Chapter 5

Other Applications, Constraints and Suggestions for Future Work

5.1. Other applications

Most of the work in osmotic membrane distillation (OMD) has been carried out at lab scale to concentrate numerous liquid foods such as fruit juices, vegetable juices and other aqueous solutions. Only a few reports are available at pilot scale.

In the present study, feasibility of OMD process has been demonstrated on large scale for the first time. For this purpose a facility has been established to carry out studies on large scale under controlled conditions.

OMD can be employed as pre-concentration step prior to relatively cost intensive processes such as lypholization (freeze drying), in case of thermally sensitive products such as enzymes/proteins, natural food colors and biological materials. Main advantage of OMD process is that it enables to concentrate aqueous solutions like fruit juices (>60°B) without product damage. OMD also finds application during de-alcolization of fermented beverages (wine or beer). The use of OMD helps in the selective removal of ethanol from these alcoholic beverages without adversely affecting their taste, odor or mouth feel. Ethanol recovered from the stripping solutions can be further used as a potential blending stock in the manufacture of fortified alcoholic beverages (Hogen *et al.*, 1998).

OMD like any other membrane process has low flux. However, the strength lies in its ability to yield a concentrate having superior product quality. In order to overcome the drawback and to improve the process economics, it has been proposed to have hybrid process involving clarification by microfiltration/ultrafiltration (MF/UF), pre-concentration by RO and final concentration by OMD.

Many researchers have carried out concentration of fruit juices (orange, passion, grape) involving MF/UF followed by OMD process on a pilot scale level. The feasibility of integrating OMD process with MF has been demonstrated during the concentration of fruit juice to an intermediate concentration (>30°B) with high flavor retention (Bailey *et al.*, 2000; Shaw *et al.*, 2001)

Further, the integrated membrane process has been explored for the clarification and the concentration of citrus (orange and lemon) and vegetable juice (carrot), using UF for clarification at pilot scale level. This was followed by concentration of juices by employing RO and OMD process in lab-scale unit. The concentrated juices obtained were of high product quality (Cassano *et al.*, 2003).

More recently, three-stage hybrid membrane process for the concentration of ethanol-water extracts of the *Echinacea* plant (which is used as immunostimulant) has been investigated. This resulted in a highly concentrated product suitable to market the product in capsule form. (Johnson *et al.*, 2002).

Work is underway in our laboratory to integrate OMD with RO for the concentration of tender coconut water. The tender coconut water, having an initial concentration of about 5°B, was concentrated by RO process (PCI membrane module) to a concentration of about 20-25°B. This RO retentate was concentrated further by OMD process up to about 56°B. The sensory analysis indicated that this process could be successfully employed for the concentration of heat sensitive products having delicate flavors such as tender coconut water (Rastogi *et al.*, 2003).

OMD process has been employed successfully to concentrate Hydroxy-citric acid (HCA) derived from *Garcinia pendaculata*. The acid content increased up to about 38% from an initial acid content of 9% without product damage during the concentration by OMD process. (Anandharamakrishnan *et al.*, 2004).

According to the reports available, hybrid process consisting of UF and RO followed by OMD has been successfully demonstrated on a pilot scale for the concentration of fruit and vegetable juices in Mildura, Melbourne, Australia. This OMD pilot plant has been designed and fabricated by Zenon Environmental (Burlington, Ont.)

Partitioning studies in ATPE of C-phycocyanin (protein/natural blue colorant) and separation of sugar from betalaines during the downstream processing of betalaines (another natural color) employing ATPE are also in progress.

Possible integration of aqueous two-phase extraction (ATPE) with membrane processes such as OMD is being explored for the purification and concentration of food colors (especially when there are proteins). The use of ATPE will enable desired products (enzyme/protein), partition to one of the phases, and the impurities to the other phase, thus purifying while reducing the volume of the process stream to be handled. OMD process can also be used as pre-concentration step prior to subsequent purification steps such as electrophoresis, chromatography etc.

ATPE appears to be a promising technique for efficient downstream processing of biomolecules due to its wide range of applications. Some applications of ATPE have been demonstrated on large/pilot scale. However, major constraint still remain with regard to the availability of information in the literature on engineering aspects of ATPE (involving mass transfer and hydrodynamics) are scant or remains proprietary and only few reports are available. In addition, the efficient methods for recovery and recycling of phase forming components are important for the development of environmentally benign aqueous two-phase extraction technique.

In case of OMD, apart from relatively low transmembrane flux, another major constraint for the wide commercial application of OMD process is dependent on the effective management of spent OA solution. Though, membrane fouling seems to be of minor importance, periodic membrane cleaning is essential in general. Several effective cleaning agents and methods are employed. However, studies have shown that repetitive cleaning and fouling can affect the membrane durability and thereby reducing its life cycle, an important aspect to be considered in regard of industrial application.

5.2. Suggestions for future work

Acoustic field assisted demixing resulted in significant enhancement in demixing rates in aqueous polymer-salt two phase systems (Chapter 2, Section 2A). In near future, the major parameters such as effect of acoustic intensity, acoustic frequency on demixing rates (which could not be studied due to the limitations of the equipment) needs to be studied. All these factors need to be considered while designing and fabricating demixing contactors/acoustic bioreactors for large-scale/industrial applications.

Faster demixing rates in the presence of electric field was observed even in case of polymer-salt aqueous two phase systems (Chapter 2; Section 2B). Detailed studies need to be undertaken to study the effect of electric field on phase volume ratio and phase composition in case of different aqueous polymer-polymer and other polymer-salt two-phase systems.

Microwave field assisted demixing has been reported (Chapter 2; Section2C). The process is simple, efficient and appears to be scalable and can be made continuous. Detailed studies to understand the effect of phase composition, molecular weight of the polymer in presence of microwave field needs to be undertaken.

The encouraging results obtained during initial electroextraction of betalaines (Chapter 2; Section 2D) can be employed further to carry out the detailed and systematic studies for the selective separation of betaxanthin and betacyanins from betalaines, isoenzymes from plant peroxidase and other charged biomoelcules. However, there is a need to arrive at an electroextraction module with better design, better control for the selective partitioning of biomolecules.

Microwave field assisted PEG recovery from spent phases has been discussed (Chapter 2; Section 2E). This method is simple, faster and efficient when compared to conventional methods of polymer recovery. Further, studies are needed on large scale and exploration of possible integration of the polymer recovery in the process stream needs to be investigated to improve the process economics.

Attention needs to be focused on the development of new phase systems for ATPE. These phase systems should be of low cost, ease availability, non-toxic, biocompatible and biodegradable, so as to improve the versatility and ecofriendliness of ATPE.

Reverse Micellar Extraction (RME) is another attractive and well established method for the liquid-liquid extraction and purification of biomolecules (Luisi and Magid, 1986). Another method employed for the extraction and purification proteins is three-phase partitioning (TPP) (Dennison and Lovrien, 1997). Hence, comparative studies for the extraction and purification of biomolecules using ATPE, RME and TPP would be of immense use for the selection of most suitable method. Work in this regard is already in progress.

Mass transfer-in-series resistance model which could predict the transmembrane flux and also the effect of the parameters was proposed (Chapter 3). Another major constraint of OMD process is relatively low flux. Attempts have been made to enhance the transmembrane flux by the application of acoustic field in lab-scale membrane cell (Chapter 3; Section 3.10). Some more studies are essential on large scale involving real systems to study the effect of various parameters on flux. Also, efforts are needed to enhance the transmembrane flux by the application acoustic field on a large scale using real systems.

The successful application of OMD process has been demonstrated for the concentration of natural food color/protein and liquid food without product damage (Chapter 4; Section 4A and Section 4B). This is followed by the large-scale studies for the processing of pineapple juice involving UF, RO followed by OMD (Chapter 4; Section 4C). Still detailed studies involving process and membrane parameters are required for hybrid processes when operated on a large scale/pilot scale.

To make OMD commercially viable option there is a need for the development of membranes with improved diffusional characteristics, new materials (polymeric, ceramic, zeolite etc.), selectivity, better.pore geometry, stability and membranes with longer life cycles at affordable costs. Another major constraint for the wide commercial application of OMD process is the management of spent OA solution. An integrated effective and environmentally benign reconcentration technique comprising of solar/thermal evaporation and RO needs to be developed.

The large diversity of plant/marine sources constitutes major source for different types of biomolecules such as natural colors, proteins/enzymes etc. having wide applications. Hence, efforts are required to carry out detailed studies in order to develop simple, efficient and economic methods for the downstream processing of these biomolecules and possible process integration of ATPE with OMD. Keeping in view of the scientific and industrial potential of ATPE/OMD, even if some of these aspects are addressed in greater depth by future researchers the objective of this thesis can be considered fulfilled, since it contributes to both these processes (ATPE/OMD) in gaining wide application in food and allied industry in the years to follow.