Experimental Modelling of Blackwater Digestate Concentration using Air Gap Membrane Distillation

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Highlights:

- **Volume reduction of blackwater digestate and tap water at different hot stream temperatures.**
- **Mathematical model for blackwater digestate concentration**

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INTRODUCTION

Most nutrients in the food eaten end up in faeces and urine, i.e. blackwater. Blackwater collected separately from greywater allows for increased potential for nutrient recovery as well as for improved biogas production compared to conventional wastewater treatment (Kjerstadius, et al, 2015). After anaerobic digestion, the liquid blackwater digestate is rich in macro and micronutrients. Nutrient reuse from blackwater digestate from cities to agriculture is logistically simplified if the digestate is concentrated. One option for concentration is membrane distillation (MD), a technique usually used for desalination for drinking water production. MD can concentrate non-volatile solutions until saturation point (Drioli, et al, 2015). MD also has the advantage of using temperature difference as a driving force. This gives the potential to use waste heat as an energy source. Several models have been described for heat and mass transport in air gap membrane distillation with the focus mostly on obtaining drinking water, instead of resource concentration, especially in water with organic matter and volatile compounds. This study aimed to develop a permeate flux model for blackwater digestate concentration with an air gap membrane distillation.

METHODOLOGY

A Polytetrafluoroethylene (PTFE) flat sheet air gap membrane distillation device was tested. The experiment setup is shown in Figure 1. The blackwater digestate went through a 5µm filter, after which phosphoric acid was added at different concentrations. Randomized runs of air gap membrane distillation with blackwater digestate (7 runs) and tap water (3 runs) at three different temperatures were studied. The total volume reduction was 50% for the first experiment and 93% for the concentration experiment. The permeate flux was measured every minute by a scale and thermometers and flowmeters were placed on the hot and cold sides of the membranes. In this setup, the cold side of the membrane was created by tap water with a temperature varying between 6.2 and 13.3°C. A chemical cleaning with isopropanol alcohol 10% was performed.

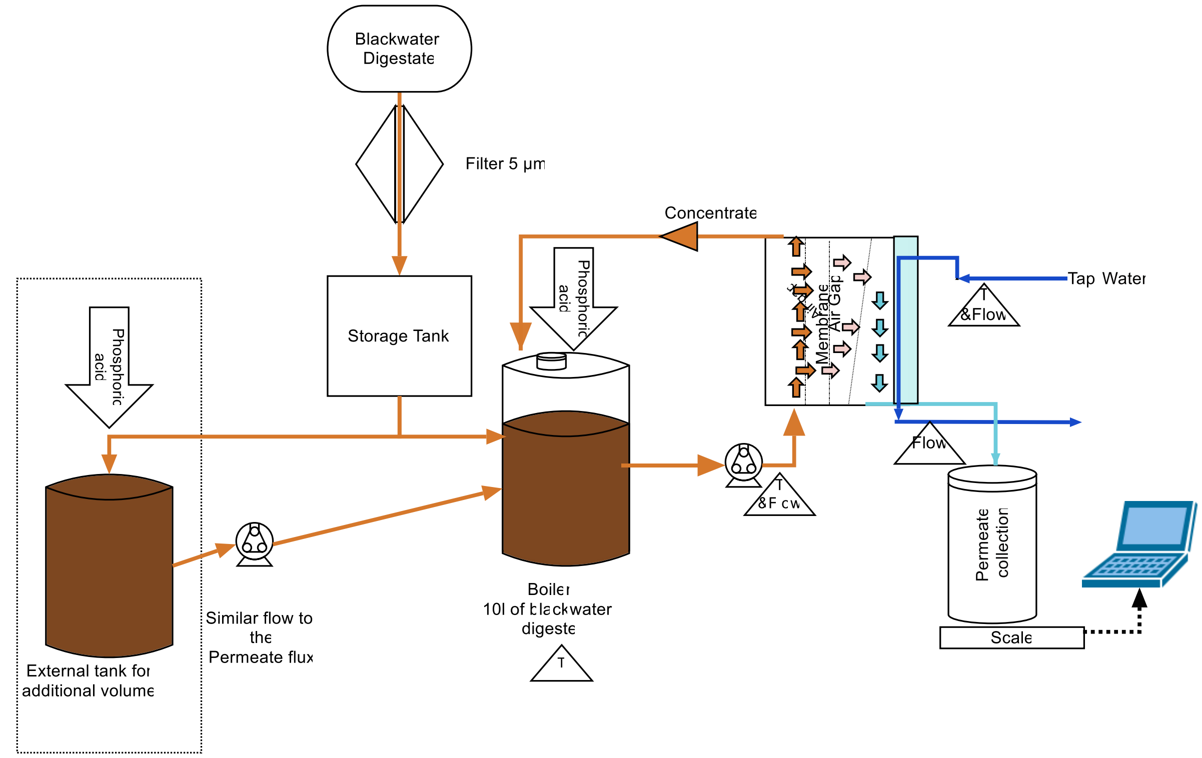

Figure 1 Experimental setup.

The model was based on equation (1) given by Liu et al (1998), where J is the permeate flux ($kgs^{-1}m^{-2}$), T is the temperature in the bulk liquid (K), α is a geometrical coefficient and β is a coefficient given by water concentration:

$$J = \frac{\Delta T}{\alpha T^{\frac{2}{3}} \exp\left(\frac{3841}{T-45}\right) + \beta} \qquad (1)$$

This equation was originally derived for sodium chloride solutions. In the current study, the model has been adapted for use with blackwater digestate. A least squares regression was done to find values for α and β from data obtained by distilling tap water. To do so, the equation was arranged as a linear equation in α and β. Since α depends only on the properties of the MD setup and not on the medium, the value of α was retained, and a new value of β was estimated using blackwater data. After testing different temperatures in the first experimental runs, 55 °C was selected for the following concentration experiment. This experiment reduced the volume of blackwater digestate from 100 L to 7 L. Then β was calculated for different volume reduction factors (VRF) given by equation (2)

$$VRF(t) = \frac{V_f}{V(t)} \qquad (2)$$

Where $V_f(t)$ is the feed volume and V(t) is the volume in L at time t.

During the concentration experiment the membrane needed to be cleaned when the VRF was 4.1.

RESULTS AND CONCLUSIONS

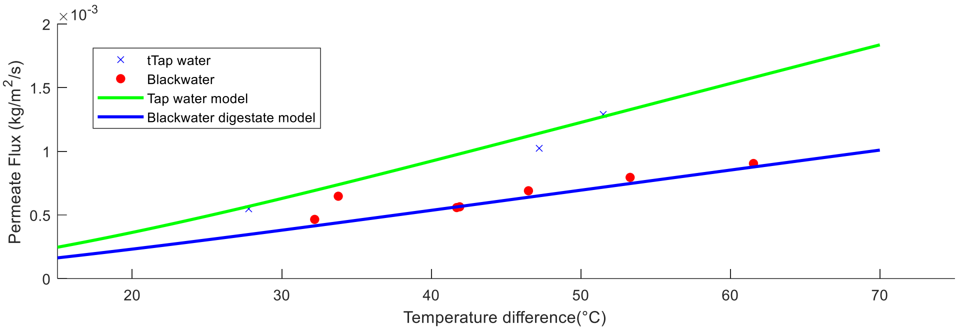

Figure 2 Experimental and modelled permeate flux of the tap water and blackwater digestate in relation to the temperature difference between the cold and hot sides of the membrane.

Figure 2 shows that the modelled flux fitted the experimental data well. The outlier at a temperature difference of 34ºC could be explained by it being the first run of the experiment when the membrane was clean. The addition of acid did not make a statistical difference in the permeate flux. The developed model offers the possibility to predict the energy cost of concentrating blackwater and to optimize the process. The initial experiments showed that a suitable temperature for concentrating blackwater digestate was 55°C, on the hot site. Therefore, longer runs for tap water and blackwater digestate were tested at this temperature.

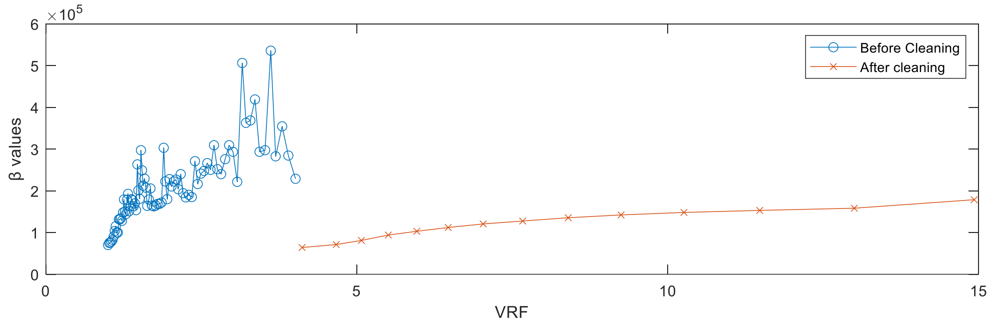

Figure 3 β estimation in the concentration experiment for every 100 minutes of operation before and after cleaning.

Figure 3 illustrates the estimation of β before and after cleaning. The noise observed in the before-cleaning curve, occurring around a permeate flux of 1 L/m²/h, was attributed to the quantization of the measurement signal occurring at low permeate flux levels. The cleaning was performed when the conductivity on the permeate was over 546 µS/cm.

When the solute concentration increases, the water evaporation temperature increases and the vapor pressure decreases, resulting in a lower flux due to colligative properties (Atkins, et al, 2014). Since this effect was not observed on β(VRF), it indicated that the membrane suffered from wetting, which was confirmed by chemical analysis of the permeate. Wetting equations could be incorporated into the model to improve its accuracy.

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