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Separation Characteristics of the Hollow Fiber Membrane Module Using Water Mixed with Small Sized Bubbles Composed of Synthesized Exhalations

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***Abstract*—**Fish can breathe freely under water using dissolved oxygen and survive for a long time without going out of the water. A human can also survive under water using dissolved oxygens, if properly used. He needs more dissolved oxygens than the fish, so efficient separation device is required. Since the amount of oxygen contained in water is weak, a person needs a lot of surface area to breathe in water, which leads to a large-sized device. It can be applied to various fields if it is developed as a device which is advantageous to carry in small size. In this paper, we have carried out a study on the effective use of exhalations and proposed the separation characteristics of the gas containing dissolved oxygen in the state of mixed gas considering the components of exhalation. The system was configured to have a fine bubble when the gas mixture injected into the front end of the separator. While the fluid containing the fine bubbles was supplied to the separator, the dissolved gas contained in water was separated using a vacuum pump. The gas separation amount of the separating apparatus with respect to the supplied mixed gas was measured. The amounts of separation of dissolved gas were increased as the amounts of mixed gas supplied were increased.

***Keywords*—**Small sized bubbles, synthesized exhalations, separation, hollow fiber module.

I. Introduction

THERE are some dissolved oxygen in the water which are used in many kinds of field. Shirtcliffe et al. showed that using porous material, dissolved oxygen in the water could be transferred into another space [1]. A small box made from porous material is placed under water. If water with rich dissolved oxygen is supplied around the box, the oxygen concentration inside the box is increased with time because of the concentration gradient. Increment of oxygen concentration is proportional to contact area between water and gas. Large contact area can transfer large amounts of oxygen into another space. Dissolved oxygen can be also used in the fuel cell [2]. There are many kinds of underwater devices which need power source. Fuel cell can generate electricity using hydrogen and oxygen. Dissolved oxygen in the water can be easily supplied to the source of oxygen of fuel cell using some porous material. Gas exchange characteristics can be also applied to artificial lung [3]-[5].

It is reported that dissolved oxygen is separated from water using the centrifugal component [6]. As pressure at the center position is decreased using the centrifugal one, dissolved oxygen can be separated from water without the vacuum pump. There are small amounts of dissolved oxygen in the water. Centrifugal force decreases the pressure at the local area, but maximum extent of pressure difference is limited due to structural characteristics.

The portable system is shown to separate dissolved oxygen from water [7]. The system composes of a battery, a membrane, a vacuum pump and a flow sensor. The system can separate dissolved gases from water during some time. To increase the amounts of dissolved gas, the large system with large surface area is requested. But it is difficult to take use of the large system under water in some view of points such as weight, size, power and operating time. So it is necessary to increase the amounts of dissolved gas efficiently. Inlet and outlet flow structure are modified to increase the amounts of inlet water and to enhance separation of dissolved gas [8]. Even if two water pumps are needed to supply water into the membrane, separation of dissolved gas is increased using same number of membrane. Exhalation mixing method without a compressor is reported to increase the amounts of separation of dissolved gas [9]. In order to mix the exhalation gas, a compressor is needed to overcome the pressure of water at the front of the membrane. If a water pump is positioned after the membrane, pressure in front of the membrane is decreased and spontaneously sucked from the gas bag which gathers exhalation gases. So no extra force is requested to mix the exhalation gas. Some factors such as weight, size and operating time needed to separate dissolved gases from water are improved. Controlling the amounts of mixing exhalation gas with water using a timer and a compressor is introduced to increase the separation of dissolved gases [10]. Operating time of a compressor is controlled by the timer. Mixing characteristics has an influence on the efficiency of separation of dissolved gases. If the diameter of mixing gas bubble is small and the number of bubbles is increased, the separation performance is profitable due to high contact area between liquid and gas.

In this paper, small sized bubbles are mixed with water in front of the membrane. To supply water into membrane, the water pump is used at the side of inlet of membrane. Bubble gases composed of synthetic exhalation gases are inserted into water between the water pump and the membrane. At first, no exhalation gases are inserted to the inlet membrane and dissolved gases are separated using the vacuum pump. And then separation of dissolved gases from water at the lumen side of the membrane is measured as the amounts of mixing gases

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are increased.

II. Experimental Setup

The outline of a separation system including a gas splitter using synthetic exhalation gases is shown in Fig. 1. The separation system composes of a water pump, a gas splitter, a hollow fiber membrane, a vacuum pump and a synthetic gas tank. The gas splitter is positioned between the water pump and the inlet of membrane. Synthetic gases are supplied into water through the gas splitter and dissolved gases are separated from water using the vacuum pump made from a Welch company through lumen side of the membrane. 17 LPM of water is supplied into the membrane from a Liqui-Cel company which has 8.1 m^2 of surface area. Separation rate of dissolved gases is measured with the flow meter made from an Alicat company.

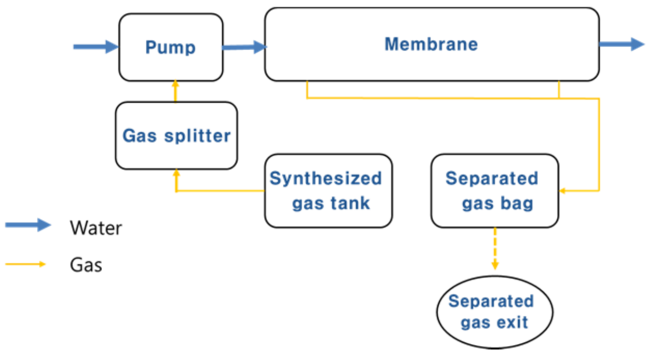

Fig. 1 Outline for the separation system of dissolved gases with small sized bubbles

III. Results and Discussion

Water mixed with synthetic exhalation gases was shown in Fig. 2. Fig. 2 (a) showed small sized bubbles at low flow rate of synthetic exhalation gases and Fig. 2 (b) had large sized bubbles at large flow rate of gases. A gas splitter includes a motor, a rotor with v-shape and a stator with many holes. Synthetic gases are supplied into holes of the stator and split by the rotor connected to the motor.

It was shown in Fig. 3 that separation of dissolved gases was increased with no synthesis gases as vacuum was increased from 760 Torr to 200 Torr. There are small amounts of dissolved gases in the water and separation of dissolved gases is not much. Large system is needed to increase separation of dissolved gases. In view of underwater breathing for a human, exhalation gases can be used. So, some exhalation gases are mixed with water in front of the membrane and dissolved gases are separated using a vacuum pump through the membrane. It was shown in Fig. 4 that 1 LPM of synthetic gases was mixed with water and dissolved gases were separated using a vacuum pump through the membrane. Separation of dissolved gases was increased over no synthetic gases. As synthetic gases were increased, separation of dissolved gases was also increased. 2 LPM, 3 LPM, 4 LPM and 5 LPM of synthetic gases were mixed with water and mixed water was supplied into the membrane. And then, separation of dissolved gases through the membrane lumen side using the vacuum pump was shown in Figs. 5-8. Also, large separation was measured at state of no vacuum. It means the size of separation system can be decreased without the vacuum pump. When small sized bubbles are mixed with water and mixed water is supplied into the membrane, separation performance is enhanced. If synthetic gases are mixed with water at the type of simple mixer which includes a tool with some holes, separation efficiency is low.

(a) at low flow rate of gases (b) at high flow rate of gases

Fig. 2 Water mixed with synthetic exhalation gases

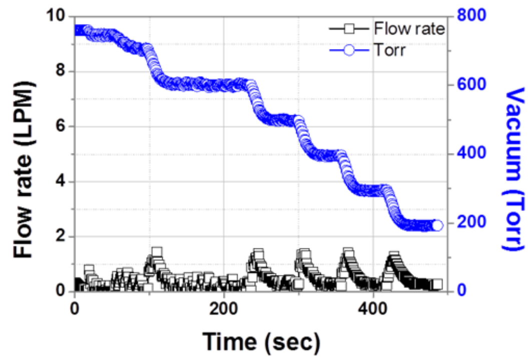

Fig. 3 Separation of dissolved gases and vacuum pressure with no synthetic exhalation gas

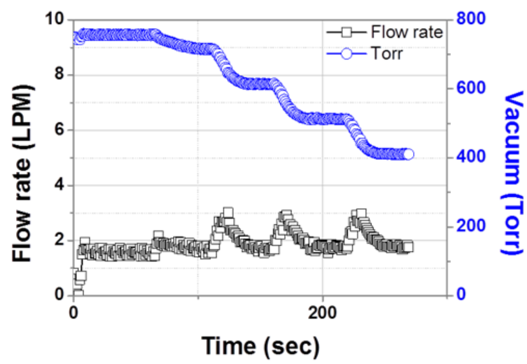

Fig. 4 Separation of dissolved gases and vacuum pressure with 1 LPM of synthetic exhalation gases

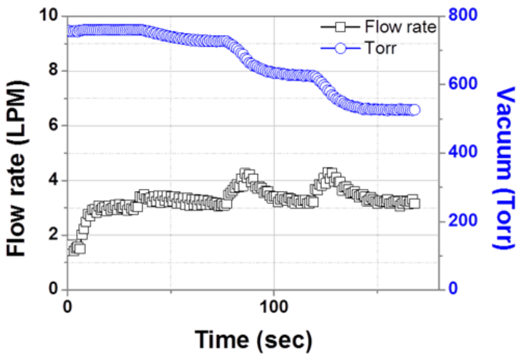

Fig. 5 Separation of dissolved gases and vacuum pressure with 2 LPM of synthetic exhalation gases

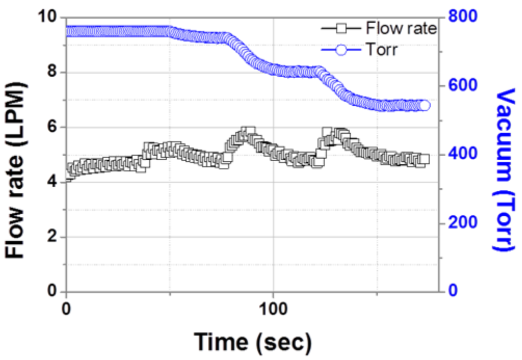

Fig. 6 Separation of dissolved gases and vacuum pressure with 3 LPM of synthetic exhalation gases

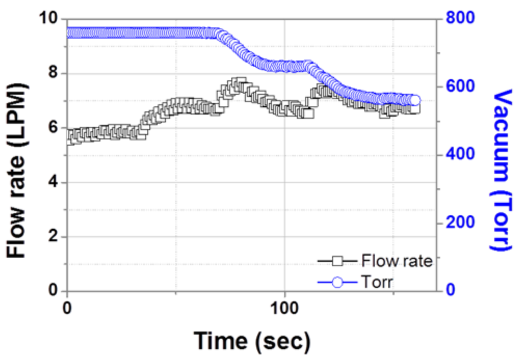

Fig. 7 Separation of dissolved gases and vacuum pressure with 4 LPM of synthetic exhalation gases

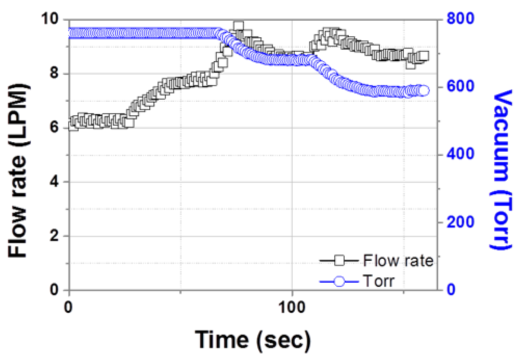

Fig. 8 Separation of dissolved gases and vacuum pressure with 5 LPM of synthetic exhalation gases

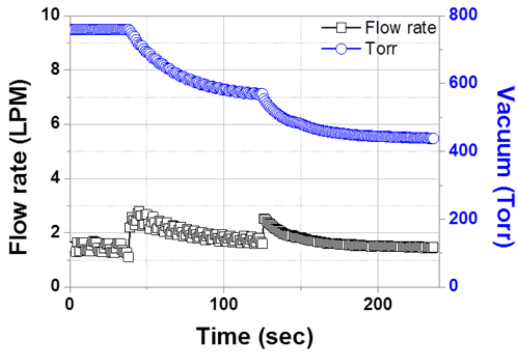

Fig. 9 Separation of dissolved gases and vacuum pressure with 1 LPM of synthetic exhalation gases with a hand-made vacuum pump

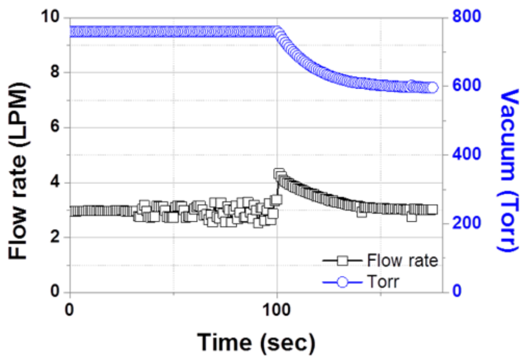

Fig. 10 Separation of dissolved gases and vacuum pressure with 2 LPM of synthetic exhalation gases with a hand-made vacuum pump

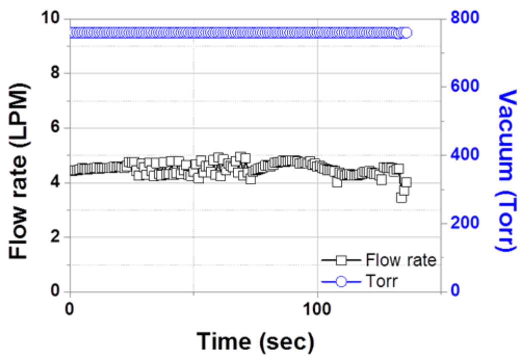

Fig. 11 Separation of dissolved gases and vacuum pressure with 3 LPM of synthetic exhalation gases with a hand-made vacuum pump

A hand-made vacuum pump was used to separate dissolved gases from water for a portable system. The vacuum pump was controlled by a knob. As the vacuum state was increased, the separation of dissolved gases increased with time. Separation and vacuum state was shown at 1 LPM of synthetic gases in Fig. 9. Figs. 10-12 represented separation of dissolved gases and vacuum state when 2 LPM, 3 LPM and 4LPM of synthetic gases were mixed with water in front of the membrane. Separation increased as the amounts of synthetic gases mixed with water were increased. When excessive amounts of synthetic gases over supplied liquid were mixed with water, synthetic gases included in water were not separated through the membrane and passed into outlet port. But if small sized bubble type of synthetic gases were mixed with water, separation of dissolved gases was effectively increased.

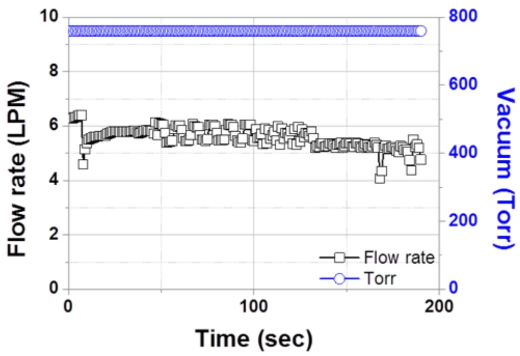

Fig. 12 Separation of dissolved gases and vacuum pressure with 4 LPM of synthetic exhalation gases

IV. Conclusion

This paper proposed the separation device with small sized bubbles made from synthetic exhalation gases. Small amount of separation of dissolved gases were measured when water without mixing synthetic gases was supplied into the membrane. After from 1 LPM to 5 LPM of synthetic gases were mixed with water in front of the membrane inlet, separation of dissolved gases using the vacuum pump through the membrane was measured. As the amounts of synthetic gases mixed with water were increased, separation of dissolved gases was increased. At just low vacuum state, large amounts of separation of dissolved gases were measured through the lumen side of the membrane. As vacuum state at the lumen side of the membrane was increased, separation of dissolved gases was increased. If exhalation gases are effectively used, it is possible to get large amounts of separation of dissolved gases without scale-up of the system size. These results are expected to be useful to apply to underwater equipment using dissolved gases.

Acknowledgments

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