APPLICATION OF MEBRANE SEPARATION PROCESSES TO THE SRI LANKAN INDUSTRY

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ABSTRACT

Membranes and membrane based separation techniques have developed rapidly over the last two decades with a considerable technical and commercial impact. The technology is now widely used for a range of applications including water treatment, wastewater treatment, separations in the Chemical and Process industries, food and biotechnological industries and in the medical field. Micro Filtration, Ultra Filtration, Reverse Osmosis, Electro Dialysis and Dialysis are the commonly used processes. Nano Filtration, Pervaporation, Osmotic Distillation and Membrane Distillation are now becoming popular with the development of novel membranes, which withstand a wide range of operating conditions. The Membrane Separation technique is attractive due to many reasons, such as suitability of the processes for heat sensitive materials, high product quality and possibilities of recovery and recycle of valuable materials.

The survey shows very few applications of Membrane Processes in Sri Lankan industries. Normal Filtration and Ion Exchange are the widely used methods for water treatment. How ever, the application of a technique such as Reverse Osmosis or Ultra Filtration for water treatment in medical and pharmaceutical field, in drinking water production from high salinity level water and in food and beverage industries may largely help in improving the product quality. Wastewater is commonly treated using biological treatment and chemical treatment in combination with sedimentation. Approximately, 51% of the industries have the possibility of using Membrane Separation techniques not only to treat wastewater, but also to recover or recycle valuable materials, energy and water. Pulp and paper, Textile and Diary industries are the major uses of Membrane technology for wastewater treatment. Further, the novel separation techniques such as Pervaporation and Osmotic distillation can be experimented for the manufacture of range of new products.

Application of Membrane Separation processes in Sri Lankan industry will be important in anticipation of future demands for high standards and minimal environmental impact.

INTRODUCTION

Membrane separation is a relatively new technology suitable for numerous processes. Membrane technologies have been widely applied to a range of conventionally difficult separations. For example conventional filtration cannot be applied for efficient processing of fine particles and colloids. Further the thermal processes such as distillation and evaporation are not suitable for heat sensitive food stuffs, pharmaceuticals and biological materials. The heat consumption is also very high for such thermal separations. Therefore, with the growth of new industries and the new concept of waste minimisation and cleaner technology necessity of advanced separation techniques arose and, membrane technology developed dramatically in the 1980's. The process is now used in the fields of water treatment, wastewater treatment, food and pharmaceutical industries and biotechnological and medical fields, either to improve established processes by improving product quality, minimising waste, treating waste or to process new materials.

This paper critically reviews membrane separation processes used for liquid systems and identifies the possibilities of applying the technique to the Sri Lankan Industry.

MEMBRANE TECHNOLOGY AND SEPARATION PROCESSES

A membrane is a permeable or semi-permeable phase, which restricts the motion of certain species in a mixture. The membrane introduces an interface between two bulk phases (liquid or gas) involved in the separation. Transport of selected species through the membrane is achieved by applying a driving force across the membrane. The driving force may be the pressure gradient, concentration gradient, temperature gradient, electrical potential gradient or combinations of above.

The schematic diagram of membrane separation is shown in Fig.1. The fraction which passes through the membrane is called the 'permeate' and its flow rate per unit area is the 'flux'. The 'concentrate' is rich in all components, which cannot pass through the membrane. The ratio between the flux and the feed is the 'recovery'. The separation factor between the concentrate and the permeate of one species is called the 'rejection'.

The heart of any membrane process is the membrane. The membranes can be polymeric, ceramic, metallic or modified natural products. Liquid membranes are also used. The membranes are manufactured by various chemical and heat treatment processes. The membrane may be symmetric or asymmetric. Figs 2a and 2b show electron micrographs of two membranes used in practice. The function of the membrane will depend on its structure as this essentially determines the mechanism of separation and thus the application. Therefore, careful selection of the membrane is extremely important and membranes and selection are described in detail by Scott[1,2] and Williams [3]. However that is beyond the scope of this paper.

Membranes need to be incorporated into modules or permeators. The module must support the membrane under high differential pressure, separate the feed side and the permeate side allowing permeate to pass through the membrane. Four main types of membrane modules are Tubular, Flat sheet, Spiral wound and Hollow fibre and are shown in Fig.3.

Membrane separations are used for various processes such as separation of solids from liquids, liquids from liquids, separation of miscible liquids, separation of dissolved solids and solutes from liquids and separation of mixtures of gases and vapours. Industrial membrane separation processes for liquid systems are classified in Table 1. However, the processes for the separation of gases are not discussed here. Micro Filtration (MF), Ultra Filtration (UF), Nano Filtration (NF) and Reverse Osmosis (RO) are the pressure driven processes used for the separation of fine particles, colloids, macromolecules and dissolved salts from liquids systems. The four processes are compared in Fig.4.

Table 1. Classification of Membrane separation processes used for liquid systems

MS processes	Driving Force and the *Mechanism of separation*	Separation achieved/ comments	Membrane types widely used
Micro Filtration	Pressure *Sieving*	Separates fine suspended solids and colloids. Operating modes: dead end mode and cross flow mode.	PTFE, Ceramic, Metallic
Ultra Filtration	Pressure *Sieving (But particle surface charge and shape may play a role)*	Separates dissolved molecules and fine particles.	CA,PA, PS, PAN
Nano Filtration	Pressure *Sieving & Charge effects, Donnan exclusion*	Separation of divalent ions but not monovalent ions.	PA
Reverse Osmosis (Hyper Filtration)	Pressure *Size, shape, ionic charge interactions with the membrane*	Separates Ionic solutes and macromolecules.	CA,PS, PA, PAN, PI
Dialysis	Concentration gradient *Diffusion*	Large molecules are separated from small molecules. A slow process.	CA
Electro Dialysis	Electrical potential *Ionic charge*	Ion free liquid can be obtained.	DVB, PTFE
Pervaporation	Partial pressure difference achieved using a vacuum *Selective diffusion of one component with respect to others via the selected membrane*	Separation of miscible liquids. Specially when conventional thermal processes are not applicable.	CA,PA, PS, PAN, PI
Osmotic Distillation	Partial pressure gradient achieved by differences in component activity in the mixture. *Diffusion due to partial pressure gradient*	Separates volatile components from a solution and concentrated solutions can be obtained.	PTFE, PVDF
Membrane Distillation	Partial pressure gradient achieved by the temperature gradient. *Diffusion due to partial pressure gradient*	Separates volatile components from a liquid and high purity distillate can be obtained	PTFE, PVDF, PP

PTFE - Polytetrafluoroethylene, CA - Cellulose esters, PA - Polyamide, PS - Polysulphone, PAN - Polyacrylonitrile, PI - Polyimide, DVB - Divinylbenzene, PVDF - Polyvinylidenefluoride, PP - Polypropylene

APPLICATIONS AND LIMITATIONS

Applications of membrane based separations of liquid streams can be broadly classified into three groups namely Water treatment, Wastewater treatment and Separations in the manufacturing processes. In a particular application permeate, concentrate or both streams may be important. Usually MS processes are used as a hybrid process in combination with other conventional processes, to reduce cost of operation and fouling problems.

Water Treatment

Water used for domestic purposes, medical and biotechnological applications and industries are obtained from various resources such as wells, rivers and lakes. Raw water contains ions, solutes, colloids and suspended solids etc. and should be treated before use. The required treatment largely depends on the necessary application and also on the raw water resource. For some applications, common water treatment methods such as coagulation/flocculation, sedimentation, filtration (F) and ion exchange (IX) can be used. However, appropriate membrane separation techniques, sometimes in combination with common separation methods should be used when high quality water is needed. Further application of membrane separation processes for water treatment avoids addition of chemicals such as coagulants and flocculants.

Some common applications of membrane separation techniques for purification of water are desalination of brackish water or sea water, production of electronic grade water, boiler feed water, pyrogen free water for medical and pharmaceutical industry, water for food and beverage and ultra pure water for biotechnological applications [1,15]. Fig.5 shows production of potable water using RO.

Waste Water Treatment

Membrane separation processes are widely used for wastewater (ww) treatment either to alleviate pollution problems or to recover valuables from waste streams. The type of pollutants in the wastewater has a major bearing on the selection of treatment technologies. Pollutants present in wastewater are particulates, suspended solids and micro-organisms, dissolved inorganics, volatile organics and non-volatile organics. Despite the fact that number of techniques such as biological treatments, chemical processes, physical processes are available for the removal of above contaminants from waste streams each method has its own disadvantages and limitations. Therefore, advanced membrane separation processes have come to play an increasingly important role in industrial wastewater treatment. Major applications of MS techniques for ww treatment includes pulp and paper [17,20,23,4,8,14,16], textile [9,11,13], electroplating, power station, diary [10,21,22], latex, laundry, low grade radioactive plant, computer related industry [7] and oily waste water [19]. Figs 6 and 7 show MS applications in cheese whey production and paper manufacturing process respectively. Comparison of conventional wastewater treatment techniques and with Membrane separations is shown in Table 2. Relative advantages and disadvantages of the techniques are described in detail by Scott [1] and Zinkus [18]. Table 2 shows that membrane separations and distillation are the only techniques suitable for all types of contaminants. The cost values in the table include installed capital costs, maintenance costs, chemical and power costs. Cost of some membrane techniques may be high compared to some of the conventional treatment methods. However, when compared with the advantages such as recovery of valuables and wide range of applications possible with Membrane Separations, the technique can be recommended for many applications.

Table 2: Applicability of wastewater treatment technologies

Treatment Process \ Type of pollutant	Suspended solids	Dissolved Organics	Dissolved Inorganics	Micro-organisms	Cost per million gallons treated *
Biological treatment	✓	✓	-	✓	40-1000
Chemical oxidation	-	✓	-	✓	200-10000
Chemical precipitation	-	-	✓	-	50-200
Adsorption	-	✓	-	-	70-1000
Filtration	✓	-	-	✓	20-100
Flotation	✓	-	-	-	20-100
Stripping	-	✓	-	-	40-250
Distillation	✓	✓	✓	✓	20-10000
Sedimentation (coagu/floccu)	✓	✓	-	✓	50-500
Ion exchange	-	-	✓	-	250-1000
Membrane separation	✓	✓	✓	✓	30-200

*- extracted from Zinkus [18]

Separations in the Manufacturing Processes

Membrane technology is now used in the manufacturing processes of many industries with the development of new types of membranes from a variety of materials. The ability of new membranes to tolerate all types of chemicals, extreme pH values and high temperature opens possibility of using membranes where conventional separation processes are inapplicable. Main applications of membrane separation processes lies on separations in food, biotechnological and pharmaceutical industries. MS processes are used for concentration of fruit juice and vegetable juice, milk, separation of enzymes, insulin, proteins, antibiotics etc., for hemodialysis, beverage industry, for purification of essential oils and production of anhydrous ethanol. Osmotic Distillation (OD) and Pervaporation (PV) are novel techniques and becoming popular in many industries. Mechanism of OD and use of OD for fruit juice concentration is shown in Fig.8.

Limitations

Membrane fouling and concentration polarisation are the two main phenomena which reduce the performance of the membranes. Fouling is the deposition of retained particles onto the membrane surface or in the pores. The build up of this deposit causes a continuous decline in flux with time. Concentration polarisation is the formation of a concentration gradient of solutes established at the membrane surface due to the preferential transport of solvent through the membrane. The higher solute concentration at the surface results in a higher osmotic pressure thereby reducing effective driving force. However, the above effects can be controlled by methods such as feed pre-treatment, adjustment of membrane properties, membrane cleaning and modification of operating conditions [1].

SRI LANKAN INDUSTRY

The main objective of this work was to gather information on current MS applications in Sri Lanka and find possibilities of future developments. A questionnaire was sent to approximately 45 Sri Lankan Chemical and Process industries, Textile industries, hospitals and hotels. The summarised format of the questionnaire is shown in the appendix. Data obtained were analysed considering source of feed, contaminants or components to be removed, capacity, necessity and possibility of recovering and recycling valuables, energy or water (for wastewater treatment) and final use of the product. The data was carefully compared with the literature on MS applications in developed countries and applicability to the Sri Lankan industry was decided. The survey shows that only 5% of the industries considered for the survey use MS technique in the process. How ever, 51% have the possibility of using MS techniques to improve product quality or to recover and recycle valuable materials and water and thereby increase profits. The results are summarised in Fig.9.

Fig.10 shows data collected on technologies used for water treatment. Municipal water supply, well water, deep well water and river water are the major sources of water used in Sri Lanka. The water is treated for drinking purposes, for the manufacturing processes, for boiler feed and for medical and surgical purposes. Normal Filtration and IX are the commonly used techniques for water treatment. Few applications of MS processes for water treatment in Sri Lanka includes use of RO and UF in hospitals and in the hotel sector.

Wastewater is hardly treated using MS in Sri Lanka. Biological treatment and Chemical treatment are the widely used separation techniques. However, only very few industries use wastewater treatment plants with recovery or recycle. But, if correctly used 56% of the industries have the possibility of using MS to treat wastewater, out of which 50% have the possibility of recovering valuable materials or energy or both (Fig.11).

Despite the wide range of applications of MS in food, biotechnological and medical fields, hemodialysis, which is dialysis of the blood against a physiological saline solution using UF membranes, is the only current usage of membrane technology for separations in Sri Lanka.

DISCUSSION

Electro Dialysis (ED) and RO are well-established techniques for desalination of seawater and brackish water. Distillation/Evaporation, Crystallisation, Ion exchange are the other processes used for desalination. Evaporation/Distillation and Crystallisation provide good quality water but the energy consumption is very high for these processes. IX is very popular in industries since the process produces good quality water. However if the dissolved solids concentration in water is high IX beds should be regenerated very often and may not be economical. Therefore IX is not normally used for water containing more than 1000 ppm of dissolved solids. RO is economically attractive for water containing high dissolved solids. In ED, transport of ions consumes electrical energy and therefore the higher the ion concentration the higher the energy consumption. Energy consumption for ED is less than that for RO at low dissolved solids concentrations. But for high dissolved ion concentrations energy consumption for ED is higher than that for RO. NF is now becoming popular with the development of novel membranes. NF can be used for water purification if the permeate can contain monovalent salts such as Na. This is advantageous since NF can be used at low pressures such as 6-15 bar compared with 30 bar for RO. Membrane Distillation (MD) can also be used for water purification, this is more economical than evaporation but not competitive with RO. However, high purity distillate can be obtain via MD since there is complete separation between feed and distillate and no entrainment. UF is a very popular membrane separation process for water clarification and disinfection. The process removes suspended solids and all micro-organisms from water. For medical and biotechnological field non-pyrogenic water is required. Pyrogen level can be reduced to below 0.05 ng/cm^3 by combination of carbon adsorption, IX and UF.

MS can be used for a wide range of applications in Sri Lanka such as production of high purity water required for hospitals and pharmaceutical field, production of drinking water specially in the coastal areas where the water salinity levels are high. Seawater is proposed as the boiler feed water for the new coal power plant at Kalpitiya. Evaporation is suggested for purification of seawater for the plant, however RO also can be alternatively used [25].

UF and RO are the most widely used MS processes for the wastewater treatment. MF is sometimes used as a pre-treatment to other membrane separations to reduce suspended solids, which may block the UF or RO membrane. NF is also becoming popular in many applications such as pulp and paper industry. Application of MS techniques for the treatment of wastewater is advantageous compared to other processes such as coagulation, oxidation, adsorption and IX since MS processes can be performed without degradation of valuable materials and without addition of new chemicals such as coagulants. Despite high capital cost of membrane separation processes recovery of valuable materials, energy, water and chemicals are so high the pay back period for installing MS system is only few months. (For example 18-30 months in textile industry [13]).

Pulp and paper, textile and diary industries widely use MS processes for wastewater treatment since these processes not only treat wastewater but also recover valuable materials and recycle. Therefore such methods are profitable to use and can be tested for the Sri Lankan industry. Black liquor from the Embilipitiya paper mill cannot be treated by commonly used methods due to its high silica content. Hence storage of black liquor in lagoons costs over 9 million rupees [26]. ED has already been tested for treatment of black liquor [23] but other MS techniques can also be experimented. Further, the novel techniques such as Pervaporation (PV) can be used to remove traces of hazardous components from wastewater.

Membrane separation processes are preferable in food, bio chemical and medical fields because of low temperature operation, low energy requirements and high product quality. Diary industry seems to be the largest membrane separation application in food industry. MF has been tested for the separation of oil from coconut water, waste from desiccated coconut industries, but not yet commercialised [28]. OD, is a comparatively new technique used for pre-concentration of many products such as fruit juice and reduce the water quantity before expensive freeze-drying.

Essential oil is exported from Sri Lanka in the raw form at low cost and the purified high-grade oils are imported at very high cost. Distillation is the commonly used technique for purification of essential oils. However, distillation is expensive due to the large number of stages required to obtain high purity products and removal of tracer components. Alternatively, PV can be used for purification of essential oils and high quality products can be achieved.

CONCLUSION

MF, UF, RO, ED and D are well-established processes. NF is becoming popular with the development of novel membranes. PV, OD and MD are relatively new operations and expensive compared to other membrane separation processes. However, such techniques are also used in many industries due to the advantage of low temperature operation. These methods are suitable for food, biochemical and pharmaceutical products, which deteriorate at high temperatures.

A wide range of membrane separation applications is possible in Sri Lanka for water treatment, wastewater treatment, and recovery of valuable materials and energy from wastewater and for the separations in food and biotechnological industry.

Adoption of Membrane Technology for the Sri Lankan industry will not only assist in cleaner production, waste minimisation and environmentally friendly future but will also direct the industrialists for investigating new products.

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APPENDIX

QUESTIONNAIRE ON APPLICATIONS OF MEMBRANE SEPARATION PROCESSES IN SRI LANKAN INDUSTRIES

i. Company :...

ii. Address :...

iii. Main Products :...

iv. Capacity :.....................
(Daily production)

1. Do you use **water purification** in your plant?

Yes	
No	

2. If water purification is done, please complete the table given below.

Technique		tick	Source of raw water	For what purpose the purified water is used	Capacity (m^3/day)
Normal Filtration					
Ion Exchange					
Distillation					
Membrane Separation	Micro Filtration				
	Ultra Filtration				
	Nano Filtration				
	Reverse Osmosis				
	Dialysis				
	Electro Dialysis				
	Osmotic Distillation				
	Membrane Distillation				
	Pervaporation				
Other processes					

3. Do you have a **wastewater Treatment** plant?

Yes	
No	

4. If wastewater Treatment is done, Please complete the table given below.

Technique		Tick	Source of waste water*	Capacity/ Flow rate	Do you recover or recycle any material?	
					Yes/No	If so give details
Biological Treatment						
Chemical Treatment						
Membrane Separation	Micro Filtration					
	Ultra Filtration					
	Nano Filtration					
	Reverse Osmosis					
	Dialysis					
	Electro Dialysis					
Other process						

* Explain from which unit the waste water generated

5. Do you use Membrane Separation processes anywhere else in the plant other than mentioned above?
E.g. Concentration of Fruit Juice, Vegetable Juice
Concentration of Proteins, Enzymes etc

Application	Membrane Separation process	Description

6. Any other comments

Name :..

Designation :..

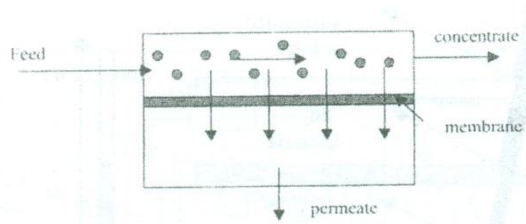
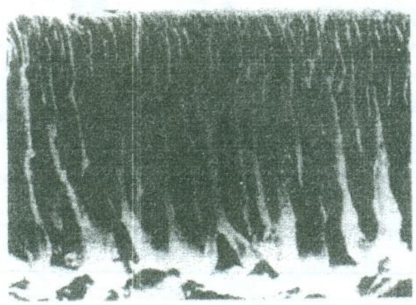
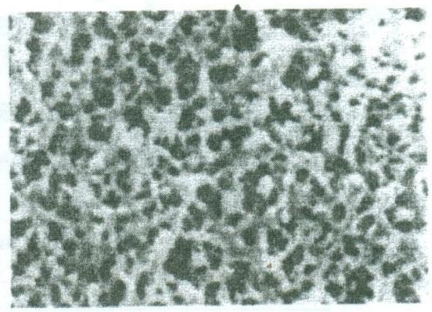


Fig 1: Schematic of a membrane separation

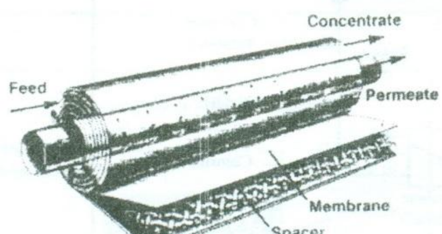


(a) Section through an asymmetric UF membrane

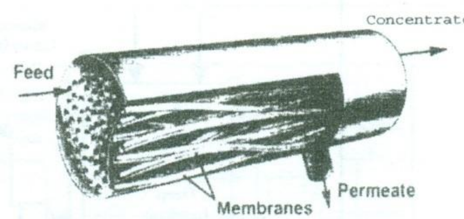


(b) PP membrane produced by stretching

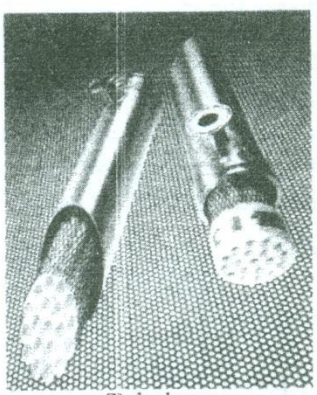
Fig. 2 : Electron micrographs of membranes



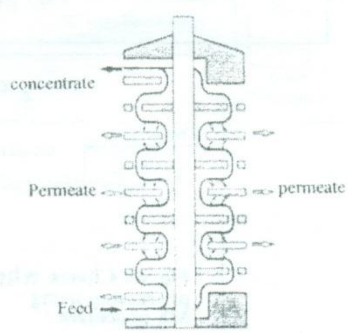
Spiral Wound



Hollow Fibre



Tubular



Flat Plate

Fig. 3: Membrane Modules

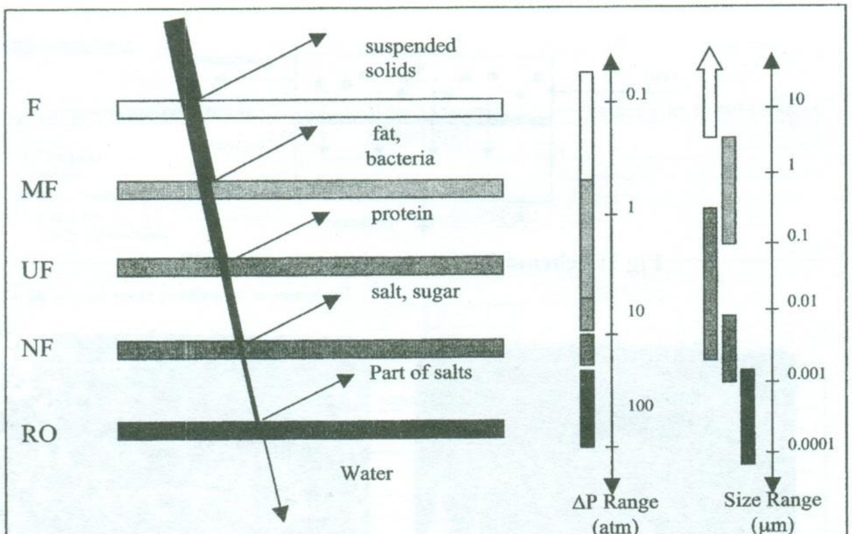


Fig.4 : Comparison of Pressure Driven Membrane Processes

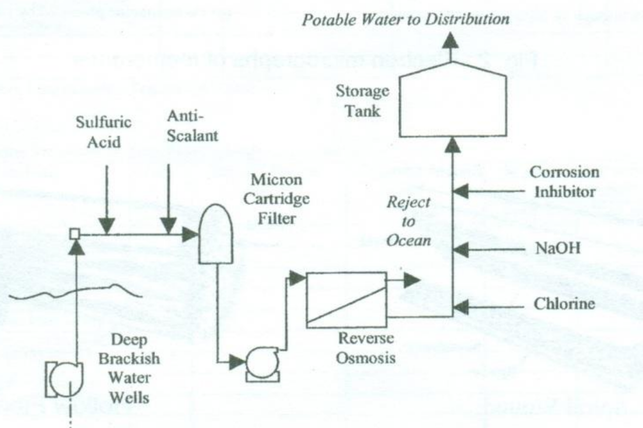


Fig. 5: Potable Water Plant

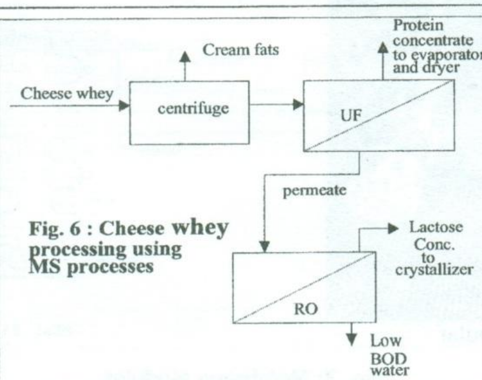


Fig. 6 : Cheese whey processing using MS processes

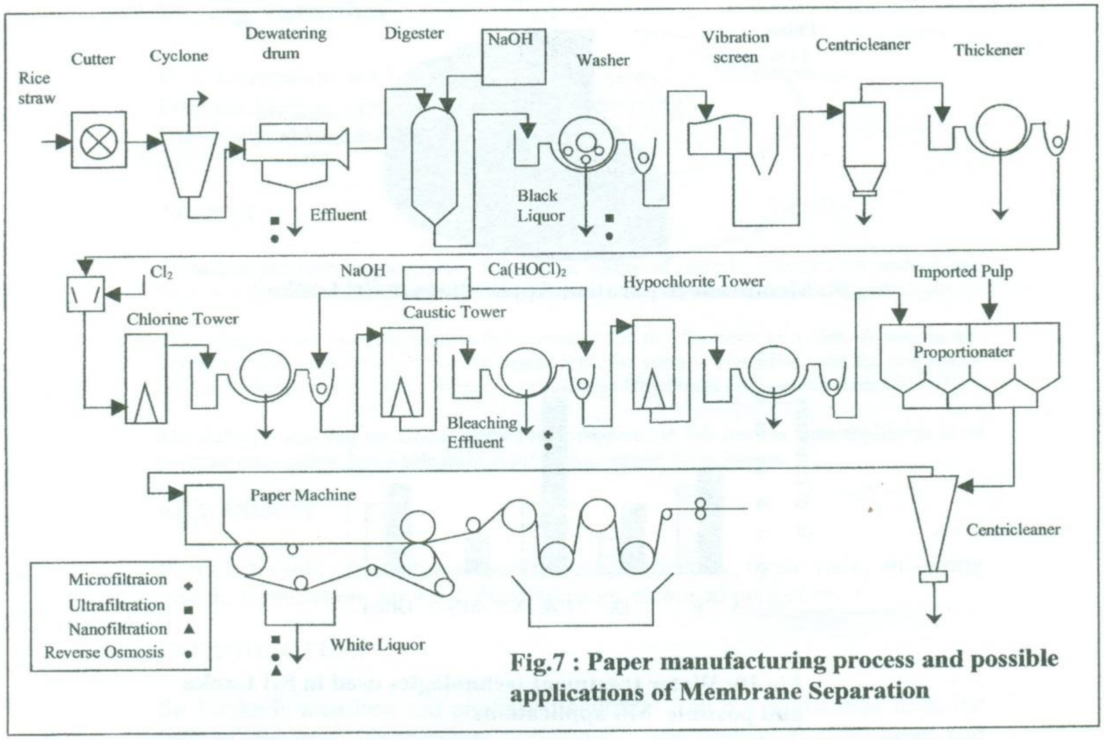


Fig.7 : Paper manufacturing process and possible applications of Membrane Separation

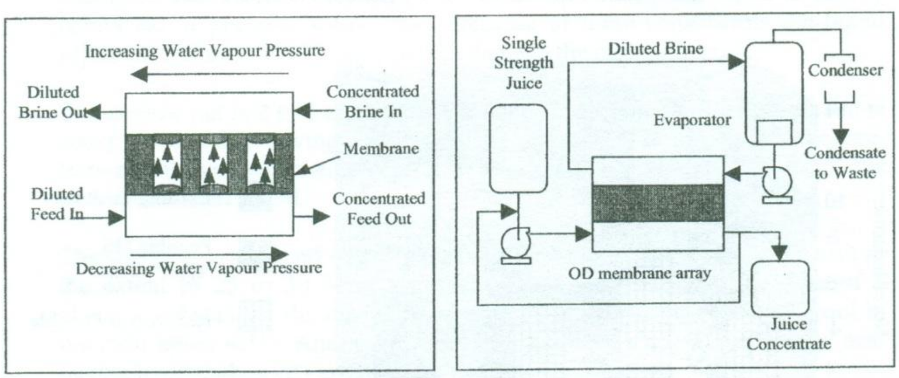


Fig. 8: a) Mechanism of Osmotic Distillation
b) Concentration of fruit juice using osmotic

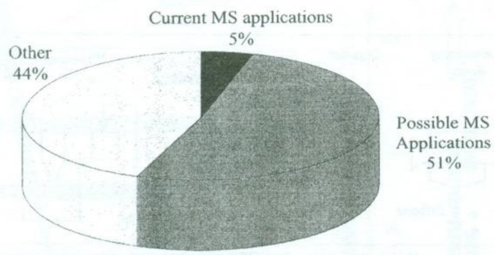


Fig.9 : Membrane Separation Applications in Sri Lanka

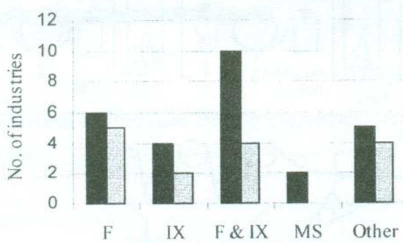


Fig 10: Water treatment technologies used in Sri Lanka and possible MS applications

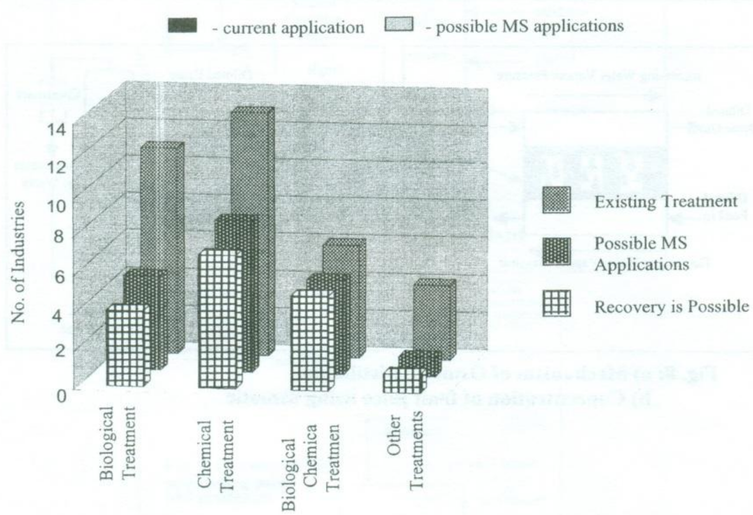


Fig.11 : Waste water treatment techniques used in Sri Lanka and Possible applications of MS