Characteristics of multi-stage AGMD-DCMD cascade system for oxygen isotope production

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1. Introduction

Membrane distillation (MD) appears to be useful for the separation of the light isotopes such as oxygen and hydrogen isotopes contained in water, because membrane permeation units are compact and simple, and more importantly its energy consumption is low compared to conventional water fractional distillation.[1-4] Permeation fluxes and the degree of oxygen isotope separation of AGMD (Air Gap Membrane Distillation) and VEMD (Vacuum Enhanced Membrane Distillation) processes were measured by using the hot water feed. Even though VEMD shows slightly higher isotopic separation degree with higher permeation flux, it is very difficult to apply VEMD to multi-stage cascade system. Since local oxygen isotope separation coefficient for a single membrane unit is low, multi-stage membrane cascade system is required to increase isotopic concentration further in product. Although AGMD is suitable for constructing the membrane cascading system, permeation flux for AGMD is still too low to apply to the isotope production system. In this investigation, we increased permeation flux of AGMD using AGMD-DCMD (Direct Contact Membrane Distillation) combined process. Permeation flux and degree of isotope separation of AGMD-DCMD combined process were measured by using 10 stages cascade system.

2. Methods and Results

2.1 AGMD-DCMD combined process

Figure 1 shows the fundamental scheme of AGMD-DCMD combined process. While the membrane permeated water vapor is collected on the cold heat exchange plate for AGMD, the permeated water vapor is mixed in the cold fluid for DCMD.

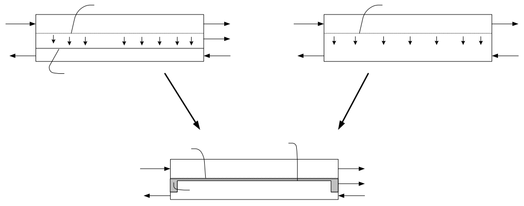

Figure 1. Conceptual diagram of AGMD-DCMD combined process

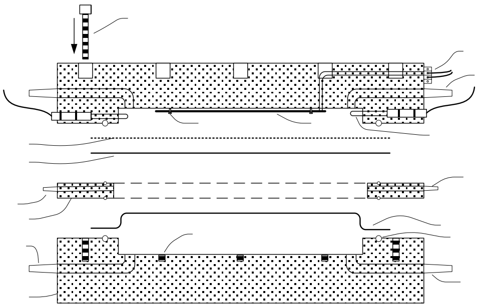

Figure 2. Schematic design of membrane permeation cell for AGMD-DCMD combined process

Figure 2 shows a design of membrane permeation cell to process the AGMD-DCMD combined process. Heat exchange cap in the cell was designed to minimize the air gap less than 1mm. Since permeation flux is determined by the temperature gradient ΔT applied to the membrane interface, DCMD whose ΔT is grater than that of AGMD permeates more water vapor during a certain period of time. After air gap in the cell is filled by the permeated water vapor, the condensed water on the cold cap surface is contacted on the lower part of the membrane, i.e. DCMD process will be dominated after air gap is filled by the cold water. Permeation fluxes were measured by weighing the collected membrane-permeated water vapor. And isotopic selectivity of each water sample was analyzed by a Tunable Diode Laser Absorption Spectroscopy.[5-6] Permeation flux was increased as much as 3 times compared to AGMD alone as shown in Table 1, while the degree of isotope separation was maintained.

Table 1. Permeation flux comparison between AGMD and AGMD-DCMD combined process

Operational Condition: $\Delta T = 33^{o}C$ ($43^{o}C - 10^{o}C$)	
AGMD process	0.95 L/hr m^2
AGMD-DCMD combined process	2.6 L/hr m^2

2.2 10 stages membrane cascade system

To increase the O-18 isotopic concentration in the product, multi-stage membrane cascade system was built. The hydrophobic PTFE porous membrane with the effective diameter 12.6 cm (effective area ~ 125 cm^2) was used. To maintain the temperature of the hot feed water in the permeation cell, a Kapton film heater of 0.2 mm thick with ~ 20W (maximum heating capacity is ~ 170°C) was installed in the upper part of the cell, and the feed temperature was then controlled by using the PID control system. Heat exchange cap was cooled by tap water whose temperature was ~10°C. Figure 3 shows the comprehensive diagram of the experimental cascade system.

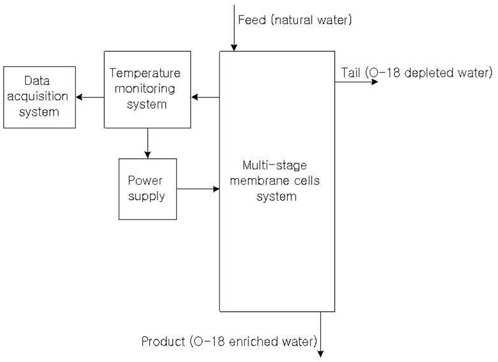

Figure 3. Comprehensive diagram of 10 stages membrane cascade system.

2.3 Stage cut and stage enrichment coefficient

The system operational conditions are shown in the Table 2. Degree of isotope separation was expressed by stage enrichment coefficient β for each stage was determined by comparing the isotopic ratio $^{18}O/^{16}O$ in the initial feed and the permeated water of each stage.

Table 2. Operational conditions and experimental results for 10 stages membrane cascade system

Experimental conditions	**Parameters**
Feed temperature	40°C
Temperature gradient	T = 30 °C
Feed flow rate	40 mL/min
Feed	6.116 Liter
Product	5.100 Liter
Permeated tail	1.016 liter
Product cut ( )	83%

As shown in the Table 3, the enrichment coefficients increased as the stage number increased due to the increase of ^{18}O concentration in the retentate (product) as the stage number increased. Stage cut was measured as 83% and single stage enrichment factor for the system was 1.005.

Table 3. Stage enrichment coefficient for each stage of 10 stage membrane cascade system.

Stage #1	Stage #2	Stage #3	Stage #4	Stage #5
1.005	1.010	1.017	1.022	1.022
Stage #6	Stage #7	Stage #8	Stage #9	Stage#10
1.028	1.029	1.031	1.031	1.033

3. Conclusion

10 stages membrane cascade system was constructed by using AGMD-DCMD combined process. Permeation flux was increased almost 3-fold without losing the isotope selectivity. Stage cut θ and stage enrichment coefficient were 83% and 1.005 for the system, respectively.

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