# CHAPTER ONE

## Introduction

Whey is an important by-product from the cheese making industry. Typically, 100 kilograms of milk yield 10 kilograms of cheese and 90 kilograms of liquid whey. Discharging wastewater containing whey into natural water bodies can result in eutrophication of the receiving waters. However, treatment of liquid whey is costly due to its high BOD content, typically about 50,000 mg/L (Raskin et al., 1998).

The success of utilizing whey proteins normally depend on increasing the solids content and reducing the ratio of lactose to protein. Ultrafiltration (UF) is used to simultaneously fractionate and concentrate proteins for making protein powder (Ghosh et al., 1998; Daufin et al., 1999; Ghosh and Cui, 2000). The protein powder is widely used as a food and feed additive. Among the major proteins of whey, the enriched α-lactalbumin fraction is mostly used by food and drug industries, e.g. for infant formula preparation and for anti-tumour activities, respectively.

The fractionation of whey proteins has been widely studied at the laboratory scale by using numerous separation techniques. Most of these have not been scaled up, mainly because of the cost and complexity. Since membrane separation processes are easily carried out at laboratories, scaling them up would be worthwhile for protein-protein separations. Nonetheless, since the two major proteins in whey, namely β-lactoglobulin (MW 33.6 kDa) and α-lactalbumin (MW 14.2 kDa) are of almost similar sizes, separating them is a challenge.

In general, UF membrane technology has been successfully applied to food processes for more than 20 years. UF membranes are characterized by their permeability and selectivity in solute retention, but the transfer of solvent and solute is limited by membrane fouling and concentration polarization.

Ultrafiltration of whey demostrates significant fouling characteristics because of the complexity of the feed composition and the surface interactions between the whey components and the porous material of the membrane. The concentration polarization caused by the accumulation of solutes near the membrane surface can have an adverse effect on the performance of many membrane systems. The accumulation of retained solute at the upstream surface of the membrane can significantly reduce the permeate flux through osmotic pressure and hydrodynamic effects. Concentration polarization can also increase protein transmission by increasing the protein concentration at the membrane (Zydney et al., 1995). The stagnant film model, also known as the concentration polarization model has been used extensively in modelling bulk mass transfer in membrane systems. It provides only an approximate description of the boundary layer transport. A number of researchers (Daufin et al., 1989, 1999; Fell et al., 1990) have tried to extend this simple model to account for the effects of a concentration-dependent viscosity and diffusivity, but the results are somewhat contradictory and are often in poor agreement with the more detailed numerical calculations.

Daufin et al. (1988) suggested that two limiting phenomena occur during UF of a solution containing macromolecules and suspended particles: (1) polarization due to a liquid layer of macromolecules concentrating on the membrane, and (2) fouling which is mostly considered as an addition to the membrane resistance. The fouling may be viewed as an additional resistance resulting from adsorption, gel formation, or particle deposition.

As for the concentration polarization model, the membrane wall-liquid mass transfer coefficient (k) is a measure of hydrodynamic conditions within a membrane module for a given feed solution. The permeate flux directly depends on the mass transfer coefficient (k), and the transmembrane pressure (TMP) drop. Hence, the success of UF in the food or dairy applications depend on how successfully the fouling can be controlled.

Hydrodynamic techniques such as helical inserts (Millwardv et al., 1995) and pulsatile flow (Finnigan and Howell, 1989) help to reduce membrane concentration polarization and fouling. Some other methods to enhance permeate flux include the pre-treatment of membrane surface by cleaning to prevent fouling and the pre-treatment of feed by settling to alter the interaction between the macro-molecules and membrane surface. These techniques can also reduce the energy cost of the process and can be used to achieve a sustainable high permeate flux. Gas sparging technique had been initially used to enhanced convective heat transfer, but it was later found to be effective in suppressing cake formation in the filtration of micro particles (Imasaka et al., 1989). Moreover, gas sparging by injecting air into the liquid feed stream, proved to be an effective and simple technique for enhancing permeate flux in UF (Cui and Wright, 1994, 1996; Cui et al.,1997 and Daufin et al., 1989).

Gas sparging is generally accepted as a simple and energy efficient means of enhancing permeate flux. Several mechanisms for this enhancement have been identified, including bubble induced secondary flow, physical displacement of the mass transfer boundary layer, reduction of membrane fouling, and pressure pulsing cause by slug flow. It is generally accepted that the main reasons for the enhancement in gas sparged UF with hollow fibre membrane systems are physical displacement and reduction in fouling resistance (Cui and Wright, 1996).

The formation of gas-liquid two-phase flow at the membrane surface by air sparging has been shown to reduce concentration polarization and fouling in ultrafiltration (Cui, 1993). The addition of air to the liquid stream increases both the turbulence at the surface of the membrane and the superficial cross-flow velocity within the system. These, in turn suppress boundary layer formation, leading to an enhancement of the filtration processes.

Imasaka et al. (1989) has reported that slug flow accelerates the crossflow filtration of methane fermentation broth. With a view to concentrating the microorganisms in a thermophilic methane fermentation broth, they studied the characteristics of cross-flow filtration using tubular ceramic membranes in liquid single-phase, gas-liquid two-phase and gas-liquid-solid three-phase flow systems. The same idea was introduced in two-phase operation of cross-flow ultrafiltration.

Cabassud et al. (1997) studied the formation of particles deposition of clay by modifying the wall shear stress in the tangential gas-liquid two-phase flow in hollow fibre membranes. They suggested that the suitable air injection ratio, $U_g/(U_g+U_L)$ for hollow fibre ranges between 0.2 and 0.9. The liquid slugs do not contain any small dispersed bubbles, contrary to what is observed in tubular membranes.

The enhancement of gas sparging is much more profound when the liquid phase is in laminar flow, particularly when the concentration polarization is more severe. The enhancing effect is not very significant when liquid flow itself is turbulent. The flow pattern proved to be an important parameter and the operation could be optimized to achieve maximum enhancement with minimum gas injection (Cui et al., 1996). Attempts had been made to introduce some dimensionless numbers which are useful for industrial applications and analyses. Elmaleh et al. (1998, 2000) introduced shear stress number and resistance number to estimate the membrane performance, taking into account the effect of gas sparging.

The major concern with using UF in the fractionation of proteins, is the poor selectivity of solute separation. The selectivity is affected by membrane pore size, protein-protein and protein-membrane interaction as well as concentration polarization. Adjustment of solution conditions such as ionic strength can alter the interaction of proteins and hence result in high separation efficiency. In addition, the membrane surface can be modified by chemical and physical methods such as irradiation and synthetic modification (Ghosh et al., 1998).



The information on the hydrodynamic effects on selectivity of protein fractionation is not readily available. Theoretically, the disruption of concentration polarization will reduce the wall concentration and hence the transmission of the solute. Cui (1993) reported an increase in rejection coefficient from 0.80 to 0.93 for 87kDa dextran with gas sparging in UF with a 100 kDa MWCO membrane. With the same membrane, Cui and Wright (1996) observed a 5 to 10% increase in rejection coefficient in UF of BSA and dyed dextran with gas sparging. Ghosh et al. (1998) explained the mechanism of fractionation in two-phase flow operation by a mathematical model and they established the causes of flux enhancement due to gas sparging. They also showed how the selectivity of the separation of BSA and lysozyme were affected in the process.

In the present work, the effect of gas sparging on permeate flux as a technique of concentrating whey proteins utilizing hollow fibre dialyzer has been investigated. The study involved the setting up of the experimental apparatus, and a series of experiments were conducted to investigate the effect of gas sparging on the enhancement of permeate flux. A range of flowrates and TMP were tested for the purpose of optimizing the whey protein concentration. The experimental data were analyzed and verified with existing models. In addition, a dimensionless analysis has been proposed for the purpose of predicting the flux enhancement.