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Analytical approximate solution of competitive facilitated transport of acid gases through liquid membranes

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Abstract

An analytical approximate solution for the competitive facilitation factor of components *A* and *E* across a liquid membrane is developed in the case of instantaneous reactions inside the liquid membranes. This analytical solution solves the dimensionless, nonlinear diffusion-reaction transport problem governing the competitive facilitated transport of two gaseous components through liquid membranes. Prediction of the facilitation factors has been obtained for the equilibrium chemical reaction regime, considering the unequal complexes diffusivities and cases of zero and nonzero permeate side solute concentrations. This mathematical solution leads to analytical expressions for the concentration profiles of the species across the liquid membrane. In comparison with the present numerical solution and also numerical calculations and experimental data from the open literature, the difference between the analytical predictions and those obtained from the numerical solution were found to be in well agreement.

Keywords: Competitive facilitated transport; Liquid membranes; Approximate solution; Gas separation; Acid gases

1. Introduction

Multiphase mass transport accompanied by chemical reactions is an interesting subject due to the simultaneous occurrence of three phenomena: phase equilibrium, mass transfer and chemical reaction [1].

Facilitated transport is a well-known process in which the reversible complexation reactions are carried out between solutes and reactive carrier and produced complex diffuses through a liquid membrane. Carrier molecules transport the solutes through a liquid membrane and then release them on the permeate side. This mechanism enhances the permeability and selectivity of liquid

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membranes. So, due to their very high permselectivity compared with conventional polymeric membranes and also low energy consumption, they have attracted the attention of many industries and researchers.

This phenomenon has attracted attention because of its numerous promising applications which have been extended to branches of science such as separation processes in oil, gas and petrochemical industries as well as physiology and biochemistry. The bulk removal of CO_2 is an important gas-treating process in synthesis gas purification and hydrogen and ammonia manufacture industries. The increased demand for acid gas treatment and the increase in the cost of purification by conventional processes suggest a need for energy-efficient and selective gas treating technology.

Historical background, applications and description of facilitated transport have been extensively discussed in several studies. Examples of facilitated transport applications are as follows:

Removal of acid gas components, H_2S and CO_2, from sour natural gas, refinery gases, and synthesis gas is of major industrial importance [2, 5,6,10,11,13,14]. The removal of CO_2, CO, SO_2, SO_3, chlorofluorocarbons, methane, etc. from industrial waste gas streams has been a highlighted subject in view of global warming prevention [3, 12,15,16].

Alkanes/alkenes separations by facilitated transport are another application of liquid membranes which is currently carried out by distillation, a high-energy intensive process [17].

Some other applications include transport and separation of 1-hexane and 1,5-hexadiene through a film of a Nafion membrane [18].

Facilitated transport of gases is important from physiological as well as engineering considerations. The facilitated transport has been recognized as a potentially valuable technology for the selective separation of precious metals and toxic metals [19,20].

From the theoretical point of view, many studies have been carried out to calculate and predict the facilitation factors, which are defined as the ratio between the facilitated transport flux to the flux without carrier or purely diffusive. A number of numerical and analytical methods have been derived to solve the diffusion-reaction non-linear partial differential equations in order to predict the permeation rates and facilitation factor theoretically using the physicochemical properties such as reaction rate constant, chemical equilibrium constant, diffusivities of the chemical species, and membrane thickness.

Many studies have been carried out in order to predict the facilitation factor for single component facilitated transport in liquid membranes [21, 22,24–30].

Cussler [4] derived an analytical solution for the steady-state problem of two gases competing for one carrier under the fast complexation reaction and equal diffusivities for all diffusing species. This model had poor agreement with experimental data which is essentially due to assumption of equal diffusivities for all species in the liquid membrane. Niiya and Noble [23] discussed a numerical model for the competitive transport experiments of two gases through an immobilized liquid membrane and reported transient and steady-state results. The only assumption was equal diffusivities of complexes which were used in the derivation of the non-linear partial differential equations. They showed that pumping of gas against its concentration gradient is possible. Way and Noble [6] developed a numerical solution for the steady-state competitive transport of CO_2 and H_2S through ethylenediamine impregnated perflurosulfonate membranes. They assumed an average value for the diffusion coefficients of complexes. The results of their model were in good agreement with experimental data. A recent approach used to model the competitive transport was the analytical solution of Dindi, Noble and Koval [21]. They assumed a constant free carrier concentration throughout the membrane phase. They compared the reduced form of