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Membrane, module and process design for the dehydration of supercritical CO_2

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Motivation

Supercritical carbon dioxide ($scCO_2$) is used to dry sensitive products, having delicate structures, such as aerogel or food. Finite phase transition, can be avoided in this case, enabling the removal of water from products without causing any disruption of their structures. In a closed loop operation, $scCO_2$ needs to be dehydrated after each process cycle in order to be used again as drying agent. Zeolite columns are currently used to dry $scCO_2$. This approach however is very costly due to the large energy demand needed to reactivate the saturated zeolite columns and the need of an additional column while the second one is in the reactivation phase.

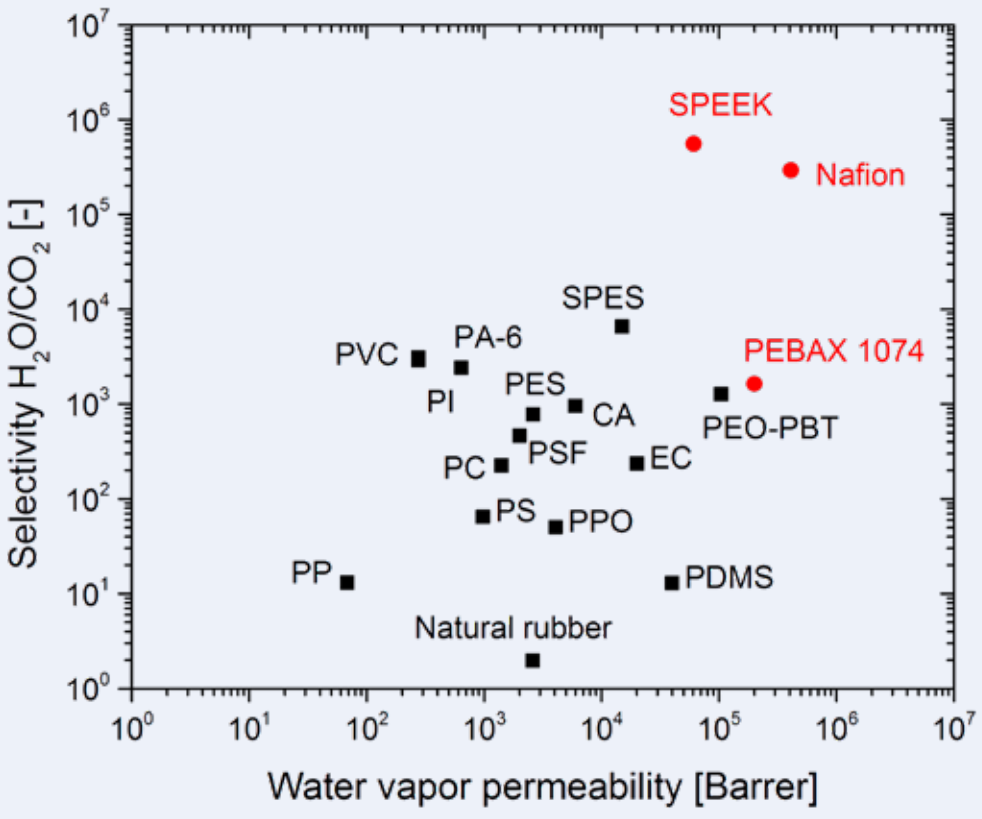
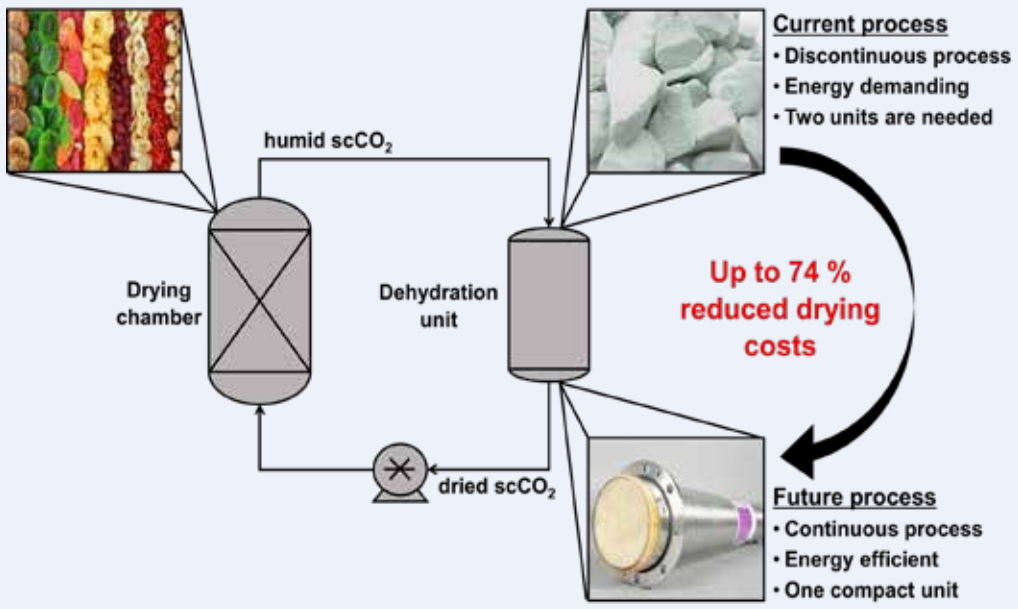


Figure 1: Water vapor permeability and water vapor/CO_2 selectivity for various polymers. SPEEK, Nafion® and PEBAX® 1074 show exceptionally high water vapor/CO_2 selectivities and water vapor permeabilities and are therefore considered for further investigations. [S. Metz "Water vapor and gas transport though polymeric membranes", University of Twente, 2003; and other sources]

Research objective

Simulations where performed to assess the economical potential of membranes as an alternative to the currently used zeolite columns. Three membrane materials where considered for this simulation due to their exceptionally high water permeability and water-CO_2 selectivity. Sulfonated poly(ether-ether-ketone) or SPEEK is especially interesting due to its high selectivity (Figure 1), which proved to be a key membrane parameter for this process.



Results

Simulations revealed that membranes are more cost efficient for a wide range of feed stream humidities and process scales ranging from pilot plant scale having 0.5 t/h of $scCO_2$ to be dried up to the industrial scale at which more than 300 t/h of $scCO_2$ is dried. In fact using membranes instead of zeolites could reduce the dehydration costs by up to 74% as, displayed in Figure 2. This outcome justifies further efforts to establish a membrane based process.

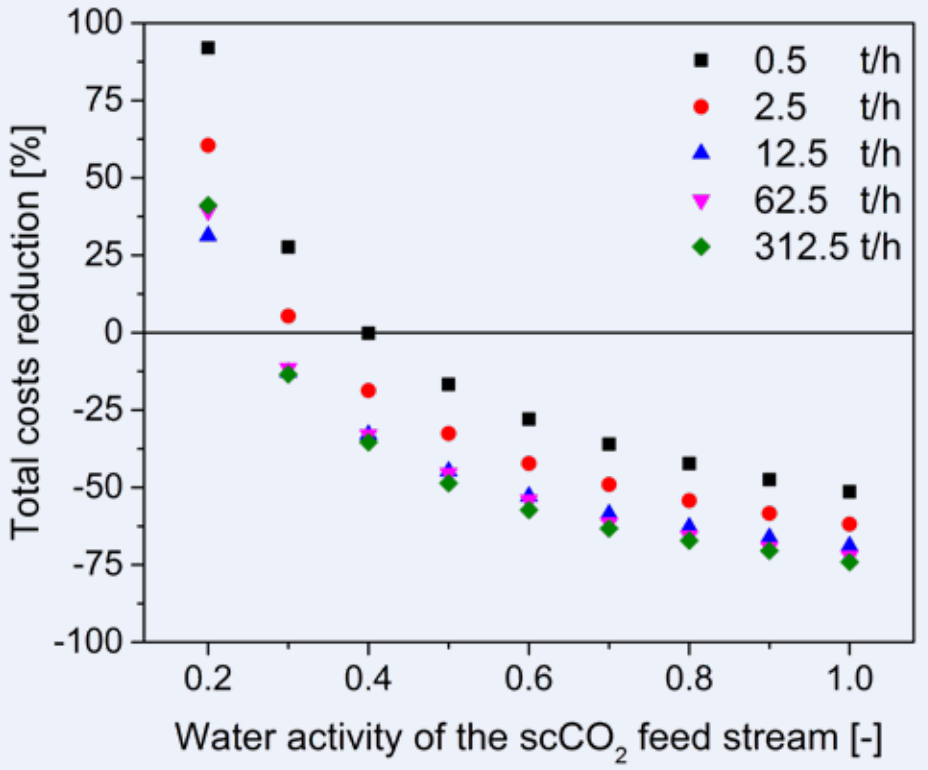


Figure 2: The total costs reduction of the membrane based process relative to the total costs of the zeolite process as a function of the feed stream water activity. At water activities above 0.4, the membrane based process becomes more cost efficient than the commercially used zeolite based process.