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Application of direct contact membrane distillation process to treat anaerobic digestate

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A B S T R A C T

In this study, a membrane distillation process was applied to treat the digestate produced from the anaerobic digestion of livestock wastewater with a high concentration of suspended solids, chemical oxygen demand (COD), total nitrogen (TN), and phosphorus (TP). Laboratory scale direct contact membrane distillation was performed to observe the variation of flux and rejection rate of each component according to the transmembrane temperature, cross flow velocity, and pH of the feed solution. In 90-min distillation, almost no fouling occurred and the permeate flux increased from 4.2 to 38.8 LMH by increasing the transmembrane temperature from 20 to 60 °C and cross flow velocity from 0.09 to 0.27 m/s. In long term distillation, a constant flux of 17.5 LMH was maintained for the initial 24 h but then decreased gradually to reach 5 LMH in 72 h. The flux decline occurred more rapidly as the pH of feed solution increased from 7 to 8.5. More than 99% rejection of COD and TP were achieved regardless of the distillation condition and processing time. The rejection rate of TN was affected dominantly by the extent of cake layer formed on the membrane surface rather than the pH and temperature of the feed solution.

1. Introduction

Use of advanced membrane separation process recently has been increased in a variety of water treatment systems such as drinking water purification, industrial water production, and the desalination of seawater. This membrane process is also applied for the treatment of municipal wastewater by using a membrane bioreactor (MBR) producing high quality effluent suitable for water reuse application. However, the application of this membrane process is limited specifically to the filtration of the wastewater with a high concentration of suspended solids and dissolved matter with regard to a membrane fouling phenomenon.

Among the numerous membrane separation processes, membrane distillation (MD) is a process that conducts separation across the macro-porous membrane driven by the partial vapor pressure difference between the feed and permeate sides [1,2]. The difference of partial pressure is established by the temperature gradient across the membrane [3–6]. In the case of water separation from a mixed liquor, vaporized water molecules at the feed side with high temperature are transported to the permeate side with low temperature, and then they are condensed into liquid water under low temperature. The strong hydrophobicity of the membrane surface and the pores prevent liquid water molecule transportation directly through the membrane [7]. As the temperature gradient is maintained across the membrane, the transport of water vapor occurs continuously, while the other matters remain still at the feed side unless they are vaporized at the feed side. This implies that the flux of membrane distillation is not seriously affected by the salinity of the feed. Therefore, membrane distillation has been considered theoretically as the process that produces nearly pure water without any serious membrane fouling [3,8–10]. For this reason, a variety of attempts have been made to utilize the membrane distillation process in a variety of water treatment systems such as seawater desalination [11,12], water reuse [13,14], food industry processing for milk and juice concentration [15–17], pharmaceutical and biomedical industries processing [18,19], and so on. Additionally, several studies have been done on the application of this membrane distillation process with regard to wastewater treatment. A laboratory scale experiment showed that the flux of 1.84 L/m^2/h was observed at the transmembrane temperature of 13.5 °C for the treatment of synthetic wastewater, which included 3.8 g/L of glucose, 1.8 g/L of peptone, 0.067 g/L of $NaHCO_3$, and other minerals [20]. This experiment also reported that the TOC concentration in permeate was 1.0–1.7 mg/L, while the rejection rate of other components like TN and TP was unspecified. Another study reported that a slightly higher flux (4.954 L/m^2/h) was observed when olive oil mill wastewater was introduced at the feed side of the membrane distillation module

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with a transmembrane temperature of 20 °C. This study focused on the extraction of polyphenol from wastewater but presented no information regarding the rejection rate of other components in the permeate [21]. Liu and Wang [22] observed the flux of 5.5–8.5 L/m^2/h for the treatment of radioactive wastewater with a transmembrane temperature of 40–48 °C between the feed and permeate sides, and all radionuclides (Cs^+, Sr^{2+}, and CO^{2+}) were perfectly rejected by the membrane distillation process. Recent exploration has been extended to combine the membrane distillation process with an anaerobic moving bed biofilm reactor (AMBBR) to treat synthetic wastewater [23]. The researchers applied PTFE, PVDF, and PP membranes for the distillation process at a transmembrane temperature of 20 °C for the treatment of effluent discharged from AMBBR. The experiments for 45 h showed that the fluxes were maintained in the range of 2.5–6.3 L/m^2/h according to the membrane materials, and a high rejection rate of conductivity, soluble COD, and total phosphorus was observed.

The previous studies showed that the application of membrane distillation is very attractive to the treatment of wastewater regarding the high quality of effluent with stable fluxes and less membrane fouling. However, most studies were conducted mainly by use of feed wastewater with almost no suspended solids and colloidal matters, resulting in no serious fouling expected. Additionally, the performance of membrane distillation has been evaluated focusing on the flux and rejection rate of a limited number of components like electrical conductivity and organic matters with less information concerning the rejection of nitrogen and phosphorus. Therefore, still required is investigation into the performances of this membrane distillation process for the treatment of real wastewater with high contaminant concentrations with regard to the flux variation, fouling propensity, and rejection rate of the general water quality components such as SS, COD, TN, and TP.

In this research, the digestate sourced from anaerobic digestion of livestock wastewater was introduced as the feed solution to a laboratory scale direct contact type membrane distillation system. The flux variation was observed under various operation conditions such as cross-flow velocity, transmembrane temperature, and pH of the feed. The rejection rate of COD, TN, and TP was assessed after a short-term distillation for 90 min as well as long-term experiment for 72-h distillation. We also employed contact angle measurement, SEM observation, EDS, and FT-IR analysis on the membrane surface after distillation for 72 h to investigate the characteristics of the fouling occurring in the membrane distillation process.

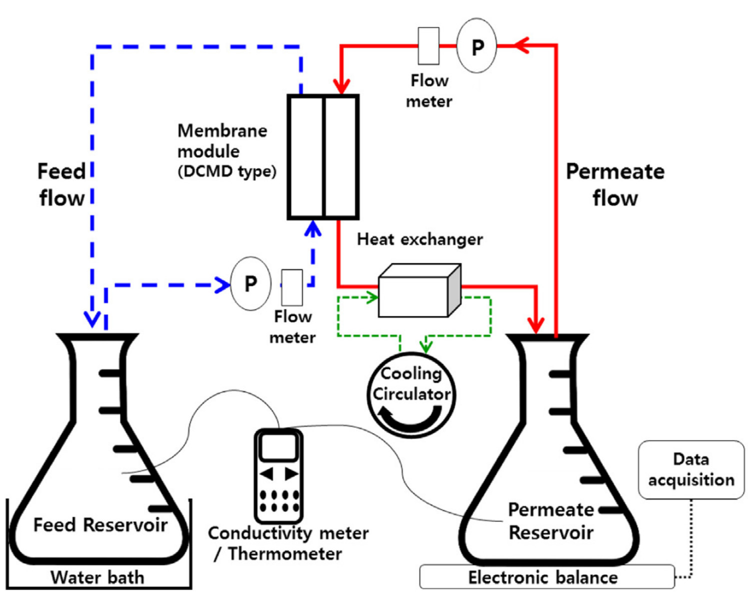
2. Materials and methods

2.1. Feed solution

The feed was prepared by collecting the digestate discharged from a conventional anaerobic digester with the capacity of 150 m^3/day treating a livestock wastewater. The collected digestate was left to settle for 1 h and then the supernatants were centrifuged at 2000 rpm for 10 min to remove large particulate matter such as animal hair, leaves, fine sand, and other debris. The prepared feed was then stored at 4 °C in a refrigerator before use. Even after the centrifugation, the feed solution still included high concentrations of organic matters (COD 1611.6 ± 115.5 mg/L), total-nitrogen (741.8 ± 22.9 mg/L), ammonium-nitrogen (731.2 ± 66.2 mg/L), total phosphorus (31 ± 3.3 mg/L), phosphate (12.5 ± 1.5 mg/L), and suspended solids (386.7 ± 52.5 mg/L).

2.2. Membrane distillation system

The laboratory scale direct contact membrane distillation (DCMD) system (Fig. 1) consisted of a membrane module, 2.0 L feed reservoir in a water bath (Scilab SB-11, Korea), 2.0 L permeate reservoir linked with a heat exchanger and a cooling circulator (Scilab SCR-P12, Korea), and gear pumps (Cole-Parmer console drive, USA) for the circulation of feed and permeate stream. Both feed and permeate reservoir were in a position lower than the membrane module to prevent the establishment of hydrostatic pressure difference through the membrane due to the change of solution level in both tanks during distillation processing. The feed solution inside the feed reservoir was heated by a water bath and circulated through the feed side of membrane module. De-ionized water (3.86 ± 2.78 μS/cm) was filled inside the permeate reservoir and used as the initial condensing liquid by maintaining a constant temperature of 20 °C as circulated through the permeate side of the membrane module. The circulation direction of feed stream was opposite to the permeate stream inducing a counter-current on the membrane interface inside the module. An electronic



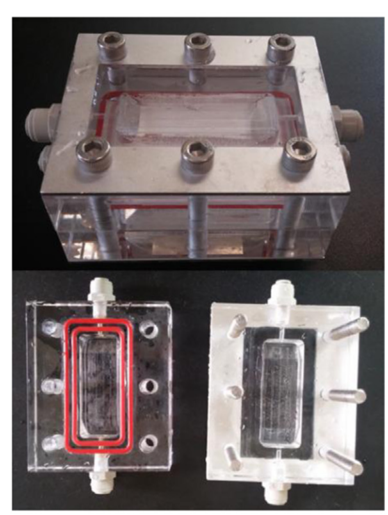


Fig. 1. Schematic diagram of laboratory scale experiment using hydrophobic microfiltration membrane (Millipore GVHP, USA) and direct contact type module.