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A Study on Application of Membrane Distillation for Recovery of VFA and Water Reuse

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Abstract

Volatile fatty acids (VFAs) are a short-chain fatty acids consisting of no more than six carbon atoms. VFAs can be undesirable at times due to potential toxicity and malodor. However, VFAs are also valuable resources convertible to bioenergy and other value-added metabolites. This study investigated the use of membrane distillation (MD) for the recovery and concentration of VFAs from wastewater. Also evaluated was the reusability of the treated wastewater as permeate. The laboratory-scale MD system was operated with synthetic wastewater adjusted to various pH values. The results showed the following removal rates: 81.2-99.7% for acetic acid, 72.7-99.6% for butyric acid, and 67.2-99.3% for valeric acid.

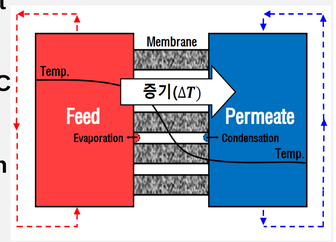
<Introduction>

Membrane Distillation, MD

- **Membrane Distillation is driven by the principle that water vaporized by vapor pressure differences caused by temperature differences on both sides of the separator passes through the membrane.**
- **Due to the highly hydrophobic membrane the surface of the feed side, water cannot pass through the pores of membrane, and water vapor passes through the pores and moves toward the treated water (cold side). cold side) by penetrating pores.**

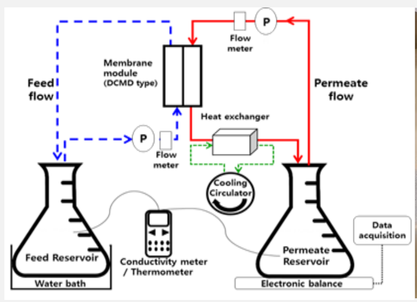
Objectives

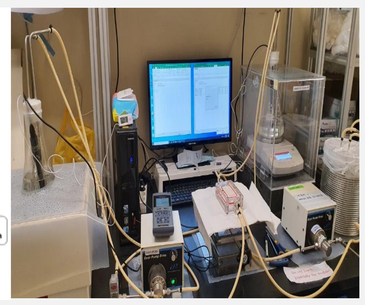
- **Development of a 2 L/d lab-scale direct contact (DC)-MD system.**
- **Investigation of VFAs permeation in DC MD system**
- **Measurement of permeability/rejection rate, VFAs fluxes, and incidence of membrane wetting**



<Materials and Methods>

Schematic diagram of the MD system





Membrane Specification

Parameters	Properties
Manufacturer	Millipore
Material	PVDF
Pore size (μm)	0.22
Porosity (%)	75
Thickness (μm)	125
Effective area (m^2)	2.1×10^{-3}
Contact angle(º)	120.1

Experimental conditions

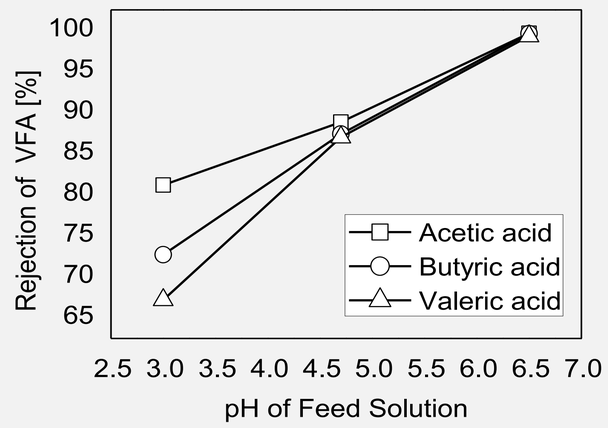
Factor	value
Temperature (Feed)	60 ℃
Temperature (Permeate)	20 ℃
Concentration of Feed Solution	2,000 mg/L
Effective Area	28.7 cm^2
Cross Flow Velocity	0.09 m/s

No	Condition of feed water	
AA-1	Acetic Acid 2,000 mg/L (synthetic wastewater)	pH 3.1
AA-2		pH 4.7
AA-3		pH 6.4
BA-1	Butyric Acid 2,000 mg/L (synthetic wastewater)	pH 3.18
BA-2		pH 4.8
BA-3		pH 6.55
VA-1	Valeric Acid 2,000 mg/L (synthetic wastewater)	pH 3.27
VA-2		pH 4.84
VA-3		pH 6.4

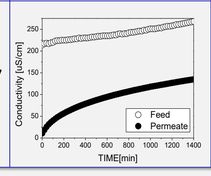
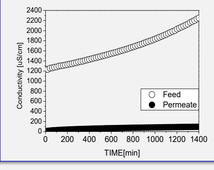
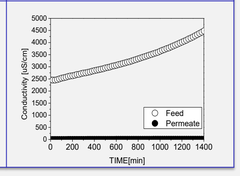
- $C_T = [HAc] + [Ac^-]$
  $\alpha_0 = [HAc] / [HAc] + [Ac^-]$, $\alpha_1 = [Ac^-] / [HAc] + [Ac^-]$
- **For each component, Experiment 1 set pH with α_0 =0.97, Experiment 2 set pH with α_0 =0.5, and Experiment 3 set pH with α_0 =0.03.**

<Results and Discussion>

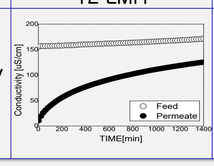
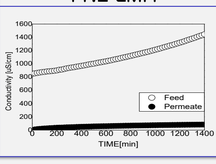
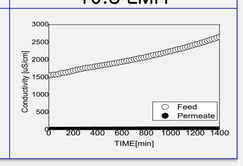
Rejection rate of VFAs at various pH



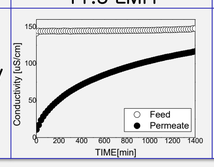
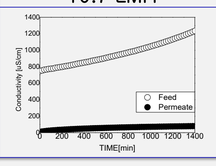
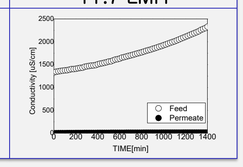
Acetic Acid(AA)

Factor		AA-1	AA-2	AA-3
Feed	C_T	2,000 mg/L	2,000 mg/L	2,000 mg/L
	pH	3.1	4.7	6.4
	α_0 , α_1	α_0 =0.97 / α_1=0.03	α_0 =0.5 / α_1=0.5	α_0 =0.03 / α_1=0.97
Rejection rate [%]		81.2	88.9	99.7
Flux		12.5 LMH	12.2 LMH	12.3LMH
Conductivity				

Butyric Acid(BA)

Factor		BA-1	BA-2	BA-3
Feed	C_T	2,000 mg/L	2,000 mg/L	2,000 mg/L
	pH	3.18	4.8	6.55
	α_0 , α_1	α_0 =0.97 / α_1=0.03	α_0 =0.5 / α_1=0.5	α_0 =0.03 / α_1=0.97
Rejection rate [%]		72.7	87.4	99.6
Flux		12 LMH	11.2 LMH	10.8 LMH
Conductivity				

Valeric Acid(VA)

Factor		VA-1	VA-2	VA-3
Feed	C_T	2,000 mg/L	2,000 mg/L	2,000 mg/L
	pH	3.27	4.84	6.4
	α_0 , α_1	α_0 =0.97 / α_1=0.03	α_0 =0.5 / α_1=0.5	α_0 =0.03 / α_1=0.97
Rejection rate [%]		67.2	87	99.3
Flux		11.5 LMH	10.7 LMH	11.7 LMH
Conductivity				

Liquid Entry Pressure(LEP)

$$LEP = \frac{-2\,B\gamma_L\,Cos\,\theta}{r_{max}}$$

- LEP : the liquid entry pressure of pure water [Pa]
- B : a dimensionless geometrical factor
- γ_L: the liquid surface tension [N m^{-1}]
- θ : the contact angel
- r_{max} : maximal pore radius [m]

No.	LEP (bar)
Virgin	2.2
AA-1	2.2
AA-2	2.2
AA-3	2.2
BA-1	2.2
BA-2	2.2
BA-3	2.2
VA-1	2.2
VA-2	2.2
VA-3	2.2

Discussion

- **As a result of operating the DC-MD system using synthetic wastewater of 2,000 mg/L acetic acid pH 3.1, 4.7, and 6.4, the removal rates of acetic acid were 81.2, 88.9, and 99.7%.**
- **As a result of operating the DC-MD system using synthetic wastewater of 2,000 mg/L butyric acid pH 3.18, 4.8, and 6.55, the removal rates of butyric acid were 72.7, 87.4, 99.6%.**
- **As a result of operating the DC-MD system using synthetic wastewater of 2,000 mg/L valeric acid pH 3.27, 4.84, and 6.4, the removal rates of valeric acid were 67.2, 87, 99.3%.**
- **Although the feed water is acidic, this experiment confirms that the LEP values are the same as the LEP of the Virgin membrane(2.2 bar) for all experimental conditions.**

Conclusions

- **Increases in pH values improve the rejection rates of the following VFAs: 81.2-99.7%, acetic acid; 72.7-99.6%, butyric acid; and 67.2-99.3%, valeric acid.**
- **At a constant concentration of feed water(C_t), α_0 depends on pH, and the removal rate of VFAs depends on the value of Ct* α_0.**
- **At pH 3.1, 4.7 and 6.4 acetic acid solutions, flux was observed at 12.5, 12.2 and 12.3 LMH, and at pH 3.18, 4.8, 6.55 butyric acid solutions at 12, 11.2 and 10.8 LMH. And at pH 3.27, 4.84, and 6.4 valeric acid solutions, flux is observed as 11.5, 10.7, and 11.7 LMH.**

References

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3. Tamis, J., Joosse, B. M., Loosdrecht, M. V., & Kleerebezem, R. (2015), "High-rate volatile fatty acid (VFA) production by a granular sludge process at low pH", Biotechnology and bioengineering, 112(11), 2248-2255.

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