Chemical Engineering

SciTech 2013 Summer Science Camp

Wetting and Separating: A separation process based on surface energy

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Background

Surface tension is the amount of energy per unit area where two interfaces meet.

Fig. 1 – The surface tension of water forms a "skin" that will hold it in place even when it rises above the rim of a glass

The contact angle is the angle formed between the drop and the surface. If it is below 90º the liquid is said to wet the surface. If it is above 90º the liquid beads up and does not wet the surface (See Fig. 2).

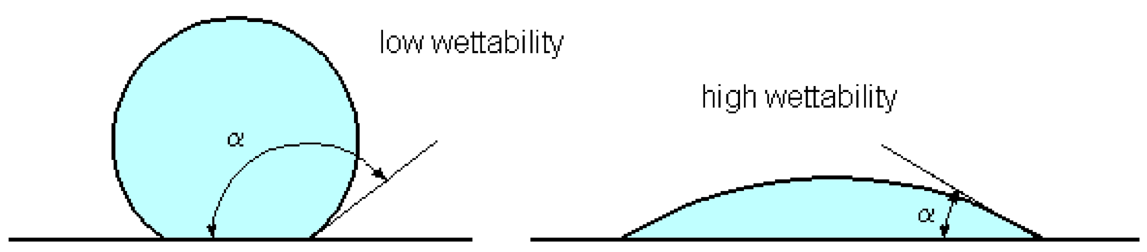

Fig. 2 – The relationship between contact angle and wettability of a surface.

Objective

Using the principle of surface energy, we tried to develop a theoretical membrane that would separate oil from water when a pressure difference is applied to it. To do so we had to use a computer programme to determine the ideal parameters and necessary pressure difference to allow one liquid to penetrate the membrane and not the other.

Mathematical Model

In order to perform this task, we divided the movement of the drop through the membrane into seven stages. In each stage, we calculated the system energy and the pressure difference.

Using these results, one can identify which pressure difference has to be inflicted in order to get the drop of oil out of equilibrium and through the membrane. The pressure difference should not be large enough to cause the water to penetrate through the pore as well.

The pressure selectivity is a variable that calculates the difference between the necessary pressure difference (to allow oil to pass through) and the maximum pressure difference (to prevent water from passing through). When the pressure selectivity has a negative value, it is possible to separate oil from water.

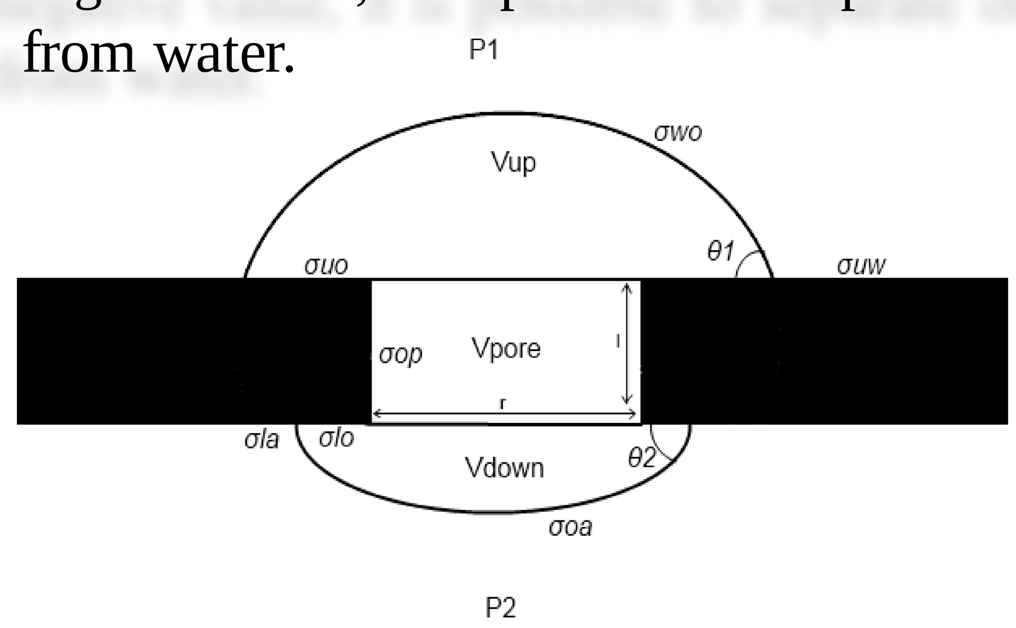

Fig. 3 – Diagram showing variables explained in scheme 1

Variables
- Upper Volume (Vup)
- Lower Volume (Vdown)
- Volume Inside Pore (Vpore)
- Contact Angles (θ1, θ2)
- Curvature of Caps

Constants
- Membrane Width (l)
- Pore Radius (r)
- Lower Pressure (P2)
- Surface Tensions (σ_{uw}, σ_{wo}, σ_{uo}, σ_{op}, σ_{lo}, σ_{la}, σ_{oa})

Calculated Parameters
- Energy of System
- Pressure Difference (P1-P2)
- Penetration of Drop
- Pressure Selectivity

Scheme 1 – The parameters involved in the mathematical model. Upper part: variables dependent on the drop's position. Middle part: physical variables to be investigated. Lower part: parameters calculated using the above variables.

Results and Discussion

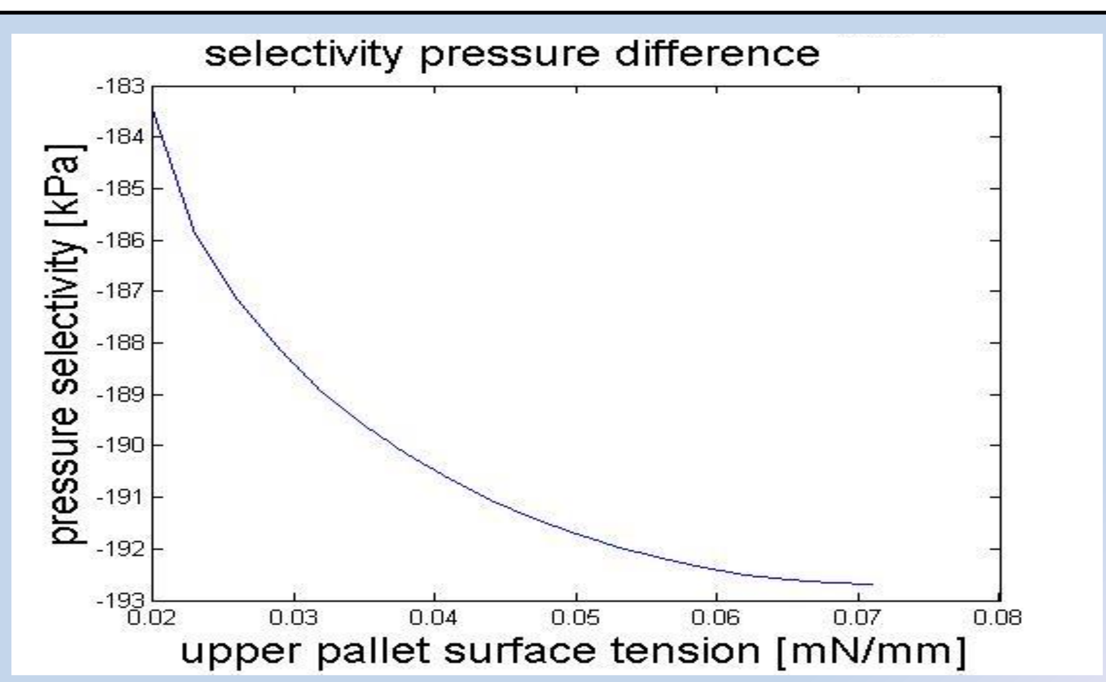

Fig. 4 - Pressure selectivity vs. upper pallet surface tension, at the point where there is the maximum pressure difference. The optimal values are found between 0.05 and 0.07 mN/mm.

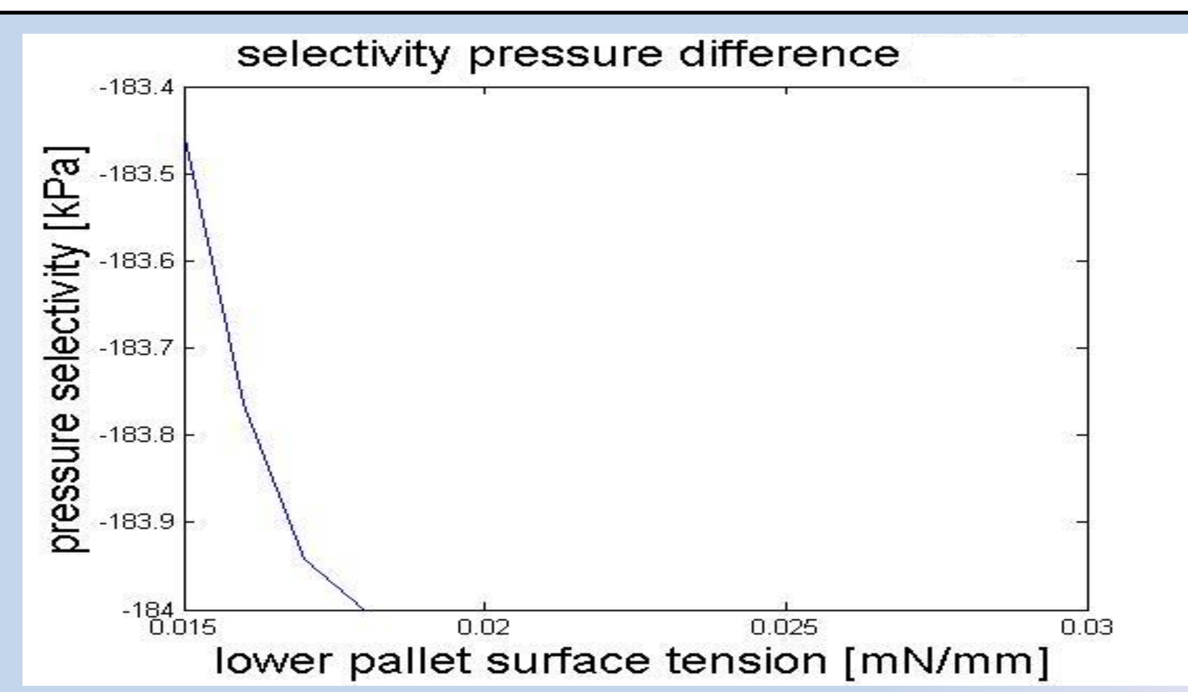

Fig. 5 - Pressure selectivity vs. lower pallet surface tension, at the point where there is the maximum pressure difference. The optimal lower surface tension is just below 0.02 mN/mm (surface tension of oil used in this experiment).

In order to check whether the system is affected by other variables, we checked what would occur when changing variables such as the pore radius, the membrane width, the drop volume and the pore surface tensions. Some of our results are displayed below.

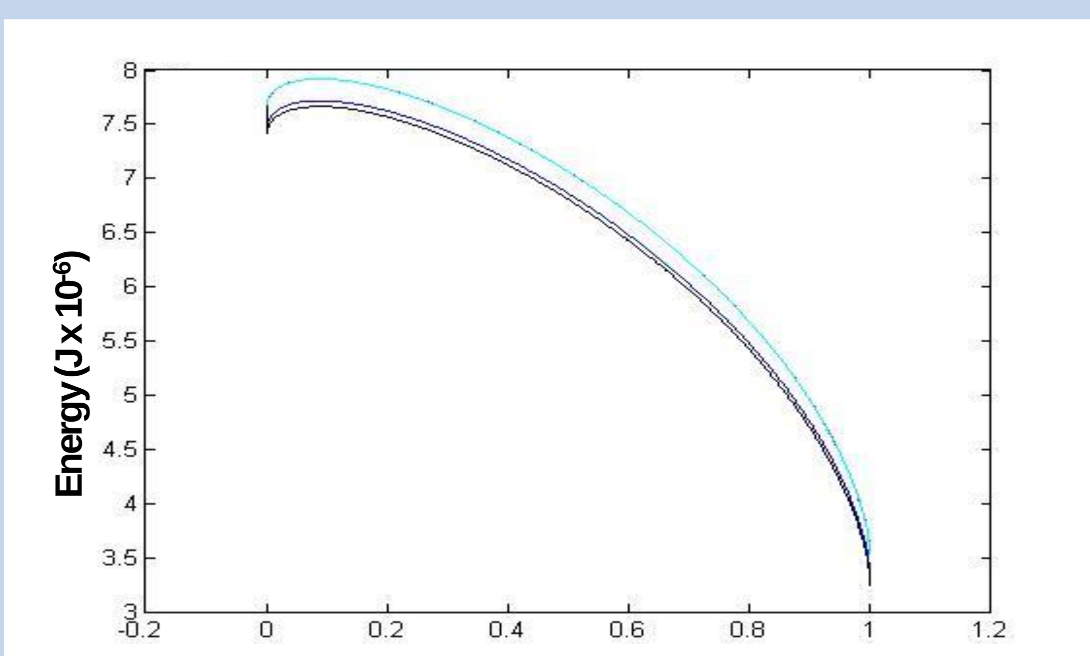

Fig.6. - Energy of the system vs. drop penetration for different surface tension values in the pore.

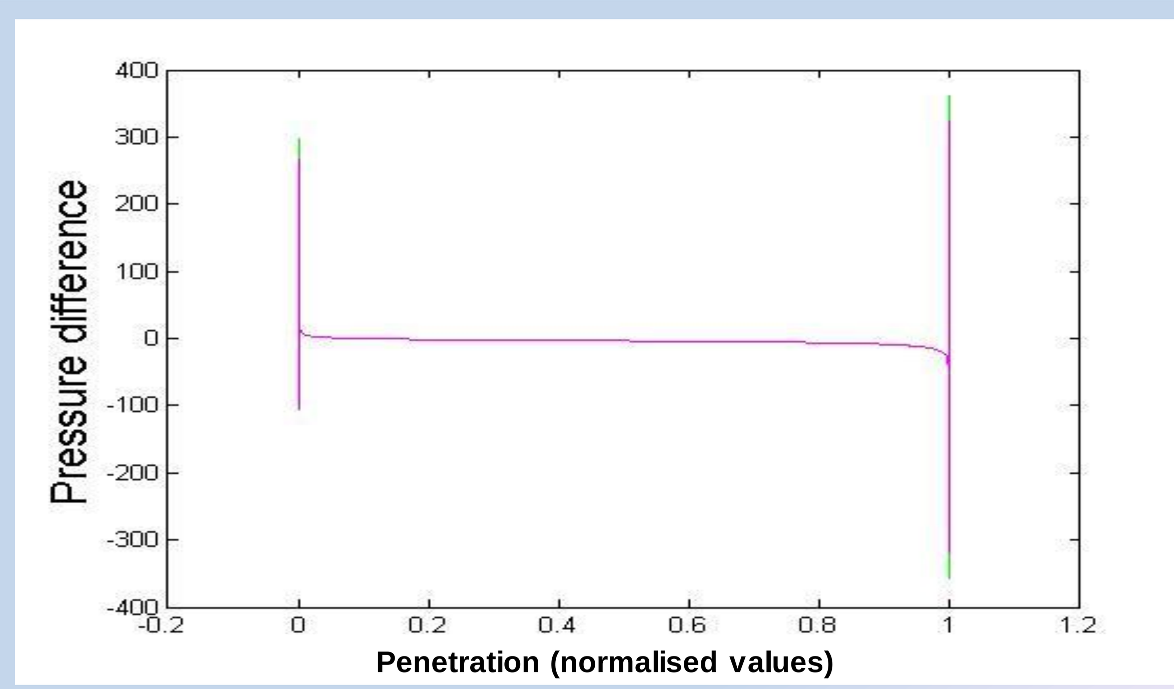

Fig. 7 – Pressure difference vs. drop penetration for different surface tensions in the pore.

As can be seen from the graphs, neither the energy of the system nor the pressure difference change dramatically due to changes in the pore surface tension. This phenomenon repeats itself for the other check variables.

Conclusion

Separation oil from water can be achieved by using surface tension based membrane.

The upper and lower surface tension that are required in order to perform the separation were found in our research.

Small changes in the several parameters (pore surface tension, pore radius, membrane width and drop volume) have little to no effect on the system performance. From an engineering point of view, this is a very useful result, as in real life, uniform parameters do not actually exist.

References

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Acknowledgements

We would like to thank Elad Dor MSc for having guided us throughout the research and for letting us use his own program. Also to Prof. Abraham Marmur and Prof. Simon Brandon for having supervised all the investigations and research that we carried out.

We would like to sincerely thank the Mitchell and Morven Heller Charitable Foundation, The Gilbert Foundation and the Cellex Foundation for their generosity and kind donations that enabled us to undertake this opportunity.