

First generation of membrane distillation microchips: characterization and proof of concept

Vincent Breukeleers

Master of Chemical Engineering Technology

Introduction

Although membrane distillation has several advantages over conventional recovery techniques, it is used in the industry to a limited extent due to a couple of different issues such as fouling, uncertainties regarding financial aspects and breakthrough. The latter, which is caused by pore wetting, can be prevented by maintaining the transmembrane pressure below a critical threshold, generally called the liquid entry pressure (LEP).

So far, a couple of empirical equations have been proposed which obtained an average error margin of 25.0% at best. Within this research, the most recent LEP correlation by Hereijgers et al. (2015) was evaluated for aqueous solutions, containing organic components (i.e., methanol, ethanol, acetone, acetic acid and acetonitrile), using a membrane microcontactor.

To address the impact of the **organic component concentration** on the LEP, the LEP was determined for each mixture at 5 different concentrations (i.e. 5, 15, 30, 45 and 60-mole percent). These experiments were performed by increasing the feed flowrate, which in turn increases the retentate pressure. Once **breakthrough** was detected, as it causes a constant flow at the permeate side, that pressure was regarded as the LEP.

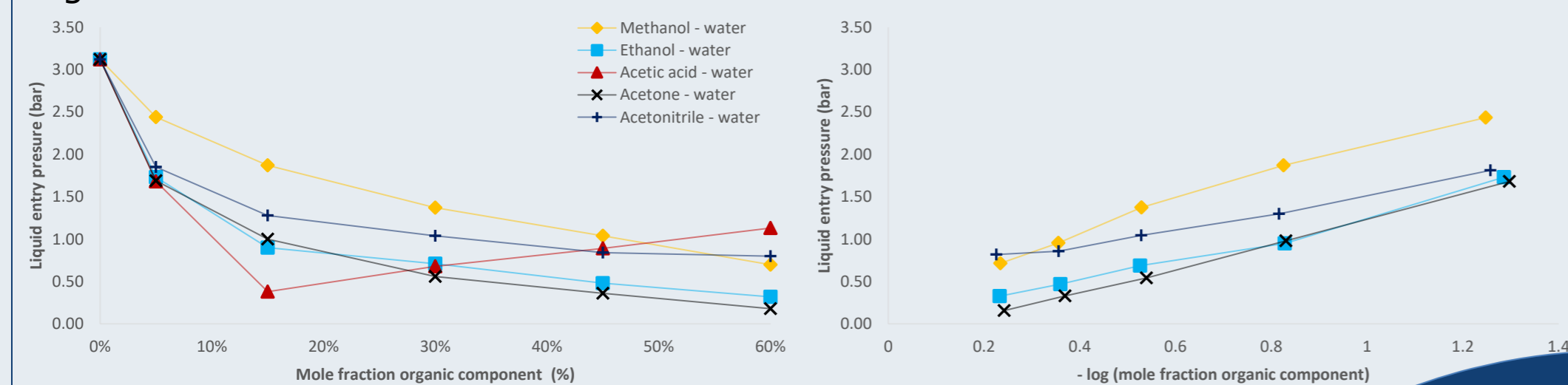


Fig. 2: Liquid entry pressure in function of mole fraction (left) and negative logarithm of mole fraction (right)

The result of these experiments indicated a **negative non-linear relation** between the LEP and the organic component concentration for all mixtures except **acetic acid-water**. This mixture was later left out of the model systems as its finding contradicted literature. Additionally, an **almost linear positive relation** was found when plotting the LEP to the **negative logarithm of the organic component concentration**.

$$LEP \sim -\log(Conc.)$$

The impact of the surface tension was evaluated using an **Attention Theta Lite** by Biolin Scientific following the **pendant drop principle**. By utilizing both the density of the solution and the **Young-Laplace fitting** of the droplet, a surface tension was derived at each concentration (i.e. 5, 15, 30, 45 and 60-mole percent). Additionally to evaluating the impact of the surface tension on the LEP, the surface tension was also displayed in function of the concentration to evaluate whether or not there is a relation between both parameters.

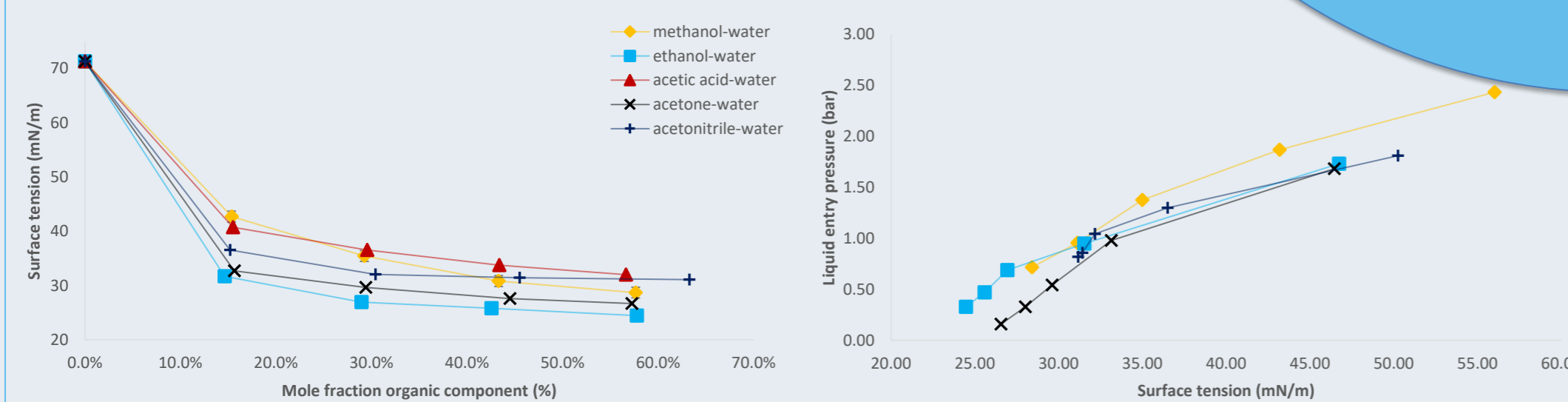


Fig. 1: Surface tension in function of mole fraction (left) and Liquid entry pressure in function of surface tension (right)

The surface tension displayed a clear **negative non-linear relation** to the organic component concentration and a **positive non-linear relation** to the LEP. This indicates that a **larger water content**, which will increase the surface tension, will yield a **larger LEP**. Also, the measured surface tensions of acetonitrile-water did not resemble those in literature, which will be evaluated with the proposed correlation.

$$LEP \sim \gamma_L$$

The contact angles were determined with an **Optical Contact Angle** by Dataphysics which used a pinned down **PTFE membrane** as the solid phase upon which a droplet was placed. Just as with the surface tension, a fitting (this time an **elliptical**) was used to determine the contact angle for each individual solution. Also, just as for the surface tension, the relation between the contact angle and the organic component concentration was evaluated.

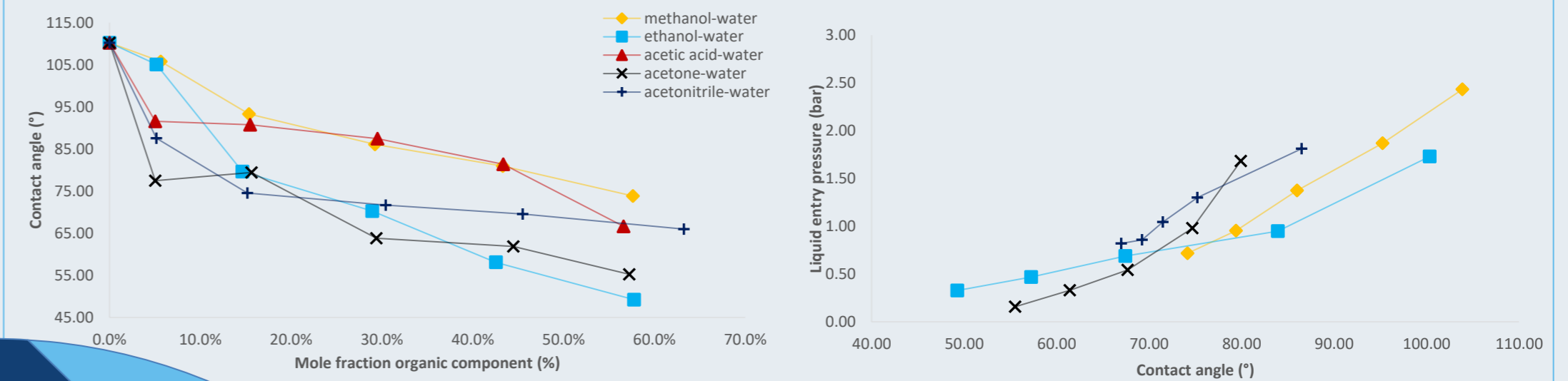


Fig. 3: Contact angle in function of mole fraction (left) and Liquid entry pressure in function of contact angle (right)

The contact angle displayed a clear **negative non-linear relation** to the organic component concentration and a **positive non-linear relation** to the LEP. This indicates that, just as with the surface tension, a **larger water content** will yield a **larger LEP**. Due to the fact that the contact angles were measured on porous surfaces, an **angle correction** must be made as the ideal contact angle for correlation purposes should be the that within the pores (where the **surface is non-porous**).

$$LEP \sim -\cos(\theta + \alpha)$$

To propose a model, all data was gathered as to perform a **curve fitting**, using Eureka-software. This resulted in the equation below:

$$LEP = -0.0459 \gamma_L \cos(\theta + 0,937)$$

with γ_L and θ corresponding to the **surface tension** and the measured **contact angle** respectively, and a **correction angle** which is equal to **53.7° or 0.937 rad**. This correlation was deemed the best fit with an **R² of 0.9703**, a **maximum deviation of 154.5%** and an **average deviation of 24.53%**. Additionally, the acetonitrile-water mixture was used to evaluate its prediction for an unknown model, which resulted in a **constant underestimation** (no larger than 25%) when using the **measured surface tension** data. For the **literature values** of the acetonitrile-water surface tension, a **constant overestimation** was found larger error margins.

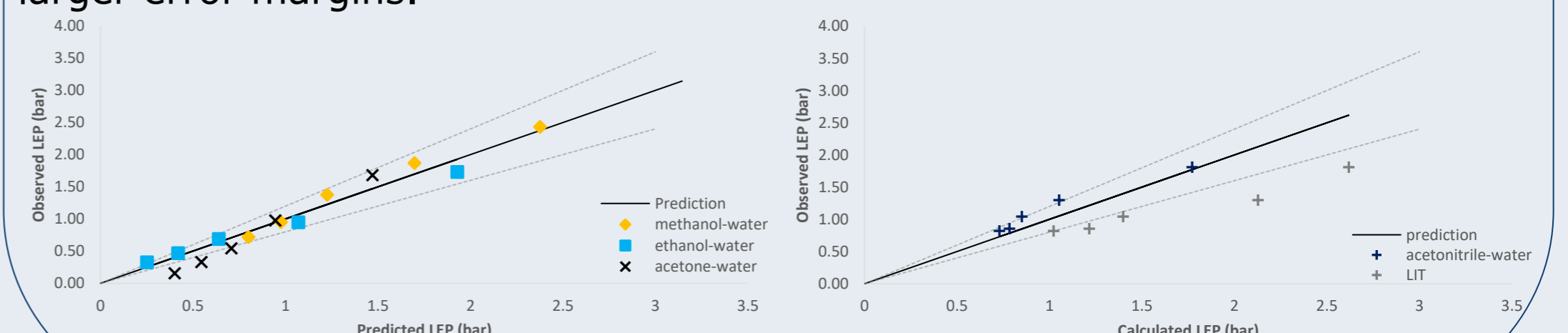


Fig. 4: Surface tension in function of mole fraction (left) and Liquid entry pressure in function of surface tension (right)

Conclusion

Four different parameters were evaluated, resulting in a positive relation with the LEP for both the contact angle (θ) and the surface tension (γ_L), while the concentration and the Kamlet-Taft polarity factors showed a negative relation with the LEP. All of

this resulted in a proposed correlation to predict the maximum allowable pressure which showed an average deviation of 24,53% for the model systems: $LEP = -0.0459 \gamma_L \cos(\theta + 0.937)$

Supervisors / Co-supervisors / Advisors Prof. Dr. Ir. Leen Thomassen
Ing. Joris Claes