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Artificial Neural Networks Methods for Predicting the Performance and Process in the Milk Industry

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Abstract - The effects of independently varying both wall shear stress (tw) and transmembrane pressure (TMP) on permeate flux and fouling during ultrafiltration of reconstituted skimmed milk in total recycle mode have been investigated. Milk ultrafiltration is a membrane process, which is highly complex in nature. The cost effectiveness of the process depends heavily on the flux permeate and the total hydraulic resistance of the membrane. In this work, a comparative study for the prediction of the performance of milk ultrafiltration with ANN and statistical method has been carried out. The result reveals that both methods carry out the prediction with a high degree of accuracy. However, the statistical method, contrary to neural nets, is both costly and time consuming and the accuracy of the data are also in doubt, as the operating conditions are not consistent throughout each of the test runs. The result also reveals that there is a good agreement between the predicted fluxes permeates and the total resistances of this work with the actual values. The findings of this study also shows that the artificial neural nets technique can be applied as a powerful tool and a cost and time effective wayin predicting and assessing the performance of milk ultrafiltration process.

Key Words: Fouling, Milk ultrafiltration, artificial neural networks, Hydraulic resistances, Flux.

1. INTRODUCTION

An artificial neural network, also called as simulated neural network (SNN) or commonly just neural network (NN) is an interconnected group of artificial neurons that uses a mathematical or computational model for information processing based on connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network. In more practical terms neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. The original inspiration of the technique was from the examination of the central nervous system and the neurons. In a neural network model, simple nodes (called variously "neurons", "neuroses", "processing elements", or units) are connected together to form a network of nodes- hence the term neural network. While a neural network does not have to be adaptive, its practical use comes with algorithms designed to alter the strengths (weights) of the connections in the network to produce a desired signal flow. These networks are also similar to the biological neural networks in the sense that the functions are performed collectively and in parallel by the units, rather than there being a clear delineation of sub-tasks to which various units are assigned. A precise estimation of the membrane area can be accomplished by using the equations describing the dependence of permeate flux and fouling on the process variables. In fact, there have been some theoretical approaches to predict the ultrafiltration performance of colloidal solutions (e.g. milk).

These are based on some models such as mass transfer (film theory), gel-polarization model, osmotic pressure model, boundary layer-adsorption model, Brownian diffusion model, shear-induced diffusion model, inertial lift model and surface transport model [4]. In addition to the complexity of mathematical equations involved, each of these models has a number of limitations: - They demand some experimental data for determining the input parameters. Perhaps this is always possible in practice, but the equipment required are especially sensitive instruments that might not be readily available .During ultra filtration of skimmed milk, permeate flux can be improved by increasing the cross-flow velocity or the transmembrane pressure of the feed. Increasing the cross-flow velocity and transmembrane pressure with spiral wound membranes leads to increased initial flux and changing flux pattern. This suggests that flux and fouling are controlled by hydrodynamic factors. However, limited information is available regarding the effect of hydrodynamic conditions on flux behaviour, fouling and retention characteristics during ultrafiltration of milk.

Previous studies on permeate flux during ultrafiltration of milk have generally aimed to predict flux under steady state conditions where the membrane may already be fouled, while little work has attempted to investigate how fouling develops and the role of hydrodynamic factors in this development. This study aimed to determine the influence of

TMP and t*w* on flux behaviour, fouling and transmission characteristics during ultrafiltration of reconstituted skimmed milk and to determine the role of these variables on the mechanisms of flux and fouling. In this way it was hoped to enable prediction of the operating conditions producing the least fouling using a critical flux concept.

The neural network model has also been used for obtaining an estimation of the permeate flux and resistance during reverse osmosis of the ethanol and acetic acid and ultrafiltration of the pulp bleach plant effluent. The ANNs predictions compared with the finely porous mass transfer model. In colloidal systems such as milk, physical and chemical properties (i.e., pH and fat milk) have a great effect on the behavior and the efficiency of the UF process owing to molecular interactions. Furthermore, the hydrodynamic factors such as transient membrane pressure (TMP), temperature and the pore size of the membrane (MWCO) have a substantial effect on the process efficiency. Therefore, in this work parameters such as temperature, TMP, fat milk, pH, time and MWCO as an inputs and the permeate flux and the total hydraulic resistance of the membrane as an outputs in predicting and assessing the performance of milk ultrafiltration process, using the statistical and ANN methods.

2. EXPERIMENTAL SET-UPS AND PROCEDURE

In this research, a membrane pilot plant from Biocon Company has been utilized for the data acquisition purposes. This apparatus is comprised from a feed tank, centrifugal pump, flow meter, membrane module, two pressure indicator, tubular heat exchanger, digital thermometer and a control valve (Fig. 2) which its specification are highlighted in table 1. In order to regulate the operating conditions for each test run, some distilled water was first introduced to the system for 10 minutes to check some parameters for the accuracy of the data. Then to run the experiment, the sample milk powder (with a constant milk fat of 8.5%) and hot water at 50 oC was mixed and added to the 12 liters feed tank at a constant rate of 15 lit/min throughout the experiment and letting the operation to be continued for 30 minutes. At the end, cleaning operation is carried out according to the instruction manual (i.e., cleaning-in place or CIP). Care must be taken to cease the washing cycle when the difference between the exit and inlet water fluxes are less than 2-3 percent. Otherwise, the fouling has not been removed and the washing process must be repeated. In this work, the affect of different parameters such as the transient membrane pressure (TMP), operating temperature, fat milk and pH on the flux permeate in m/s (Jp) and the total resistances in m-1 (Rt) has been analyzed. To obtain this objective, a total of sixteen-test run have been carried out and during each run the feed flow rate and concentration of the sample milk fat are regulated and kept constant using pasteurized and homogenized cream (28-30% fat). In order to measure the fat milk, a device called Lacto star from Funko Gerber Company was used and the measurement was repeated for three times at 25 oC. Furthermore, for regulating the milk pH an amount of 1% normal lactic acid have been used. To measure the sample milk and washing solution pH, a pH meter called Jenway (model 3010) was also adopted in this work.

2.1 ANALYTICAL METHODS

Total solids and protein contents of milk samples were measured using a Dairylab2 (Multispec Ltd, York, UK). *Protein content of the permeate* samples was measured using the Bradford Assay Kit (Sigma Diagnostics, London, UK). *Viscosities* of permeate and milk samples were measured using an Ostwald U-tube (BS/U) capillary direct flow viscometer.

3. NEURAL NETWORKS MODELING

In this research, the effectiveness of UF milk modeling has been assessed using a multi-layer perception (MLP) and neural nets software (i.e., Mat lab), for learning purposes different structures have been adopted, and the results achieved are compared together. The structure of neural nets is constructed in a way that a weak prediction and the time learning process expenditure could substantially be reduced by lowering the number of hidden layers. Furthermore, neural nets with different structures can also reduce the learning procedure and to converge the results in the lowest number of iteration and to obtain a better prediction for the new data. As a typical example, the results obtained from feed forward back propagation neural nets (or multilayer perception). 5. In this work, the MLP have made with 3 layers that 1 neurons in first layer, 10 neurons in second layer and 1 neurons in last layer. The momentum coefficient and learning rate are 0.7, 1, respectively. The total numbers of data utilized in this work are about 2500. From this about 30 percent of the input output data was selected in a random manner for training (number of data 860) and the rest of the data were used to test (number of data 1360) and cross validate (number of data 280) the outcome and assess the error resulted from it.

3.1 CRITICAL FLUX CONCEPT

The critical flux concept for membrane filtration has been proposed by Field et al. . Critical flux can be considered to be the flux just below that at which deposition onto the membrane to form a cake layer begins. At this point a concentration polarization layer is present, but this does not become solidified into a cake on the membrane surface and in principle is reversible. They claimed that operating membrane filtration at a permeate flux lower than or equal to the critical flux could reduce or eliminate irreversible membrane fouling. Critical flux is determined by hydrodynamic conditions, pore size and composition of the feed, and is sometimes equal to limiting flux but in other cases operating membrane filtration at the limiting flux causes more fouling. The critical flux can be evaluated by investigating TMP at controlled permeate flux levels. Increasing TMP at a given flux indicates that the balance of particle convection and removal has shifted towards deposition, and hence the critical flux has been exceeded. At fluxes equal to or lower than the critical flux, the relationship between TMP and flux should be linear with no hysteresis. Two forms of the critical flux have been proposed. The "strong" form of critical flux exists if the flux of a suspension is identical to the flux of clean water at the same TMP. The "weak" form of critical flux exists if the relationship between flux and TMP is linear, but the slope of the line differs from that for clean water. The latter case only would be relevant to the current study.

3.2 MEMBRANE FILTRATION

3.2.1 WHAT IS MEMBRANE FILTRATION?

Membrane filtration is a separation process used to separate different molecules based on size (Nielsen, 2000). A membrane filtration process can be viewed as a selective sieving mechanism, where certain molecules permeate through the pores in the membrane (Winston and Sirkar, 1992; Cuperus and Nijhuis, 1993). Permeation of certain molecules from a solution results in an increase in the concentration of the remaining particles in the retained solution (Winston and Sirkar, 1992). The concentrated feed retained by the membrane is known as the retentive or concentrate. The rate of permeation of the molecules through the membrane is defined by the driving force (Strathmann, 1987).

3.2.2 TYPES OF MEMBRANE FILTRATION

Membrane separation processes can be split into different categories based on the driving force used for filtration (Nielsen 2000). The pressure driven filtration processes are reverse osmosis also known as hyper filtration, nano filtration, ultrafiltration and microfiltration (Mistry, 2002; Kuriyel, 2000). The concentration driven membrane filtration process is known as dialysis and the electrode potential difference driven filtration is called the electro dialysis process (Niel sen, 2000). The different pressure driven processes can be classified on the basis of the size of the components passing thought the membrane, which in turn relates to the required differential pressure needed to operate the system. The required operating pressure for reverse osmosis is higher in comparison to the other pressure driven membrane processes. The high pressure is required to overcome the osmotic pressure difference to separate water from the feed solution (Winston and Sirkar, 1992).

The transmembrane pressure achieved during reverse osmosis filtration ranges from 10 -100 bar (Mulder, 1991). In reverse osmosis, ideally, water is the only material that passes through the membrane, all the dissolved molecules (solutes) and suspended material is rejected (Nielsen, 2000; Wagner, 2001). An application of reverse osmosis in the dairy industry is the removal of water from milk and whey (Wagner, 2001) . In the food and beverage industry reverse osmosis is used to recover substances that are temperature or pH sensitive and solids from wastewater to reduce waste treatment costs (Meyer et al., 1995).

Nanofiltration is very similar to the reverse osmosis filtration process (Winston and Sirkar, 1992). In nanofiltration small monovalentions such as sodium and chloride pass through the membrane (Mistry, 2002). As the osmotic pressure to overcome is not as great as that of reverse osmosis, the required transmembrane pressures are in the range of 5-35 bar (Nielsen, 2000). Nanofiltration is used in the environmental industry to purify and reuse caustic cleaning solutions (Nielsen, 2000). In the dairy industry nanofiltration can be utilised to remove water and small io ns suc h as sodium, potassium and chloride from a feed solutions. It is also used to remove salt and water from whey to produce desalted whey concentrate (Wagner, 2001). As nanofiltration is still new in terms of cheese making, it is still in the development stages (Mistry 2002). In ultrafiltration, water, minerals, sugars, organic acids and vitamins pass through the membrane (Nielsen, 2000), while large molecules such as proteins, fat and carbohydrates are fully or partially retained depending on the pore size of the membrane (Mulder, 1991).

The transmembrane pressures attained in ultrafiltration range between 1-10 bar (Wagner, 2001; Nielsen, 2000). Microfiltration is utilized to retain larger components of feed solutions such as proteins in milk (Mistry 2002). The transmembrane pressure of microfiltration is lower than that of ultrafiltration, usually less than 2 bar (Wagner, 2001). Ultrafiltration and microfiltration are most commonly used in the dairy industry. Microfiltration in the dairy industry is used to improve the quality of milk for cheese-making and extend the shelf life of market milk (Nielsen, 2000). It can also be used for protein separation and for the removal of fat, bacteria or suspended solids. Applications of microfiltration in other industries include clarification and biological stabilization in the beverage industry (Winston and Sirkar, 1992).

3.3 ULTRAFILTRATION

3.3.1 APPLICATIONS

Ultrafiltration is used in latex concentration, pigment recovery and concentration of proteins for biopharmaceuticals. It is used in sewage treatment and production of sterile water for antibiotics (Kuriyel, 2000).

Ultrafiltrat ion is us ed in the food industry for production of concentrates and isolates from soya beans, sunflower and cotton seeds. Ultrafiltration is utilized to remove glucose from egg white and partial concentration before drying. Other useful applications in the food industry include refining sugar solutions, fractionation and concentration of gelatin (Pal, 2003).

In the dairy industry ultrafiltration is used in a number of applications including cheese making. Ultrafiltration is successfully implemented into the cheese making process for cheeses such as feta, quarg, camembert, goat's milk cheese and mozzarella (Cheryan, 1998). Other applications of ultrafiltration in the dairy industry are recovery of protein from cheese and casein whey that are produced from traditional cheese making processes (Kuriyel, 2000). Ultrafiltration is also used for protein standardization to eliminate seasonal differences in protein content of milk (Pal, 2003). High value whey protein concentrates are produced from ultrafiltration of whey to remove lactose and salt. Ultrafiltration can also be used to produce milk protein concentrates (Nielsen, 2000). Ultrafiltration is also used to produce superior taste and textured milk based fluids and fermented products (Cheryan, 1998). Research has been carried out to investigate using ultrafiltration to recover lactose from the dairy wastewater (Chollangi and Hossain, 2007). It decreases the biological oxygen demand and allows direct discharge of wastewater into the sewage (Atra et al., 2004). Other applications of ultrafiltration include electro coat paint recovery, textile size recovery and recovery of lubricating oil in the chemical industry. For medical applications it is used in kidney dialysis operation and in the biotechnology industry it is used to recover protein from animal blood, gelatin and glue (Yeh, 2002).

4. CONCLUSIONS

In colloidal systems such as milk, the physical and chemical properties such as pH and fat percentage have an immense influence on the system due to molecular interactions and consequently on the efficiency of the UF process. In addition, parameters such as temperature, transient membrane pressure and the extent of the pore sizes of the membrane has a huge affect on the hydrodynamics of the membrane and the effectiveness of the process. In this research, two methods that are a proper substitute for the physical and phenomenological modeling of the process and in addition a statistical method have been chosen to predict the efficiency of the UF process. Current studies aim to discover the effect of wall shear stress, concentration, the physico-chemical properties of the milk as well as the influence of membrane characteristics on the critical flux. This should help to ensure more efficient ultrafiltration of milk.

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