Membrane Experiments for Pollution Prevention

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Abstract

A major objective of the Junior and Senior Engineering Clinics at Rowan University is to introduce students to open-ended design projects. The purpose of the clinic classes is to provide engineering students with a hands-on, multidisciplinary experience throughout their college education. This type of innovative approach for allowing students to become involved in realistic open-ended design problems is beneficial for enhancing their problem solving skills and encourages them to pursue graduate studies. The engineering clinics emphasize multidisciplinary design on projects of progressive complexity. This paper focuses on the design and development of experiments to illustrate membrane technology for pollution prevention. A multidisciplinary student team conducted a thorough literature search and developed innovative membrane experiments to demonstrate pollution prevention. These experiments can be used by various disciplines in engineering such as environmental and chemical engineering.

Introduction

Membrane technology has gained wide popularity in the environmental and chemical industries in recent years. A membrane is an ultra-thin, semi-permeable barrier separating two fluids that permits the transport of a certain species or components through the barrier from one fluid to the other. Typically the water treatment industry has relied on membrane processes such as reverse osmosis, ultra- and nano- filtration. Beyond the expected use of membranes for water filtration, the chemical engineering industry uses membrane technologies for the separation/filtration of solvents so that water can meet the minimum specifications needed for a given chemical reactor. Also, membranes are used in the pharmaceutical, biomedical, food processing, and hazardous waste treatment industries. The wastewater industry has also started using membranes in bioreactors and also for tertiary treatment and wastewater reclamation. Membrane technology is also the viable solution for reclamation of wastewater for NASA space missions. Campers can now also carry portable membrane water filtration units in their backpacks that allow them the flexibility to drink water from streams, which may not be typically fit for human consumption. Finally, marine ships use reverse osmosis to remove the salt from seawater to meet the demands of the crew. The popularity of membrane technology indicates a need for changes in traditional environmental and chemical engineering curriculum. This paper describes the development of common membrane experiments to illustrate pollution prevention to engineering students. A multidisciplinary team of students at Rowan University developed these experiments in their Junior/Senior Engineering clinic class.

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The junior and senior clinics at Rowan University have been described in details in numerous publications [1-8]. Multidisciplinary student teams engage in single semester or multi-semester projects. Funding for the majority of these projects are mainly sought from industry, federal and state agencies.

The overall membrane clinic project objectives were to:

- Demonstrate membrane applications for water, wastewater and hazardous waste treatment.
- Demonstrate an ability to work effectively in a multidisciplinary team.
- Demonstrate acquisition of new technology skills through use or development of appropriate computer hardware, software, and/or instrumentation.
- Demonstrate improved communication skills including written, oral, and multimedia.

Three experiments using membranes were developed. Experiments included ultrafilatration, reverse osmosis and gas transfer using hollow fiber membranes. A list of courses in the Rowan Engineering Curriculum that will be using these experiments is presented in Table 1.

Table 1: List of Courses

Environmental Engineering Courses	**Chemical Engineering Courses**
Water Treatment	Separation processes
Wastewater Treatment	Unit Operations
Introduction to Environmental Engineering	Chemical Processes

Membrane Experiments

Reverse Osmosis

Reverse osmosis (RO) is presented in this series of water purification technologies, which use membranes to perform the separation.

Refer to Figure 1 of a reverse osmosis system related by contrasting it with an osmosis system.

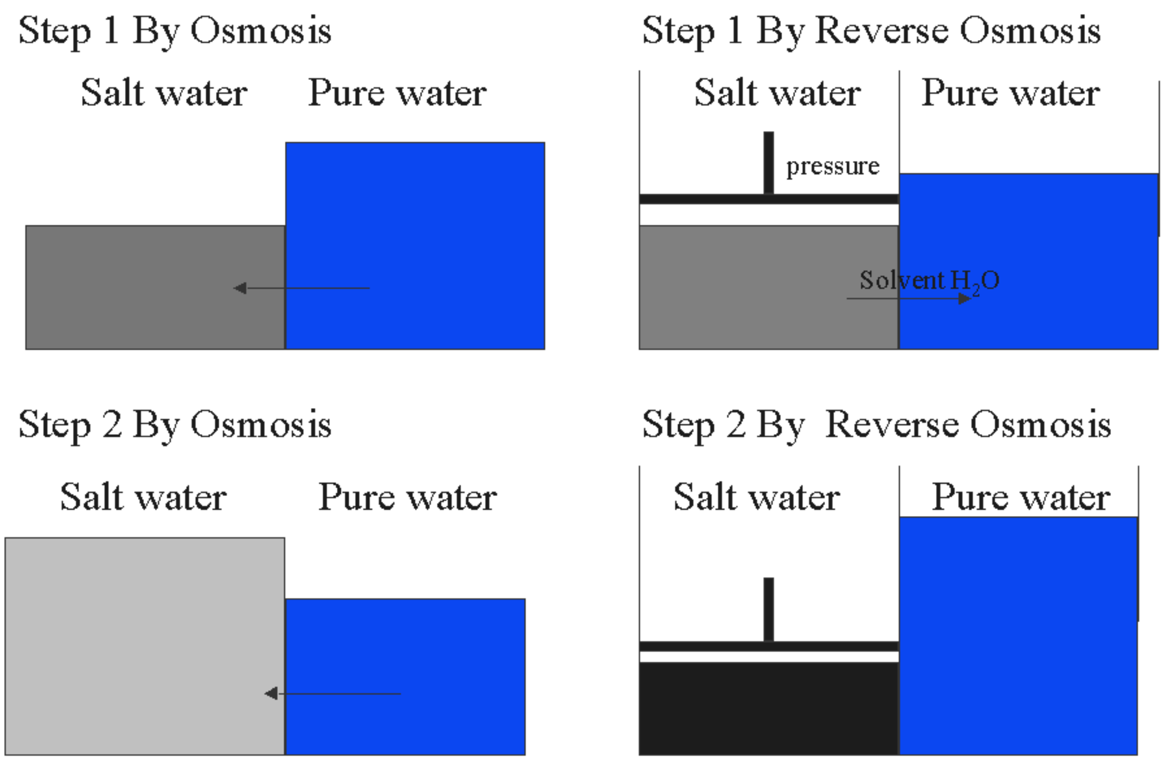

Figure 1: Reverse Osmosis Process [9]

When two containers containing different concentrations of dissolved salt in water solvent are allowed to mix through a selective membrane, the lower solute side will dilute the higher concentration container until the concentration of both containers reaches equilibrium. This process involves the transport of water to the higher concentration side. The change in pressure on the high concentration (resulting from a larger volume of water) container is the osmotic pressure.

Reverse osmosis works by applying greater than the osmotic pressure to the salt (high concentration container) thus forcing solvent water to flow (through a selective membrane) to the permeate (pure water) stream.

Our goal is to introduce the membrane separation process of reverse osmosis to students and to familiarize students with calculations used to determine flux and rejection coefficient of the membrane unit. The PUR power survivor 40 and 80 are used. These two models of reverse osmosis are built for use in marine applications where salt free water is not readily available. Table 2 compares the PUR 80 and 40 RO units.

Table 2: Comparison of PUR 80 and 40

	PUR 80	PUR 40
Power requirement	12 volt DC 8 amps	12 volt DC 4 amps
Water production	12.9 L/hr	5.7 L/hr
Pretreatment Module	Yes	yes
Feedwater flow rate	128.7 L/hr	75.7 L/hr
Salt Rejection	98.4% average	98.4% average

Students measure the Total Dissolved Solids (TDS) of the feed stream and permeate streams with a conductivity meter attached to Lab View to determine the salt rejection of each unit. Students also measure the flow rate of the feed, retentate, and permeate streams to calculate the rejection coefficient (i.e. the efficiency) of each RO unit using $R^0=(c_b-c_p)/c_b$. Each of the reverse osmosis units are compared to each other and to other water filtration techniques.

The goal of this laboratory experiment is:

- To introduce students to the RO technology
- To familiarize them with the advantages and disadvantages of different size units, and to
- Perform basic RO calculations in a real world application.

Also, longer term experiments can be performed to demonstrate how efficiency reduces over time, and TDS increases in the permeate stream to if the reverse osmosis units are not changed or cleaned.

Ultrafiltration

Ultrafiltration is used for retaining larger solutes than in reverse osmosis. Using ultrafiltration, high molecular weight materials can be removed from solution. Two experiments developed to demonstrate this are the separation of riboflavin from dextran blue, and the separation of humic acid from surface water. A similar experiment was developed by Lodge et al. 1997 [10].The first experiment focuses on the separation of riboflavin (molecular weight – 2 x 10^6 g/mol) and dextran blue (molecular weight – 376.37 g/mol) from a solution of riboflavin and dextran blue. The dextran blue is caught in the membrane while the riboflavin passes through. The concentration of each is determined with a spectrophotometer.

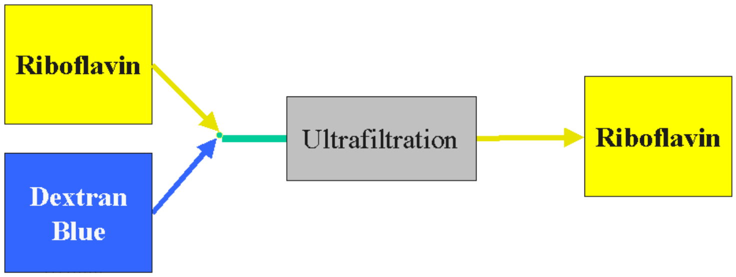

Figure 2: Riboflavin/Dextran Blue Experiment

A second experiment focuses on the removal of humic acid from water to improve water quality. Humic acid is made up of decomposed organic matter and occurs naturally in surface waters. Humic acid reacts with chlorine to make trihalomethanes, which are carcinogens. Humic acid has a molecular weight range of 2000 to 500,000 g/mol, and will be retained by the membrane allowing the clean water to pass through.

Gas Transfer Using Hollow Fiber Membranes

This project focuses on developing some novel membrane applications to water and wastewater treatment. In conventional aeration systems it is difficult to attain high concentrations of gases into water without avoiding problems of wastage, supersaturation and bubble formation. A novel sealed end hollow fiber membrane gas transfer device allows gases to be dissolved without bubble formation, thereby allowing very efficient gas transfer. A bubbleless gas transfer device was fabricated to conduct studies on aeration of various industrial wastewaters. The experimental setup is presented in Figure 3. Celgard X 20 microporous polypropylene membranes from Hoechst Celanese, Charlotte NC, were selected for the hollow fiber module. These membranes have a wall thickness of about 25 micrometers and pore diameters of 0.02-0.05 micrometers. Sealed-end fiber modules were constructed and evaluated for the oxygenation of water. The experiment has been described in details by Jahan et al., 2001 [11]. Pure oxygen was maintained inside a bundle of sealed-end membranes at a pressure below the bubble point. The water to be aerated was pumped over the outside of the membranes. This process provides 100% oxygen transfer efficiency at reasonable power input. This experimental project allows students to evaluate the feasibility of membrane aerators in comparison to conventional ones. The students were also involved in predicting mass transfer performance of the membrane system.

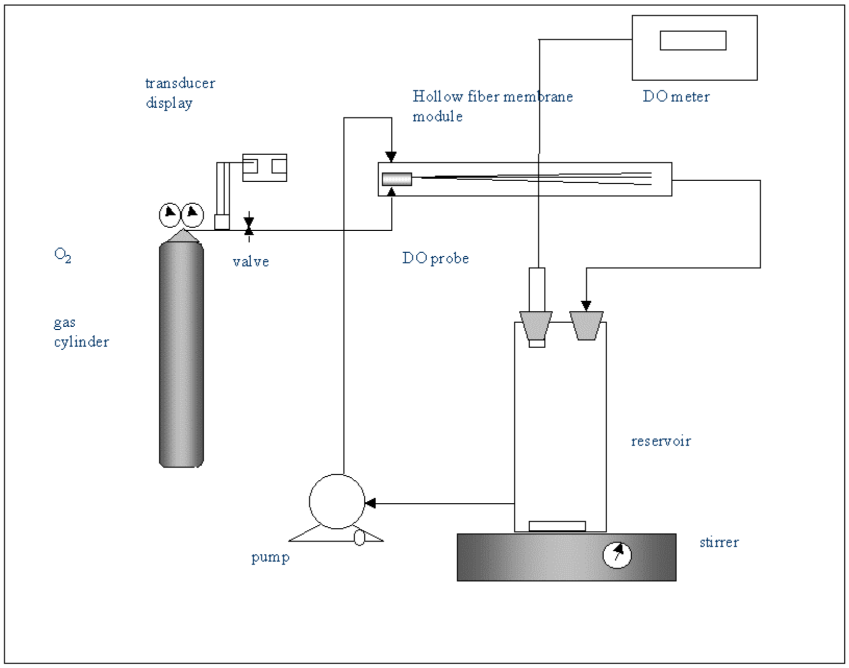

Figure 3: Gas Transfer Experimental Setup

A detailed list of equipment used for the above experiments is presented in Table 3.

Table 3: Experimental Equipment Prices

Item	**Price (2001)**
Millipore Ulatrafiltration Unit (Model # 29751)	$ 3200.00
Includes Pumps	
PUR PowerSurvivor 40E (Model # MROD-40E)	$2440.00
Membrane Aerator	$1,500.00

Conclusions

Experiments were developed to demonstrate important separation technologies: Reverse Osmosis, Ultrafiltration, and Gas Transfer using Hollow Fiber Membranes. These membrane experiments provide students with hands on learning allowing students to have both textbook and laboratory experiences in separation technology. The experiments can be used by both chemical and environmental engineering disciplines. Each membrane experiment can be used to demonstrate applications in water/wastewater treatment, chemical processing and hazardous waste treatment.

Acknowledgements

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Authors

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Jesse Condon and **Chasity Williams** are seniors in the Civil and Environmental Engineering program at Rowan University. They helped develop these experiments in the Spring and Fall semesters of 2001. **Benjamin Fratto** is a senior in the Chemical Engineering Program at Rowan University.