Abstract

Animal manure contains sufficient amount of nitrogen, phosphorus, and potassium for plant growth that, if appropriately separated and administered could compete with mineral fertilizers. However, an increasing livestock production centered on relatively small land leads to pollution of water streams and air if nutrients surplus are released to the environment. Problems associated with excess load of nutrients and their loss to the environment can be partly solved by separation of animal wastes into a liquid fraction rich in inorganic nitrogen and potassium and a solid fraction rich in phosphorus. The liquid fraction has high water content and relatively low nitrogen concentration, thus further separation to increase nitrogen concentration is crucial. One of the methods allowing ammonia recovery is membrane distillation.

In membrane distillation a microporous hydrophobic membrane is used to separate ammonia from a feed solution into a strip solution. However, one of the major obstacles in the widespread use of membrane distillation is the problem of membrane fouling, and subsequent wetting.

Earlier investigations in methods for ammonia stripping have shown that a membrane distillation could be a cost effective option for removing volatile ammonia from wastewater or as a post treatment of biogas plant effluent. The hypothesis in this thesis is that ammonia removal via membrane distillation from pig manure performed with a hydrophobic membrane, where ammonia is captured in an acid is a both simple and profitable. This thesis evaluates the potential of membrane distillation for ammonia recovery from animal wastes.

The performance of membrane distillation has been assessed at different temperatures (30°C, 40°C and 50°C) and feed flow velocities (0.4 $m \cdot s^{-1}$, 0.9 $m \cdot s^{-1}$ and 1.8 $m \cdot s^{-1}$) using tubular polypropylene membrane and flat sheet polypropylene and polytetrafluoroethylene membrane. As feed solutions to membrane distillation have been applied pre-treated effluents from a AL-2 system (flocculation with gravity belt filter followed by screw press), a decanter centrifuge, a screw press and an anaerobic digester. Furthermore, membrane fouling has been investigated, including testing fouling mitigation techniques such as manure pretreatment via micro-/ultrafiltration and membrane cleaning strategies.

From manure management point of view, no significant difference was found between manure effluents with different dry matter content, but similar particle size distribution, meaning that preprocessing of manure prior to sieving has little influence on ammonia mass transfer. Nevertheless the cost of necessary drainage prior to membrane distillation was the lowest for decanter centrifuge effluent than for the investigated alternatives.

From optimization of operating parameters, it was found that increasing temperature from 30°C to 50°C doubles the overall mass transfer coefficient of ammonia, while increasing feed velocity has negligible effect on overall mass transfer of ammonia. From module configuration and material point

of view, polypropylene tubular membranes are recommended to be applied for ammonia membrane distillation based on knowledge from fouling autopsy results and economical assessment.

Based on the analysis of fouled membranes, it is concluded that membrane fouling is dominated by organic fouling (mainly proteins, carbohydrates and lipids) in combination with deposit of inorganic elements and microorganisms. The fouling problem is the more acute as the membrane surface changes from hydrophobic to hydrophilic hindering ammonia stripping.

Cleaning in series with 1 M sodium hydroxide solution and 1 M citric acid solution was found to be efficient to recover the initial ammonia flux, irrespective of manure pretreatment. However the original membrane hydrophobicity could not be regained suggesting presence of irreversible fouling. Although in no runs within the first 30 h, membrane wetting was observed.

Furthermore, pretreatment with microfiltration and ultrafiltration reduced fouling intensity due to proteins and carbohydrates removal, thus leads to increase in an overall mass transfer of ammonia twofold in the case of PTFE and fourfold in the case of PP.

Membrane distillation ammonia stripping was found to be a viable method for ammonia recovery from animal wastes at a price of 3.3-3.5 US$/$m^3$ feed using ultrafiltration as pretreatment, if chemical cleaning is applied every 30 h.