Separation Characteristics of Dissolved Gases from Water Concurrently Variable Mixed with Exhalations for the Hollow Fiber Membrane

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***Abstract*—**Water contains dissolved oxygen that a fish needs to breathe. It is important to increase the amounts of separation of dissolved oxygen from water for diverse applications using the separation system. In this paper, a separation system of dissolved gases from water concurrently variable mixed with the exhalations using a compressor is proposed. This system takes use of exhalations to increase the amounts of separation of dissolved oxygen from water. A compressor with variable off-time and on-time is used to control the exhalations mixed with inlet water. Exhalations contain some portion of carbon dioxide, oxygen, and nitrogen. Separation of dissolved gases containing dissolved oxygen is enhanced by using exhalations. The amounts of separation and the compositions of carbon dioxide and oxygen are measured. Higher amounts of separation can make the size of the separation device smaller, and then, application areas are diversified.

***Keywords*—**Concurrently, variable mixed, exhalations, separation, hollow fiber.

I. Introduction

IT is very interesting to investigate the structure of the gill of a fish in order to use dissolved oxygen under water. The fish gill is composed of gill arches and gill filaments. There are many lamellas containing two veins in the filament. Oxygen-poor blood flows out of the body of a fish and goes to the gill where dissolved oxygen is exchanged. The oxygen-poor blood is changed to oxygen-rich blood in the fish gill due to the difference of concentration of oxygen between a sea and the vein. The concentration of oxygen in water is larger than the one in the oxygen-poor blood. The carbon dioxide-rich blood is vice versa changed to carbon dioxide-poor blood in the gill. The amounts of carbon dioxide in the carbon dioxide rich blood are larger than that in water. So, carbon dioxides in the vein are transferred to water. The fish gill is biologically designed to take effective use of dissolved oxygen during many years. The structure of the gill was investigated in view of microfluidics [1].

Insects can survive under water using bubble between furs on the surface [2]. An insect generally lives in the air. When the insect is suddenly drowned, it is impossible to survive under water. But, researchers observed some insects survived under water. They found that the insect had bubbles between furs on the surface and got airs using bubbles. The size and formation of furs have effects on depth beneath water where they can survive. So, if furs are properly designed, liquid-gas interface between furs does not break out. Under the deep water, water pressure is increased and interface expands inward. Above the depth, interface breaks, out and bubbles are removed.

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Dissolved oxygen can be transferred through the porous hydrophobic material [3]. When the oxygen depletion water is supplied, oxygen inside of the small box which is made with porous material is transferred to water outside the box. The amounts of oxygen inside of the box are decreased. It means that oxygen inside of the box is transferred into water outside of the box. When there is an oxygen consuming component inside of the box, if the oxygen rich water is supplied in the tank including the small box, the concentration of oxygen is at first decreased and saturated. It means that oxygen in water is transferred into the box as much as the decreased amounts of oxygen. The oxygen consuming component can be regarded as breathing of a human. If the box is properly manufactured and enough large to get more oxygen from water, the human can survive under water. To do so, the enhancement of separation of dissolved oxygen is needed. If the carrier solution which has larger solubility than water is used, the separation of dissolved oxygen from water is increased [4], [5]. The dissolved oxygen is transferred into the carrier solution through the membrane. The concentrated carrier solution is circulated, and dissolved oxygen is separated using another membrane. The carrier solution has higher solubility than water, and so, efficiency of separation of dissolved oxygen is increased. Higher amounts of oxygen are separated from carrier solution. The carrier solution used in this area is variable with temperature or light. So, by taking the use of temperature or the amounts of light, the amounts of separation of dissolved oxygen can be easily controlled. But, even if carrier solution method has high efficiency, it needs large system, high complexity, and high cost.

As another method to increase separation of dissolved oxygen from water, the method using magnetic materials was reported [6]. The oxygen is reportedly influenced by magnetic material. By using magnetic coated membrane, separation of dissolved oxygen from water is enhanced. The paramagnetic material has magnetic characteristics only when there is electric current. So, by controlling the electric current, the separation can be easily controlled.

The exhalation gas does not have small amounts of oxygen, so if only carbon dioxide can be minimized, it is possible to take use of oxygen for breathing of a human. The method without a compressor was reported [7]. This method was useful for a portable device because it had a simple structure, a low power consumption, and a low weight. But, even if the structure is simple, the amounts of carbon dioxide need to be decreased. If the carbon dioxide concentration is decreased, more exhalation can be used for breathing and it can make the size of the separation system smaller.

In this paper, a separation system of dissolved gases from water with a compressor is proposed. This system is composed of a compressor connected to an inlet storage bag containing exhalation gases of a human, a pump, a hollow fiber membrane module, a vacuum pump, and an outlet storage bag including separated gases. The exhalation gases were supplied into the hollow fiber membrane using the compressor and mixed with water by the water pump. And then the fluid containing exhalation gases flows into the membrane, and dissolved gases are separated from water through hollow fibers inside the module using a vacuum pump. The amounts of separation of dissolved gases are increased with respect to those of separation without the inlet bag.

II. Experimental Setup

The outline of a separation system using exhalations is shown in Fig. 1. The system composes of an underwater pump, a membrane module, a compressor, a vacuum pump, an exhalation gas bag, and a bag for separated gases. The exhalation bag is filled with exhalation of a human before experiments. Water flows into membrane module by an underwater pump. During flowing water through the membrane, exhalation gas is mixed into water before the membrane module using the compressor. Two variable timers for controlling off-time and on-time of the compressor are used. The DC compressor with 20 LPM flow rates is used, and flow rates of supplying exhalation are controlled by off-time and on-time of the timer.

Mixed water is supplied into the membrane module, and the separation of dissolved gases containing oxygen is executed using a vacuum pump and stored in the separated gas bag. The amounts of separation of dissolved gases and the compositions are measured using a data acquisitions unit and a GC.

The membrane module has hollow fibers with polypropylene materials and mixed water flows outside of fibers, and separated gases flow in the lumen side of fibers. Mixed water has high atmosphere by the underwater pump, and it is necessary to mix exhalation gases with supplied water using the compressor. The membrane module is made from Liqui-Cel and has 8.1 m^2 surface area for hollow fibers included in the module. DAP-5286 compressor provides a clean oil free pressure source. It has low power consumption for the use in the medical equipment and lightweight component.

Compositions of exhalation gases are measured using GC, and the results are shown in Fig. 2. The carbon dioxide concentration of an exhalation gas is more than that of an air. But, because there are some oxygen in an exhalation gas, if only carbon dioxide concentration can be decreased less than 1%, the exhalation gas can be used for breathing for a human.

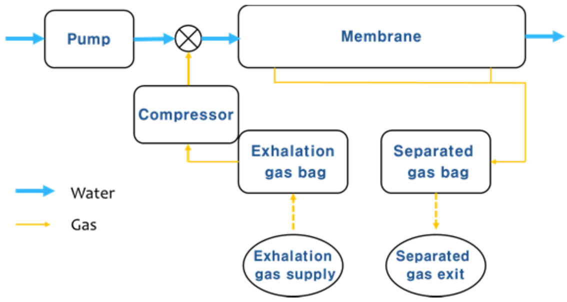

Fig. 1 Outline for the separation system of dissolved gases with a compressor

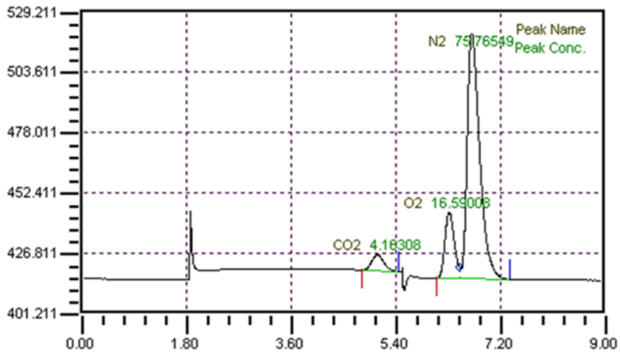

Fig. 2 Compositions of the exhalation gas

III. Results and Discussion

At first, without the compressor, water is supplied by the water pump into the membrane unit, and dissolved gases using the vacuum pump are separated from water to be stored in the bag. Separated gases are measured using the data acquisition unit and the GC. The amounts of separation of the proposed system with the compressor off are showed in Fig. 3, and the saturated flow rates are represented in Table I. Compositions in gases separated from water are shown in Fig. 4. The oxygen concentration is more than that of the air, and the carbon dioxide concentration is less than that of the exhalation gases. The compressor is operated by an off-time and an on-timer control state as shown in Fig. 5. Off-time and on-time can be controlled by the nobs, and flow rates in exhalation gases and separation gases measured are showed in Table II. Larger on-time for same off-time increases flow rates in exhalation and separation gases.

The compositions of separated gases in 3:1 off-timer and on-timer are measured in Fig. 6. When 5 L/min of exhalation gases is supplied and mixed using the compressor with timers before the membrane module, the carbon dioxide concentration reaches nearly to 1%.

When 2:1 off-timer and on-timer are used, the compositions of gases separated from water using the membrane module are shown in Fig. 7. The amounts of carbon dioxide are a little increased relative to the ones in 3:1 timer state.

When 1:1 timers are used, the compositions of separated gases state are analyzed in Fig. 8. As off-time for the same on-time is decreased, exhalation gases supplied by the compressor are increased, so carbon dioxide concentration of gases separated from water is increased.

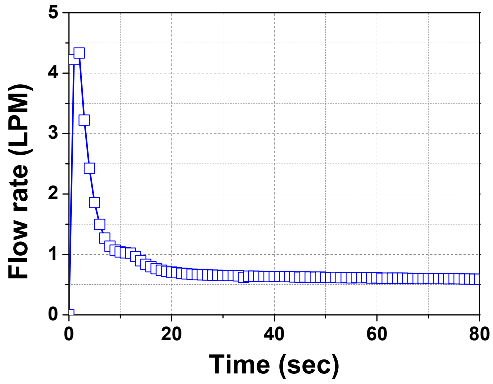

Fig. 3 Flow rate of dissolved gases with compressor off

TABLE I
SEPARATION OF DISSOLVED GASES

Time(s)	Value(L/min)
71	0.599
72	0.598
73	0.598
74	0.597
75	0.598
76	0.596
77	0.592
78	0.592
79	0.59
80	0.59
Average	0.595

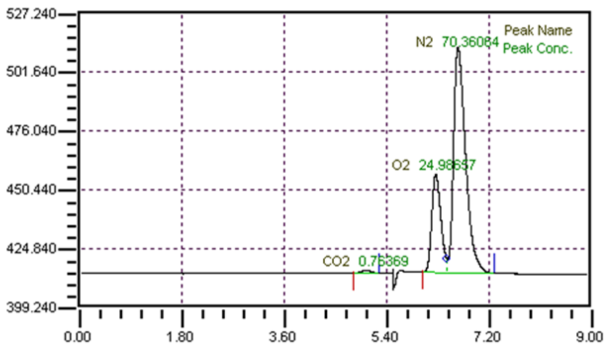

Fig. 4 Compositions of the separated gas with compressor off

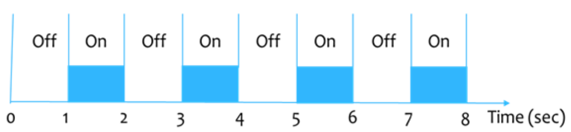

Fig. 5 Timing of a variable compressor

TABLE II
FLOW RATE OF SUPPLYING GASES BY A VARIABLE COMPRESSOR

Type	Supplying gas (L/min)	Separated gas (L/min)
Compressor (3:1)	5	4.6
Compressor (2:1)	6.7	6
Compressor (1:1)	9.7	7.5

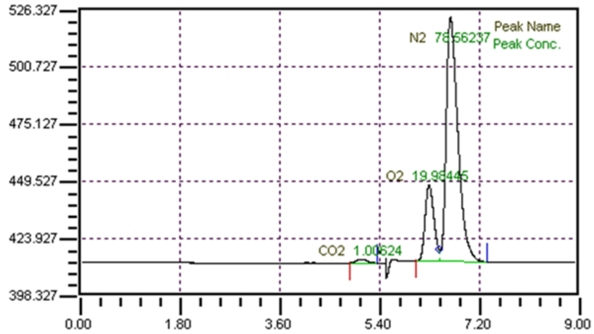

Fig. 6 Compositions of separated gases by a compressor (3:1)

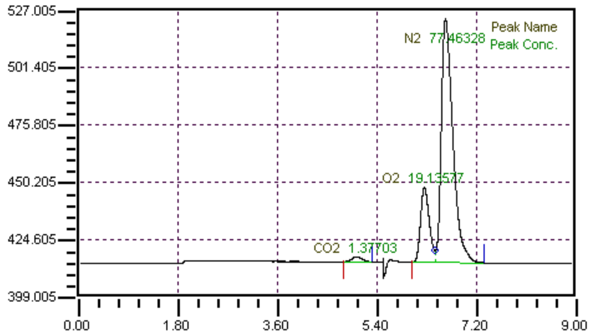

Fig. 7 Compositions of separated gases by a compressor (2:1)

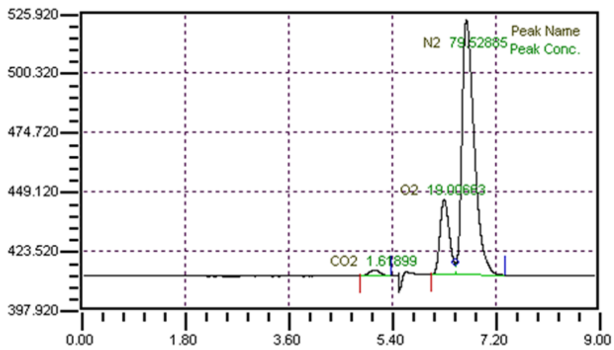

Fig. 8 Compositions of separated gases by a compressor (1:1)

IV. CONCLUSION

This paper proposed the separation device that used the exhalation to increase the amount of separation of dissolved gas. The device used a variable compressor to supply and to mix the exhalation with the water in front of the membrane module, and then the dissolved gas was separated from the membrane module using a vacuum pump. The off-time and on-time of the compressor were controlled to change the amount of exhalation by the compressor. As the off-time for the same on-time was decreased, the amount of dissolved gas separated from the water was increased, while the amount of carbon dioxide contained in the separated dissolved gas was increased. When the off-time was 3 s and the on-time was 1 s, the amount of exhalation supplied was 5 LPM, and the amount of dissolved gas separated by the membrane module was 4.6 LPM. At that time, the amount of carbon dioxide contained in the separated dissolved gas was almost 1 LPM. The results of this study are expected to be applied to the field of underwater breathing apparatus using dissolved oxygen.

References

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