industry and protecting aquatic ecosystem by reducing the quantity of nutrients.

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