Membrane Separation Process in Wastewater Treatment of Food Industry

Sejal J. Solanki[1] Prof. Rupande N. Desai[2]
[1,2]L.D. College of Engineering, Ahmadabad, Gujarat, India

Abstract— Wastewaters produced in the food industry depend upon the particular site activity. Animal processors and rendering plants will generate effluents with different characteristics to those from fruit/vegetable washers and edible oil refiners (suspended/colloidal and dissolved solids, organic pollution and oil and greases as well as microbial contamination). The favourable characteristics (modular) of membrane technologies allow to use different techniques as it has be seen all along this chapter. These hybrid processes can include traditional techniques as centrifugation, cartridge filtration, disinfection and different membrane techniques building a "cascade design" very used in many of the applications reviewed. The risk of membrane damage due to the contact with particles, salt conglomerates, chemicals or others substances must be minimized to prevent short membrane life.

Keyword- Membrane application in food industry, Membrane Characteristics, Trans membrane pressure

I. INTRODUCTION

Wastewater derived from food production is highly variable, depending on the specific types of food processing operations (e.g., fruit, vegetable, oils, dairy, meat, and fish).Advances in membranes technology have showed many advantages for wastewater treatment of food industry. By implementing membranes, the separated substances and clean water are often recoverable in a chemically unchanged form and are therefore easily re-used. Maximum benefits are obtained when one or both the output streams from the membrane system are recycled or re-used, thereby reducing process materials requirement and minimizing waste disposal costs. This chapter reviews the development and applications of membrane processes in wastewater treatment of food industry. Particular focus is given to membrane's special abilities to wastewater treatment for water regeneration and various re-uses purposes. Influence of engineering aspects is analyzed, specially operating conditions near critical flux to improve processes in wastewater treatment. Detailed discussions are provided with respect to constituents of concern in water reuse applications including recovery of other products with value for food industry.

II. WASTEWATER OF FOOD INDUSTRY VOLUME AND QUALITY

The types of food production processes (e.g., fruit, vegetable, oils, dairy, meat, fish, etc.) vary widely, with associated differences in the specific wastewater contaminants. The characteristics and generation rates of food wastewater are highly variable, depending on the specific types of food processing operations, including wastewater from of activities of food cleaning (sanitizing, peeling, cooking, and cooling); mechanically activities (conveyor medium to transport food materials throughout the process) and clean production equipment between operations. In addition, one important attribute is the general scale of the operations, since food processing extends from small, local operations. Food processing can be divided into four major sectors: Meat, poultry and seafood; fruit and vegetables; dairy and beverage. Table 1 shows the wastewater volume and pollution charge of some food industries. Wastewater from food industry Primary and secondary treatments are often used to decompose the high organic contents of wastewater of food industry by aerobic and anaerobic fermentation processes. After of traditional treatment of wastewater, general requirements are covered by regulations of each country, usually complemented by consent limits based on avoidance of pollution. Discharge licenses may include maxima for flow, temperature, suspended solids, dissolved solids, BOD5, nitrogen, phosphorous and turbidity. According at quality of water, in most cases, final disposal of treated waste water is into a water course where it will be diluted by the existing flow. However, subsequently one advanced process of effluent treating can be an option desirable to recycle water within a factory of food processing.

III. MEMBRANE PROCESS

Membrane filtration is a process used to separate dissolved substances and fine particles from solutions. Membrane acts as a semi permeable and selective barrier that separates particles based on molecular or physical size. Solutes smaller of solution than the membrane pore size are able to pass through the membrane as permeate flux while particles and molecules larger than the membrane pore size are retained. The two fluxes at outlet of membrane are important because this process has a high efficiency in the separation. The majority of commercial membranes are made usually of organic polymers (polysulfones and polyamides) and inorganic materials (ceramic membranes based on oxides of zirconium, titanium, siliceous and aluminum). The membranes are implemented in several types of modules. The membrane configuration determines the manner in which the membrane is packed inside the modules. Four main types of membrane configurations are used in the industry. These are: plate-and-frame, spiral wound, tubular and hollow-fiber configurations. The membrane geometry is planar in the first two and cylindrical in the two others. The membrane system is operated in a cross-flow feed mode. The concentrated stream passes parallel to the membrane surface as opposed to perpendicular flow that is used traditionally in filtration. This operating mode allows that accumulation of solute molecules at the membrane surface decreases and the permeate flux remains constant for a long time due to decreased hydrodynamic resistance at the membrane surface by cross-flow induced hydraulic turbulence. Flow direction is usually inside-out, i.e. the concentrate flux inside the fibers and the permeate flux is collected at the shell-side. It is often possible to reverse the flow (outside-in) for cleaning and unclogging of the membrane. Cylindrical configuration provides the possibility of maintaining high tangential velocity in the feed stream and is therefore particularly suitable for applications where the feed contains a high proportion of suspended solids or must be strongly concentrated. The choice for a certain kind of membrane system is determined by a great number of aspects, such as costs, risks of plugging of the membranes, packing density and cleaning opportunities. The effects of the feed properties, the membrane properties, and the filtration conditions are obviously very important for the success of a membrane filtration process.

IV. MEMBRANE APPLICATIONS IN FOOD INDUSTRY FOR WASTEWATER TREATMENT

Membrane separation process has special recognition in food wastewater treatment, applied to the end of conventional treatment systems The process is used primarily to reduce the volume of the food wastewater that is achieved by recovering of two fluxes: permeate water flux having the majority of the original volume, and concentrated flux in a lesser volume (constituents of effluents retained). The membranes used in food wastewater treatment differ widely in their structure and function. Mainly they are operated in four membrane processes: microfiltration (MF), ultra filtration (UF), nanofiltration (NF) and reverse osmosis (RO). Solvent permeability and separation selectivity are the two main factors characterizing at these membranes. Transport mechanisms and operating membrane conditions can also explain the pass of species through membranes. Particle size is practically the sole criterion for describer the permeation or rejection of membranes. However, micro porous membranes (NF and RO) have ability of separate particles at molecular level and their selectivity is mainly based on the chemical nature of the species. Several works have been focused on these factors to explain separation selective of residues of food wastewater. Effluents treatment of dairy industry by RO and NF membranes are reported in many investigations, however, a strong development and growth of membrane technology can be observed in the results from the other food industries. Food industry standards specify that, spent process water intended for reuse (even for cleaning purposes) must be at least of drinking quality. Regulations for other applications, such as boiler make-up water or warm cleaning water, are even more stringent. There has been a study on the possibilities for reuse of vapor condensate in a milk processing company (dried milk production) as boiler make-up water (Hafez et al., 2007), and the reuse of chiller shower water in a meat processing company (sausage production) as warm cleaning water.

V. MEMBRANE CHARACTERISTICS

Generally membranes are characterized by pore flow or molecular weight of particle that is retained or is filtered by the membrane. However, important membrane properties such as structure, porosity, thickness, wet ability surface and operating conditions, are also studied because affect rejection of solutes. The electrostatic repulsion between the membrane surface and the contaminant may be particularly analyzed to enhance waste solute retention and to increase water flux. The smallest particle size present in the feed is very important for the selection of membrane pore size. However, currently the feed properties can be changed by pretreatments such as pH adjustment, thermal treatment, addition of chemicals, and pre-filtration. The pH adjustment and thermal treatment can decrease the precipitation of certain substances. In addition, chemicals can be added to the feed to increase the particle size through aggregation, and the retention of specific substances can be enhanced through micellation or complexation.

A. Pore-flow and material membranes

Membrane pore flow is differentiated by the size of particles diameter that they can separate and nominal molecular weight cutoff MWCO (kilo Daltons), which is a Performance -related parameter, defined as the lower limit of a solute molecular weight for which the rejection is 95-98% . In theory, compounds having a molecular weight greater than the molecular weight cut off (MWCO) will be retained by the membrane and compounds with molecular weights less than the MWCO will pass through the membrane as permeate. Table 3 shows size range of particles retained with range of MWCO membranes for treatment of wastewater of food industry. Retention is obviously affected by the pore size due to the sieving effect, especially when using MF and UF membranes. With tighter (NF and RO) membranes retention will be governed more and more by the electrostatic forces as well as by other interactions between membranes and solutes. Thus MWCO is only a rough indication of the membrane's ability to remove a given compound as molecular shape because polarity and interaction with the membrane affect rejection. Respect to pore diameter, it has frequently been seen that the membrane with the most open pores does not usually give the highest permeate flux in filtration process. Porosity (ratio of void space to total membrane volume in porous membrane) and pore size distribution may influence the apparent size of particles retained. Typical micro porous membranes have average porosities in the range 30%–70%. Porosity can also be measured by analyzing processed images obtained from microscopic analyses such as scanning electron microscopy (SEM). Figure 2 shows SEM image of an asymmetric porous structure of a ceramic membrane. It may be noted that the membrane has fine pores through which raw water is filtered (Figure 2a). The most of ceramic membrane elements are constructed from supported multiple ceramic layers constituting an asymmetric porous structure. Carbon macro porous material is used as support for ceramic membrane deposition (Figure 2b and 2c). Multiple layers are usually resulting from residual spaces created between ceramic particles during sintering. The bottleneck geometry is representative of pores resulting from sintering of almost spherical particles, for example, this is the case of porous structures obtained with titanium, zirconium. The porous sites are uniformly distributed in the membrane and effective diameter of the membrane pore can be determined assuming pores are circular in shape. However, pore geometry can also affect the retention of molecules by a membrane. Tortuosity reflects the length of the average pore compared to the membrane thickness.

B. Trans membrane pressure

The driving force for transport behind membrane process MF, UF, NF and RO, is the pressure difference between feed and permeate flux of the membrane (TMP; bar, psi). TMP is defined as the difference in pressure between the filtrate side of the membrane and the permeate side of the membrane. The average TMP is in general calculated as follows: The permeate flux depends directly on the applied TMP for a given surface area under uniform operational conditions. The flux of the pure water is linearly pressure dependent. However when food wastewater is treated by membrane system the flux is more complex. The behavior depends of wastewater composition, membrane type and cross flow velocity. In food wastewater treatment, one has to keep in mind that the permeate flux will be determined by the combination of cross flow velocity and TMP, due to contaminants. The experiments were performed by Escobar, 2010. The results indicated that the flux enhancement caused by increasing cross flow velocity was particularly pronounced at range values of the TMP and cross flow velocity of 3 ms-1. Fouling occurred over a range of TMPs of 5-6 bar and cross flow velocities at 3.5 ms-1. The permeate flux decreased with time during the development of the fouling layer, but once the fouling layer was established, the permeate flux became constant for a given set of experimental conditions. Therefore these results indicate that at moderate values of TMPs and high flow rates at the membrane surface are operating conditions that conduce at high permeate fluxes in these experiments. Besides, figure 4c shows an overall positive effect of enhanced flow hydrodynamic conditions (TMP = 4 bar) on the average permeate flux, although in the turbulent regime (Re>3,000) a weaker correlation and more data scattering were observed. Therefore a clear correlation between the 3 h flux and Re in the transient regime (Re<3000) could be expected. treatment of a cereal industry using membranes of MF and UF (a) 300 kDa. (b) 15 kDa. (c) The interdependence between average flux and hydrodynamic conditions for two membranes in a wide range of Re numbers at TMP = 4 bar (From Escobar 2010. PhD thesis, Institute Technogical of Toluca). Particularly, operational membrane conditions in wastewater treatment show moderate TMP and high flow rates at the membrane surface are conducive of high permeate fluxes in the MF and UF. An increase in TMP is required to maintain a particular water flux (constant-flux operation) independently of the membrane type and MWCO. However, an increasing flux could lead to an increase in polarization and fouling, which will limit the permeate flux .High pressure can also allow membrane compaction, ultimately resulting in the formation of a denser membrane with smaller pores, or one possible enlargement of membrane pores with time, which enables particles to penetrate through the membrane matrix. Choi et al., (2005) showed clearly that pore sizes are modified in the membrane matrix increased with increasing TMP.

C. Membrane fouling control in food industry for wastewater treatment

Fouling is the most important issue affecting the development of membrane filtration-as it worsens membrane performance and shortens membrane life. Membrane fouling by food wastewater filtration is attributed to depositation of species from effluents onto the membrane surface or within membrane porous, it causes a permeate flux decline with time because the filtration resistance is significant increased (Foley, 2006). Fouling studies on membranes are based in proteins deposition and their interaction in membranes surface. Polydispersity of naturally occurring macromolecules such as polysaccharides and humic substances, have also added a particular complexity on investigation to the fouling membrane mechanisms. Advances in understanding fouling of other species such as bacteria, yeast, emulsions, suspensions, salts and colloids from food wastewater have occurred in microfiltration and ultra filtration literature (Chan et al., 2002; Foley et al., 2005; Hughes & Field, 2006; Cheng et al., 2008). There are two form of membrane fouling: the fouling layer that is readily removable from the membrane, it is often classified as polarization phenomena or reversible fouling and is removed by physical procedures. Internal fouling caused by adsorption of dissolved matter into the membrane pores and pore blocking is considered irreversible, which can be removed by chemical cleaning and other methods (Hughes & Field, 2006). Several aspects such as pretreatment of feed solution (example add flocculants before filtration), membrane surface modification, operating conditions and heavy cleaning procedures such as high temperature, while using caustic, chlorine, hydrogen peroxide, ozone, and strong inorganic acids are carried out on the membrane plant in operation to decrement fouling problem. Hydrodynamic methods used for performance enhancement of membrane filtration as back-pulsed (permeate flow reversal technique), creation of pulsed flow in membrane module, TMP pulsing, creation of oscillatory flow, generation of Dean vortices in membrane module, generation of Taylor vortices in membrane module and use of gas-sparging, have also been developed to reduce membranes fouling.

REFERENCE

[1] Abbasi, M.; Sebzari, M.; Salahia, A.; Abbasi, S. & Mohammadi, T. (2011). Flux Decline and Membrane Fouling in Cross-Flow Microfiltration of Oil-In-Water Emulsions. *Desalination and Water Treatment*, Vol.28, No.1-3, (April 2011), Pp. 1–7, ISSN00119164
[2] Afonso, M. & Bórquez, R. (2002a). Review of the Treatment of Seafood Processing
[3] Wastewaters and Recovery of Proteins Therein by Membrane Separation Processes
[4] Prospects of the Ultrafiltration of Wastewaters from the Fish Meal Industry.
[5] *Desalination*. Vol. 142, No. 1, Pp. 29-45, ISSN 0011-9164

[6] Afonso, M. & Bórquez, R. (2002b). Nanofiltration of Wastewaters from the Fish Meal
[7] Industry. *Desalination*. Vol.151, No. 2, Pp. 131-138, ISSN 0011-9164
[8] Akdemir, E.O. & Ozer, A. (2009). Investigation of Two Ultrafiltration Membranes for
[9] Treatment of Olive Oil Mill Wastewater. *Desalination*, Vol.249, No. 2, (December2009), Pp. 660-666, ISSN 00119164
[10] Al-Akoum, O., Mercier-Bonin M., Ding, L.; Fonade, C.; Aptel, P. & Jaffrin M. (2002).
[11] Comparison of Three Different Systems Used for Flux Enhancement: Application to