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Ammonia recovery from agricultural wastes by membrane distillation: Fouling characterization and mechanism

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ABSTRACT

One of the main obstacles impeding implementation of membrane distillation for the recovery and concentration of ammonia from swine manure is wetting caused by fouling. Due to the different types of fouling which can occur in a membrane system, foulants characterization is a complex problem. To elucidate the fouling mechanism, deposit morphology and composition of foulants have been determined using Scanning Electron Microscopy, X-ray Energy Dispersive Spectrometry, Attenuated Total Reflectance Infrared Spectrometry, Ion chromatography and Inductively coupled plasma-optical emission spectroscopy. Based on the analysis of fouled membranes, it is concluded that membrane fouling is dominated by organic fouling in combination with deposits of inorganic elements and microorganisms. After a week of running the membrane process without cleaning, the average fouling layer thickness was estimated to 10–15 μm. The fouling layer further results in a loss of membrane hydrophobicity. This indicates that fouling could be a severe problem for membrane distillation performance.

1. Introduction

Membrane distillation (MD) has been successfully used for ammonia removal from water streams or as a post treatment of anaerobically digested effluents. They have a potential as a technology for ammonia fertilizer production (du Preez et al., 2005; Semmens et al., 1990). However, one of the major obstacles for the widespread use of membrane distillation is the problem of membrane fouling, even though this problem in general is less severe than in traditional pressure driven membrane processes (Srisurichan et al., 2005).

Fouling leads to deterioration of flux, an increase in power consumption, increased membrane area requirement, change in membrane hydrophobicity and a decrease in membrane lifespan. Thus reducing fouling will increase the economic viability of using membrane distillation significantly (Kavanagh et al., 2009; Xu et al., 2010). Due to the different types of fouling which can occur in a membrane system, characterizing fouling is a complex problem (Mairal et al.,

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List of symbols and abbreviations

A_M	Membrane area [m^2]
ATR-FTIR	Attenuated total reflectance Fourier transformed infra-red spectroscopy
C_t	Concentration of total ammoniacal nitrogen at time t in the feed [$kg \cdot m^{-3}$]
C_0	Initial concentration of total ammoniacal nitrogen at time t in the feed [$kg \cdot m^{-3}$]
DM	Dry matter content [%-weight]
EDS	Electron dispersive X-ray spectrometry
IC	Ion Chromatography
ICP-OES	Inductively coupled plasma optical emission spectroscopy
J	Ammonia flux [$kg \cdot m^{-2} \cdot h^{-1}$]
k_m	Overall mass transfer coefficient for ammonia [$m \cdot h^{-1}$]
MD	Membrane distillation
M_W	Molecular weight of ammonia [$kg \cdot mol^{-1}$]
PP	Polypropylene
$p_{NH3,acid}$	Partial pressure of ammonia on feed side of the membrane [Pa]
$p_{NH3,feed}$	Partial pressure of ammonia on the acid side of the membrane [Pa]
R	Universal gas constant [$Pa \cdot mol^{-1} \cdot m^3 \cdot K^{-1}$]
SD	Standard deviation
SEM	Scanning electron microscopy
T	Temperature [K]
TAN	Concentration of total ammoniacal nitrogen, available in NH_3 and NH_4^+ [$g \cdot l^{-1}$] unless otherwise stated
TKN	Total Kjeldahl nitrogen [$g \cdot l^{-1}$]
t	Time elapsed after experiment was started [min]
V	Liquid volume in the feed tank [m^3]

2000; Gryta, 2008). Since inorganic, organic, particulate and biological fouling each can contribute to a characteristic flux decrease, change in membrane surface properties or product quality, one of the major challenges is to characterize and distinguish among the various phenomena underlying the observed performance decline (Mairal et al., 2000).

The presence of undegraded organic matter and multivalent ions in pig slurry can significantly affect membrane fouling due to surface adsorption and pore plugging (Ko et al., 1993; Schafer et al., 1998). Calcium which is an abundant cation in manure slurry might form complexes with some organics and accumulate on membrane surfaces (Gryta et al., 2001; Masse et al., 2005). Depending on the hydrodynamics, the physicochemical properties of proteins in solution and the structure of the membrane, the interactions between proteins and membrane at the interface and within the pores may change (Ko et al., 1993).

The aim of this work is to add information as to how membrane fouling from swine manure during ammonia removal occurs, and how it can be suitably characterized. This will improve knowledge about the mechanism behind the fouling and help to optimize future pretreatment and cleaning procedures.

2. Methods

2.1. *Experimental setup*

The experimental set-up used in this work is shown schematically in Fig. 1. The membrane module was mounted in a vertical position. The feed was supplied on the tube side and the strip solution on the shell side. The streams flowed counter-current through the module. As feed 4 l of undigested slurry was placed in a 5 l glass tank located on an analytical balance (A&D HP-22K, Japan). Similarly 4 l of acid was placed in a 5 l glass tank also located on an analytical balance (Kern & Sohn GmbH 6KO.5N, Germany). Tanks were placed above the pumps (feed pump: Caster pump, MT 3006 PP, Italy; acid pump: Tutton pumps Nemp 50/7, Southampton, United Kingdom), which were connected to the bottom outlet of the tanks to ensure the pumps net positive suction head requirements. The acid solution was pumped through a flow meter (Roxspur Measurement & Control Ltd Platon AGSS-CA11201, Hampshire, United Kingdom), while the feed was pumped through a stainless steel pipe connected to a Mag flow meter (Krohne DN15 Optiflux 1100 PFA). A thermostatic water bath delivers water to both stainless steel heat exchangers (Alfa Lavel, Nakskov, Denmark) to heat up both streams before entering the membrane. The temperature (VWR Enviro-Safe 620–0883) and the pressure (Wika 2404 P2K) of the streams were measured before and after the membrane. Both streams were returned to their respective tanks.

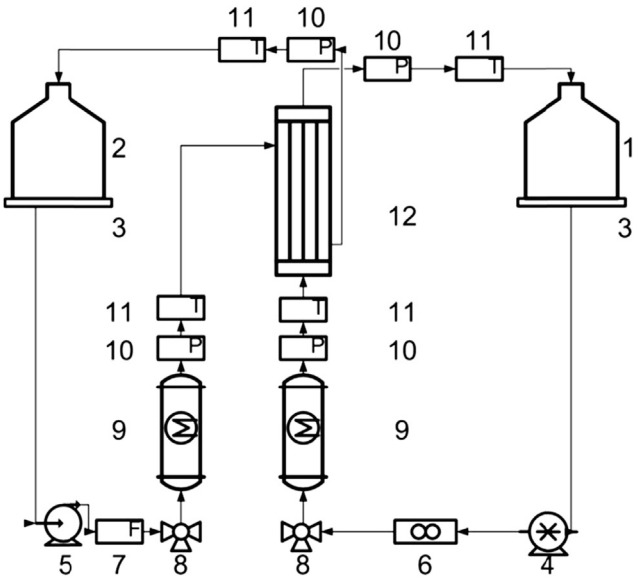

Fig. 1 – The MD experimental set-up: 1: feed reservoir; 2: acid reservoir; 3: balances; 4: magnetic drive turbine pump; 5: centrifugal pump; 6: IFC 100 Krohne Mag flowmeter; 7: Platon Bobbin flowmeter, 8: 3-way valve; 9: heat exchanger; 10: pressure gauge; 11: thermometer; 12: PP membrane.