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Separation Characteristics of Dissolved Gases from Water Using a Polypropylene Hollow Fiber Membrane Module with High Surface Area

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***Abstract*—**A polypropylene hollow fiber membrane module is used for separating dissolved gases which contain dissolved oxygen from water. These dissolved gases can be used for underwater breathing. To be used for a human, the minimum amount of oxygen is essential. To increase separation of dissolved gases, much water and high surface area of hollow fibers are requested. For efficient separation system, performance of single membrane module with high surface area needs to be investigated.

In this study, we set up experimental devices for analyzing separation characteristics of dissolved gases including oxygen from water using a polypropylene hollow fiber membrane module. Separation of dissolved gases from water is investigated with variations of water flow rates. Composition of dissolved gases is also measured using GC. These results expect to be used in developing the portable separation system.

***Keywords*—**High surface area, breathing, vacuum, composition.

I. Introduction

WATER deoxygenation is important for preventing corrosion, poor heat transfer and efficiency reduction in the boiler [1]. Hollow fiber contactors for oxygen removal from water have been widely used in the process for ultrapure water in microelectronic and pharmaceutical parts. In the membrane degassing process, the gases diffuse through the membrane, and the membrane is used as a barrier between the gas phase and the liquid phase. So, this process provides many advantages, such as a fast mass transfer efficiency, large surface area per unit volume, and tight module structure [2], [3]. The water vapor permeation permeation enhances the mass transfer of DO across the membrane and thus, favors the DO removal [4]. Nguyen et al. said that the well-defined geometrical arrangement of fluid and gas channels, separated by semipermeable membranes provided a new platform for increasing the function of liquid chemical solutions to capture gases [5].

But, these gases separated from water can be used in underwater breathing for a human [6]. Water contains oxygen and nitrogen, so, if sufficient amounts of dissolved gases are separated from water, these gases can be used for breathing. So, human beings could spend more time under water, greatly increasing their mobility [7]. An artificial gill system has been developed for oxygen uptake from water to deoxygenated air using perfluorooctyl bromide (PFOB), which has high oxygen solubility. This method is favorable to extract dissolved oxygen from water; system is complex for developing portable device underwater.

In this study, instead of special solution, to increase the amounts of dissolved gases separated from water, hollow fiber membrane module with high surface is used. So, we set up experimental devices for analyzing separation characteristics of dissolved gases including oxygen from water using a polypropylene hollow fiber membrane module. Separation of dissolved gases from water is investigated with variations of water flow rates. And composition of dissolved gases is also measured using GC. These results expect to be used in developing the portable separation system, the artificial lung [8]-[10], and fuel cell for underwater robots [11].

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II. Methods

Fig. 1 shows outline for experimental devices which include a reservoir, a water pump, a flow meter, a hollow fiber membrane module, a data acquisition system, and a vacuum pump. Water flow ranges from 40 LPM to 80 LPM with interval of 20 LPM. The FSP 200 flow meter from Fns PLUS Company is used for measuring water flow. The membrane module made from Liqui-Cell is used for separation of dissolved gases and its specifications are showed in Table I. Water flows into shell side of hollow fiber membrane module and dissolved gases are placed inside of tube. The Data acquisition system contains NI acquisition card, a flow sensor and a vacuum sensor. It measures flow rates of dissolved gases and vacuum state inside of tube and stores measured data at proper time intervals. The M-1SLPM-D model from ALICAT company is used for gas flow which ranges to 1 LPM.

TABLE I
POLYPROPYLENE HOLLOW FIBER CHARACTERISTICS

Name	Spec.
Material	Polypropylene
Potting materials	Epoxy
Surface area (m^2)	20
Porosity (%)	~25
OD/ID (μm)	300/200
Shell side volume (L)	4.2
Lumen side volume (L)	1.1
Height (mm)	889
Diameter (mm)	116.1
Maximum water flow (m^3/hr)	6.8
Pressure drop (bar) at 6.1 m^3/hr water flow	0.69

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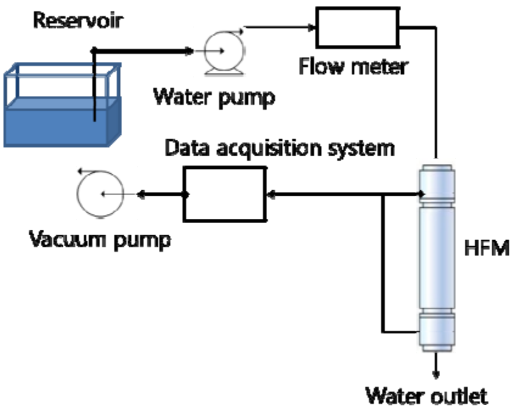


Fig. 1 Outline for experimental devices

III. Results and Discussions

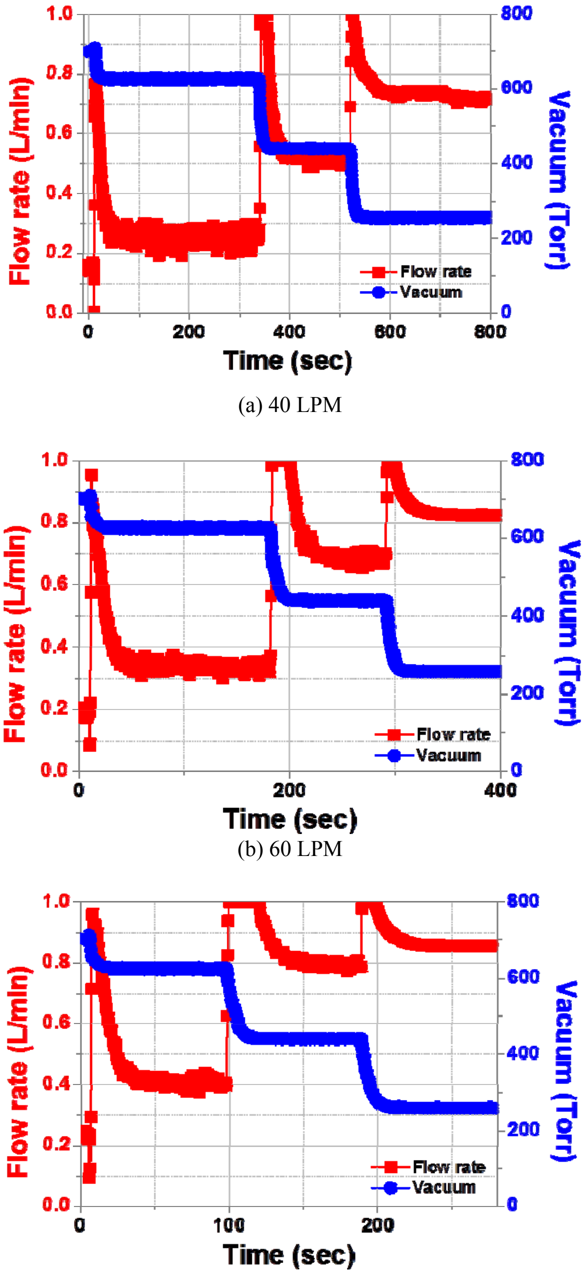
Fig. 2 shows separation characteristics of dissolved gases for water flow rates. Red lines mean flow rates of gases separated from water and blue lines represent vacuum inside of tube, which is measured using vacuum sensor. The vacuum sensor is placed in the data acquisition system. The DAQ is possible for users to store flow rates of separation of dissolved and vacuum states. Maximum range, time intervals, and measuring range are controlled using GUI. DAQ uses a NI acquisition card and Lab view program. Flow rates of separation of dissolved are increased with vacuum inside of tube. Sometimes, at high vacuum state, water permeation can be measured due to hollow fiber problems but no water permeation is showed in this experiment. Good separation of dissolved gases from water needs to block water permeation at high vacuum state.

Fig. 3 shows separation characteristics of dissolved gases at same vacuum state. Separation of dissolved gases is in proportion with water flow rates. From the manual supplied by the membrane module company, it is reported that removing dissolved oxygen is decreased with increasing water flow rates. Until 80 LPM of water flow rates, removing rate is slowly decreased with increasing water flow rates. More water flow rates mean more dissolved gases, so it shows larger flow rates of separation of dissolved gases.

Fig. 4 shows comparison of controlled vacuum and measured vacuum inside of tube. Pressure valves in the measured vacuum are a little bit higher than ones in controlled vacuum. It is considered to be attributed to the vacuum loss inside of tube.

Fig. 5 represents composition of dissolved gases separated from water. The amounts of oxygen contained in separation of dissolved gases are more than one in the air. To use gases separated from water for underwater breathing, oxygen concentration of separated dissolved gases needs to be decreased similar to one in the air.

Fig. 6 shows pressure drop against water flow rates. Higher flow rates results to higher pressure drop. Pressure drop at high water flow rate is a little bit larger than membrane module specification from company. It's considered to be attributed to the increment of fluid resistance.

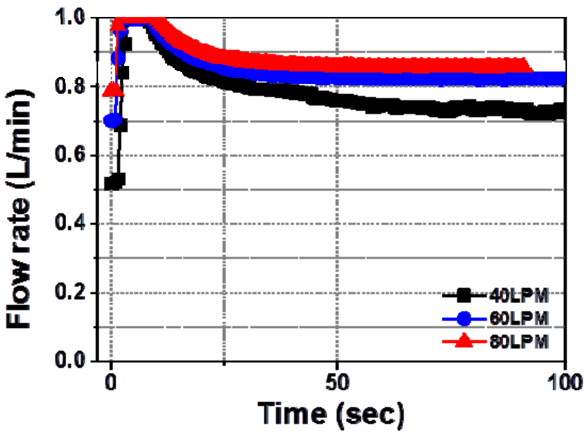


(a) 40 LPM

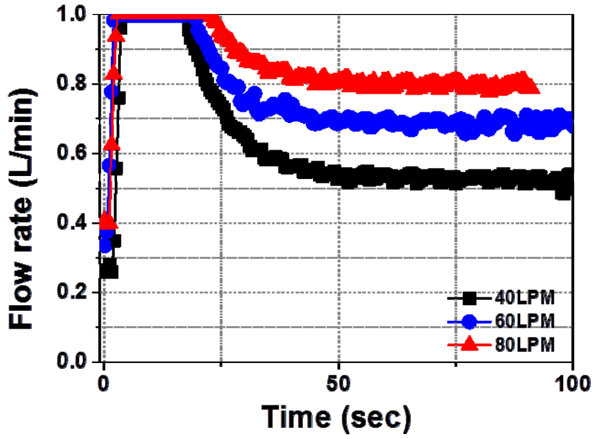
(b) 60 LPM

(c) 80 LPM

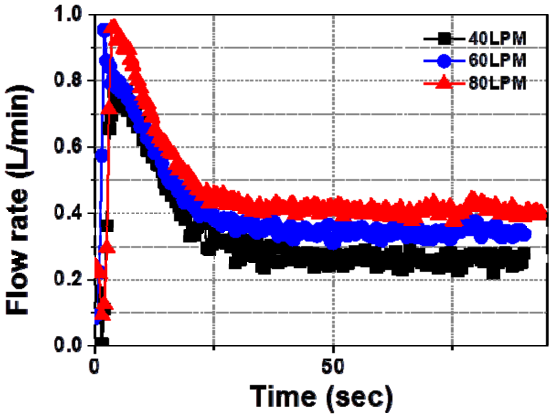
Fig. 2 Separation of dissolved gases for water flow rates



(a) 200 Torr



(b) 400 Torr



(c) 600 Torr

Fig. 3 Separation characteristics for different vacuum states

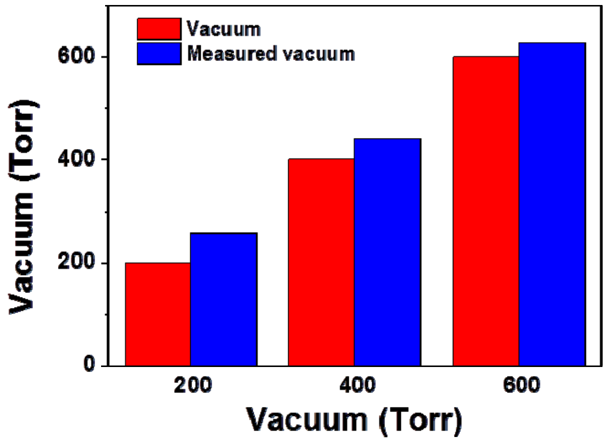


Fig. 4 Comparison of controlled vacuum and measured vacuum states inside of the tube

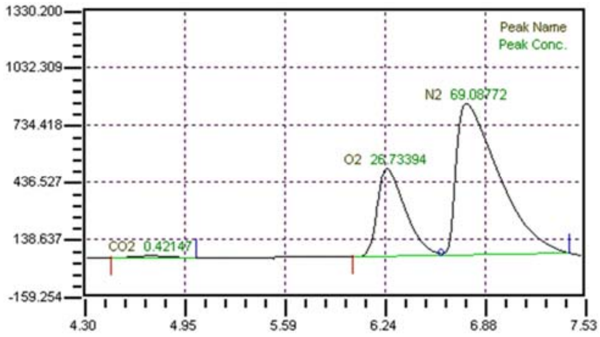


Fig. 5 Composition of gases separated from water

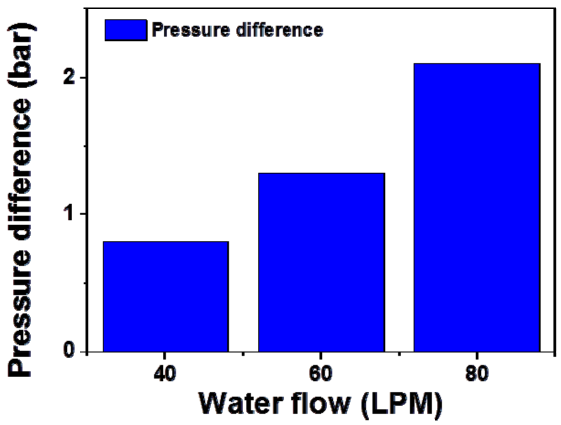


Fig. 6 Pressure drop for different water flows

IV. Conclusion

The amounts of dissolved gases were investigated using PP hollow fiber membrane module with high surface area. Separation of dissolved gases was increased with increasing water flow. Until 200 Torr, there was no permeation of water, through hollow fiber membrane module. Composition of dissolved gases was measured using GC, and concentration of oxygen was increased in comparison with one in the air. From these experimental results, it is considered that dissolved gases separated from water using polypropylene hollow fiber membrane will be used for a human to breathe underwater, if properly treated.

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