

# Separation of Dissolved Gas for Breathing of a Human against Sudden Waves using Hollow Fiber Membranes

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**Abstract**—The separation of dissolved gas including dissolved oxygen can be used in breathing for a human under water. When one is suddenly wrecked or meets a tsunami, one is instantly drowned and cannot breathe under water. To avoid this crisis, when we meet waves, the dissolved gas separated from water by wave is used, while air can be used to breathe when we are about to escape from water. In this thesis, we investigated the separation characteristics of dissolved gas using the pipe type of hollow fiber membrane with polypropylene and the nude type of one with polysulfone. The hollow fiber membranes with good characteristics under water are used to separate the dissolved gas. The hollow fiber membranes with good characteristics in an air are used to transfer air. The combination of membranes with good separation characteristics under water and good transferring one in an air is used to breathe instantly under water to be alive at crisis. These results showed that polypropylene represented better performance than polysulfone under both of air and water conditions.

**Keywords**—separation, wave, dissolved gas, hollow fiber

## I. INTRODUCTION

It is very useful for a human to breathe under water without an oxygen storage tank which has fixed amounts of oxygen.

A skin scrubber stays under water during limited time. A fish can use dissolved oxygen from water and stay under water for long time. If a human uses oxygen dissolved in water, he can stay under water for long time. A fish typically needs small amounts of oxygen because she is smaller and has a cooler body than a human, while a human needs larger amounts of oxygen to breathe under water.

Some diving insects use dissolved oxygen by carrying an air bubble that provides both an air reservoir and a water-vapor interface across which gaseous diffusion occurs, thus allowing oxygen to be replenished and carbon dioxide to escape [1-3]. Some aquatic insects, such as the great diving beetle *Dytiscus marginalis*, have morphological adaptations on their abdomen consisting of rigid nonwettable hairs, which support a noncollapsible film of air (a plastron). To investigate whether a superhydrophobic material could mimic the plastron action of biological systems, they created a sol-gel foam material using methyltriethoxysilane and investigated a phase separating process. When the concentration of dissolved oxygen in the water was reduced, the oxygen concentration within the cavity decreased and as the water was reoxygenated, the oxygen level within the cavity increased. Also, they demonstrated the slower decrease and nonzero (~12%) equilibrium value of oxygen levels in the cavity formed with MTEOS, compared with an equal volume sealed cavity formed with material which didn't permitted gas exchange. That means the foam is working as an external physical gill.

To characterize the plastron theoretically, the idealized two-dimensional geometry of the hair lattice and plastron interface was proposed [4]. The plastron is maintained against the pressure of the overlying fluid via surface tension. The diffusion of dissolved oxygen from the ambient water may allow this layer to function as a respiratory bubble or 'plastron', and so enable certain species to remain underwater indefinitely. By coupling the bubble mechanics, surface and gas-phase chemistry, they demonstrated criteria for plastron viability and thereby deduced the range of environmental conditions and dive depths over which plastron breathers could survive. Biomimetic characteristics were discussed. An artificial gill was discussed using a concentrated hemoglobin solution containing inositol hexaphosphate (IHP), as the oxygen carrier solution, with the oxygen affinity controlled by temperature [5]. The enhancement factors of the oxygen carrier solution that indicated its performance were obtained from the oxygen uptake rate and oxygen release rate. Another artificial gill using the photoresponse of a molybdenum porphyrin was proposed [6]. This used an oxygen carrier solution and the energy of visible light. The oxygen partial pressure in the oxygen carrier solution was changed by photo-irradiation to enhance both the oxygen uptake from water and the oxygen release to air. In this study we investigated the separation characteristics of dissolved gas including dissolved oxygen using pipe type of a hollow fiber membrane with polypropylene and nude type of one with polysulfone. The hollow fiber membranes with good characteristics under water are used to separate the dissolved gas. The hollow fiber membranes with good characteristics in an air are used to transfer air. The combination of membranes with good separation characteristics under water and good transferring one in an air is used to breathe instantly under water to be alive at crisis.

## II. METHODS

We tested the amounts of transferred gas through the membrane with pressure. Our experiments composed of a pipe type of hollow fiber membrane (HFM) with polypropylene, a nude type HFM with polysulfone, a vacuum pump, a gas sensor, a hydraulic pump and a reservoir. The overview of experimental devices underwater is shown in Fig. 1. Fig. 2 shows the manufactured system which is operated underwater.

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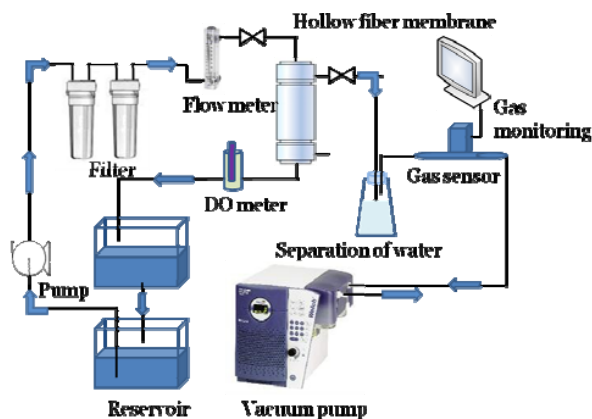


Fig. 1 Overview of experimental devices for separating dissolved oxygen from water

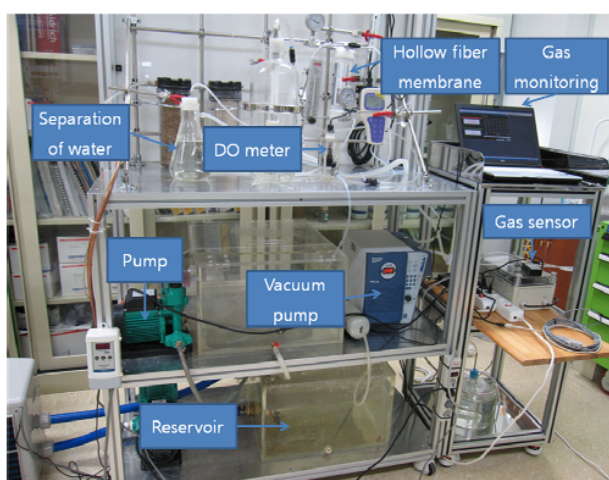


Fig. 2 Manufactured experimental devices for separating dissolved oxygen from water

The characteristics of a pipe type of HFM with polypropylene made from LiquiCell is shown in Table I. Its surface is hydrophobic and has about 25 % porosity. Its inner diameter and outer diameter are 200  $\mu\text{m}$  and 300  $\mu\text{m}$ . Its effective area is 1.4  $\text{m}^2$ . Parallel connection of membranes is needed to increase the amounts of separated gas.

TABLE I  
POLYPROPYLENE HOLLOW FIBER CHARACTERISTICS

Name	Spec.
OD/ID ( $\mu\text{m}$ )	300/200
Length of housing (mm)	282.5
Material	Polypropylene
Potting materials	Polyethylene
Effective area ( $\text{m}^2$ )	1.4
Porosity (%)	~25

TABLE II  
CHARACTERISTICS OF A NUDE TYPE OF POLYSULFONE HOLLOW FIBER

Name	Spec.
OD/ID ( $\mu\text{m}$ )	400/200
No. of fibers	3000
Length of a fiber (mm)	800

Material	Polysulfone
Potting materials	Epoxy
Effective area ( $\text{m}^2$ )	3
Weight (Kg)	0.31

The amounts of separated gases are proportional to the surface area of the membrane. Table II shows the characteristics of a nude type of HFM. Its material of HFM is polysulfone.

Its inner diameter and outer diameter have 200  $\mu\text{m}$  and 400  $\mu\text{m}$ . Its effective surface area is 3  $\text{m}^2$ . The nude type of HFM with polysulfone has larger surface area than the pipe type of HFM with polypropylene.

### III. RESULTS AND DISCUSSIONS

Firstly, we measured the amounts of transferred air rate using a polypropylene and a nude type of HFM. Inhalation rate for a human in an air was shown in Fig. 3. It had a range of transferred rate of 3 to 11.45 L/min using a gas flow sensor.

Transferred air rate with pressure in an air using a vacuum pump was shown in Fig. 4. Transferred air rate was increased with decreasing pressure. Fig. 5 showed the transferred air rate in an air using polypropylene with decreasing pressure. Transferred air rate using a nude type of HFM with pressure was shown in Fig. 6. Transferred air rate using polypropylene was higher than using a nude type of HFM in an air. Fig. 7 showed the transferred air rate using both of a polypropylene and a nude type of HFM. The amounts of transferred air rate using both of them were increased over separately used condition.

Secondly, we investigated the dissolved gas separated from water using a polypropylene and a nude type of HFM. Dissolved gas separated from water using polypropylene with pressure was shown in Fig. 8. The gas separated from the water using a polypropylene was increased with decreasing pressure. Fig. 9 showed the gas separated from water using a nude type of HFM. It was also increased with decreasing pressure. The dissolved gas separated from water using polypropylene was higher than one using a nude type of HFM with polysulfone.

These results showed that polypropylene represented better performance than polysulfone under both of air and water conditions. But for breathing against sudden waves, more surface area of HFM should be needed for more amounts of oxygen.

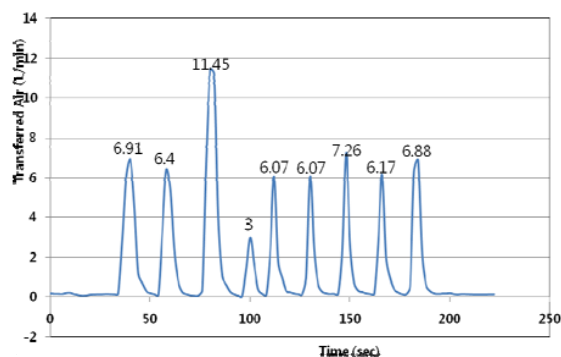


Fig. 3 Inhalation rate for a human

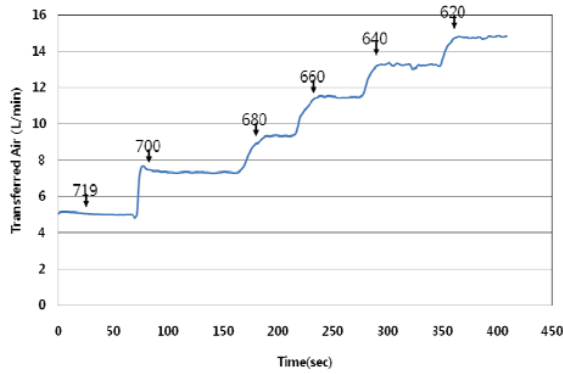


Fig. 4 Transferred air rate with vacuum pump pressure

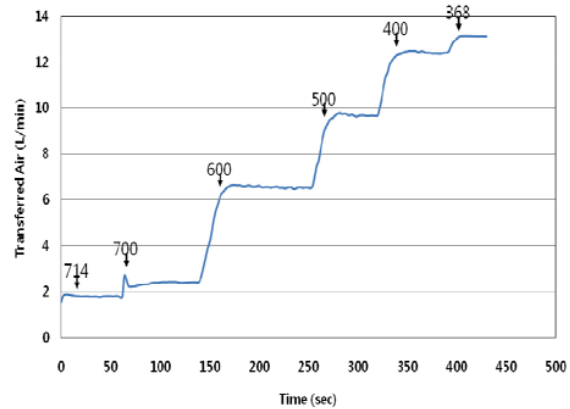


Fig. 7 Transferred air rate using both of the polypropylene and the nude type of HFP with pressure

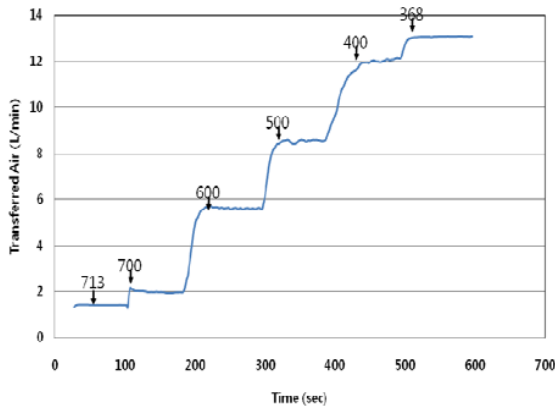


Fig. 5 Transferred air rate using polypropylene with pressure

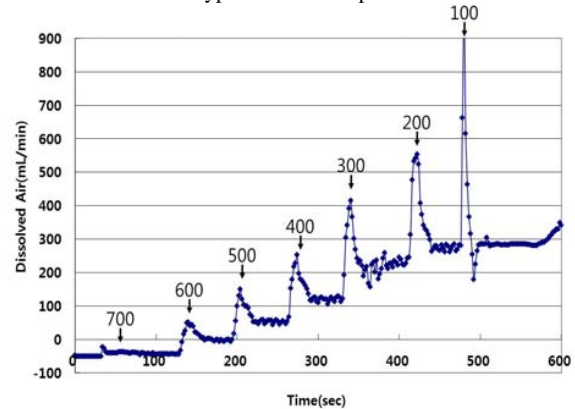


Fig. 8 Dissolved gas separated from water using polypropylene with pressure

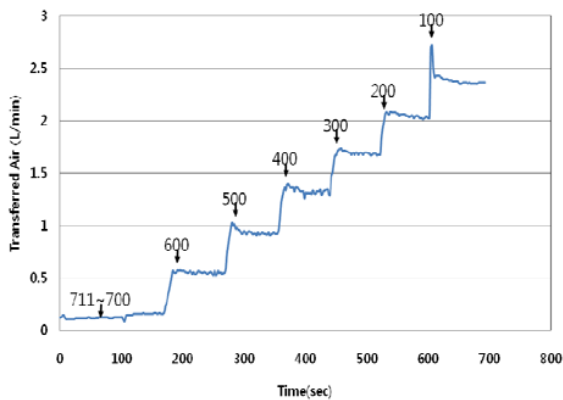


Fig. 6 Transferred air rate using a nude type of HFM with pressure

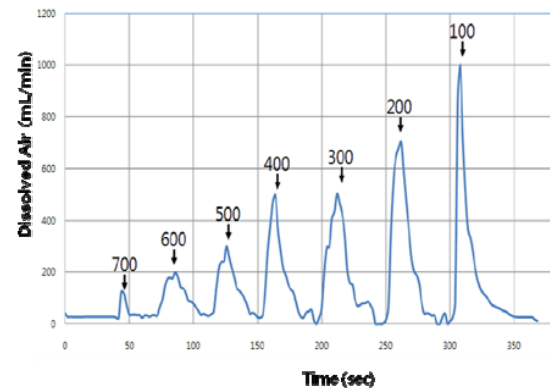


Fig. 9 Dissolved gas separated from water using a nude type of HFP with pressure

#### IV. CONCLUSION

We investigated the amounts of inhalation rate for a human. It had a range of transferred rate of 3 to 11.45 L/min. In an air, the hollow fiber membrane with polypropylene had higher amounts of transferred gas than using a nude type of hollow fiber membrane with polysulfone. Also, the dissolved gas separated from water using polypropylene was higher than one using a nude type of HFM with polysulfone.

These results showed that polypropylene represented better performance than polysulfone under both of air and water conditions.

When people were suddenly wrecked, they couldn't breathe by periodic waves. The one wave shortly passed away people. If some portable device can be used to supply dissolved oxygen separated from water to people, it's possible to breathe in the sea. After the wave passed away, it was more efficient for a human to breathe using air than the dissolved oxygen separated from water. So, it is profitable to use two membranes. One has good characteristics in an air, the other has good characteristics underwater. These results expect to apply to the technology of the artificial gill in the future. The artificial gill needs more dissolved oxygen separated from water, so more surface area should be prepared for sufficient breathing for a human.

And more efficient technique for multiple membranes will be needed.

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