Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

Numerical performance investigation of vacuum membrane process for nuclear wastewater decontamination

Jung-Gil Lee [a*], Cheonkyu Lee [a], Jin Man Kim[a]
[a]*Carbon Neutral Technology R&D Department, Korea Institute of Industrial Technology, Cheonansi, 31056, Republic of Korea*
[*]*Corresponding author: jglee@kitech.re.kr*

1. Introduction

The membrane process has received an attention as new waste reduction process, especially in radioactive wastewater treatment. The nuclear waste water typically has large amount of waste heat thus the conventional wastewater treatment process should cool down the radioactive wastewater to separate the waste. There is a conventional membrane process for wastewater treatment or desalination process including reverse osmosis (RO), but the temperature of the treated water should be also cooled down and supplied. Here, we focus on the membrane distillation (MD) which can achieve the high rejection rate and It is operated by water vapor pressure difference by the temperature difference as the driving force. It means that the radioactive waste water which has waste heat has large amount of benefits in terms of the energy consumption rate for the reduction of radioactive wastewater contaminant [1]. Current, many researchers have been discussed the potential of the membrane processes to treat radioactive wastewater. In this study, the numerical performance investigation of vacuum MD (VMD) process for the nuclear wastewater decontamination. The treatment water was replaced with seawater as salt water to calculate the VMD performance in terms of the influence of the inlet feed temperatures and inlet feed velocity at constant permeate temperature.

2. Methods

In order to calculate the performance of VMD process for nuclear wastewater decontaminant in terms of inlet feed temperature at constant permeate temperature. The schematic of diagram can be shown in Fig. 1.

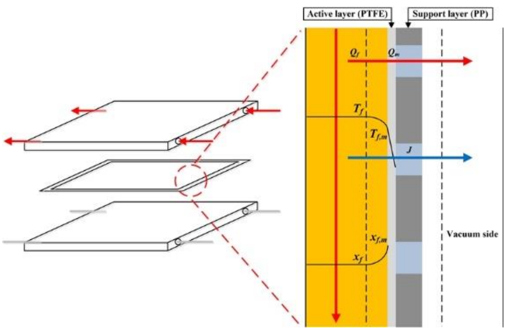

Fig.1 Schematic of VMD module [1].

The micro porous PTFE/PP (hydrophobic/hydroph-ilic) composite membrane was employed as a wastewater separator. The detailed characteristics of the PTFE/PP composite membrane can be shown in Table 1.

Table. 1 Physical properties of the membrane [2]

Material	PTFE	PP
Thickness (μm)	20	80
Porosity (%)	70	34
Mean pore size (μm)	0.5	0.1
Liquid entry pressure (kPa)	207	160

The VMD process is modeled including the mass transfer equations (1)-(3) and the momentum pressure and energy balance equations (4)-(7) [3].

$$J = R_K(P_{f,m} - P_v) \quad (1)$$

$$R_K = C_K\left(\frac{RT_m}{M_w}\right)^{0.5} \quad (2)$$

$$C_K = \frac{\gamma\epsilon}{\tau\delta} \quad (3)$$

$$\frac{dP_f}{dz} = -\frac{3\mu_f}{h_c^2}v_f \quad (4)$$

$$\frac{1}{X_f}\frac{dv_f}{dz} - \frac{v_f}{X_f^2}\left(\frac{M_s}{\rho_s} - \frac{M_w}{\rho_w}\right)\frac{dx_f}{dz} = -\frac{J}{M_f h_c} \quad (5)$$

$$\frac{x_f}{X_f}\frac{dv_f}{dz} + \frac{v_f M_w}{\rho_w X_f^2}\frac{dx_f}{dz} = 0 \quad (6)$$

$$\frac{d\rho_f v_f c_{p,f} T_f}{dz} = -\frac{Q_f}{h_c} \quad (7)$$

3. Results and discussion

3.1 Influence of inlet feed temperature on the permeate flux

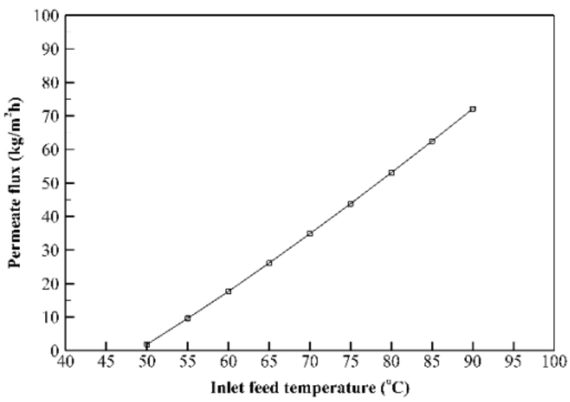

Fig.2 Influence of the inlet feed temperature on the permeate flux

Fig. 2 shows the influence of the inlet feed temperature on the permeate flux. The permeate flux increases from 1.87 kg/m^{2}h to 72.08 kg/m^{2}h with an increase in the inlet feed temperature from 50 ºC to 90 ºC. This is because the water vapor pressure difference between the transmembrane for feed sided and the vacuum side increases with an increase in the inlet feed temperature. The water vapor pressure increases exponentially according to the increase in the temperature. However, the increase of permeate flux with an increase in the inlet feed temperature seems to slightly linear, This is because the latent heat transfers through the membrane to vacuum side.

3.2 Influence of inlet feed velocity on the permeate flux

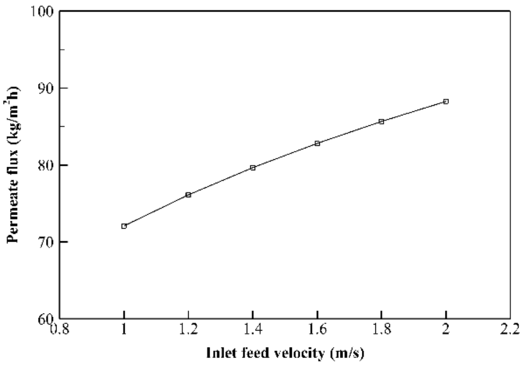

Fig.3 Influence of the inlet feed velocity on the permeate flux

Fig.3 represents the influence of the inlet feed velocity from 1 m/s to 2 m/s on the permeate flux from 72.08 kg/m^{2}h to 88.26 kg/m^{2}h. The increase of the inlet feed velocity can increase the water vapor pressure difference due to its increase of Reynolds number. This is because the high Reynolds number can reduce the temperature polarization between the bulk temperature and the transmembrane temperature. The transmembrane temperature is typically different with the bulk temperature due to the latent heat transfer through the membrane and conduction heat loss by the membrane permeate side.

4. Conclusion

In this study, the performance of the vacuum membrane distillation process for the nuclear wastewater decontamination was investigated with the various inlet feed temperature and inlet feed velocity. The higher inlet feed temperature and higher inlet feed velocity can contribute increase of the permeate flux through the membrane. Nuclear power plants use a large amount of seawater as cooling water and the contaminated cooling water exhausts to the ocean. This may cause the residual heat loss and marine radioactive contamination. This research shows the possibility of separation of the nuclear contaminant in the wastewater which is exhausted nuclear power plant as cooling water with the temperature below an evaporation temperature. The adoption of membrane distillation process in the wastewater treatment system of nuclear power plant can reduce the marine pollution.

ACKNOWLEDGEMENT

본 연구는 2022 년도 기획재정부 재원 한국생산기술연구원 “청정생산시스템기술제조혁신연구개발사업” (No. EO220001)의 지원을 받았습니다. 이에 관계자 여러분들께 감사드립니다.

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