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Simulation of Forward Osmosis Using CFD

Shyama Pankaj[a], N. Sajikumar[b] *, Roopesh Kaimal[c]

[a]*Graduate student Dept. of Civil Engineering, Govt. Engineering College,Thrissur, India*
[b] *Professor,Dept. of Civil Engineering, Govt. Engineering College,Thrissur, India*
[c] *Graduate student Dept. of Mechanical Engineering, Govt. Engineering College,Thrissur, India*

Abstract

If fresh water and salt water are separated by a membrane, the fresh water would flow across the membrane from fresh water chamber to salt water chamber in a forward osmosis process. Forward osmosis and reverse osmosis processes have been used for many new applications like wastewater treatment, food processing industry, and desalination of seawater. Computational Fluid Dynamics (CFD) software, viz., FLUENT software is used for simulating FO process. The water moved across the membrane from fresh water side to salt water chamber indicating that FO was well represented by FLUENT**.**

Keywords: Forward Osmosis (FO); Computational Fluid Dynamics (CFD); FLUENT.

1. Introduction

Modelling of osmosis process, both experimental and numerical has become a hot subject of research over the last few decades. Osmosis is defined as the phenomenon of water flow through a semi-permeable membrane which does not permit the transport of salts or other solutes across it. More specifically, it is the movement of water through a semi-permeable membrane from one side of the membrane with low solute concentration to the other side of the membrane with high solute concentration. Osmosis is a reversible thermodynamic process (Cath et al. 2006; Sabah et al., 2013). That is, by proper adjustment of external pressure on the solution side, the direction of water flow across the membrane can be controlled. There are three types of osmotic processes: Forward Osmosis (FO),

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: saji@gectcr.ac.in

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Reverse Osmosis (RO) and Pressure Retarded Osmosis (PRO) (Gruber et al., 2011). In FO, the driving force for transport of water through the membrane is the osmotic pressure difference ($\Delta\pi$) across the membrane.. Flux in FO is from low concentrated salt solution to high concentrated salt solution when applied pressure difference is zero, i.e. $\Delta P=0$. In RO, the driving force for the transport of water through the membrane is the applied pressure. Flux in RO is in the opposite direction of FO, i.e. from highly concentrated salt solution to low concentrated salt solution. In PRO, the hydraulic pressure is applied to the draw solution but is less than the osmotic pressure existing between the solutions in the system; as a result, the water flux is in the direction of the concentrated draw solution similar to Forward Osmosis. The main advantage of FO over RO and PRO is that it is more cost effective due to the lack of need for hydraulic pressure (Cath et al., 2006).

Modelling of complex flow patterns in membrane systems using Computational Fluid Dynamics (CFD) have become increasingly popular as it provides more robust approach capable of including many flow parameters (Cath et al. , 2006; Gruber et al. 2011). Studies on modelling of Osmosis using CFD have utilized User Defined Function (UDF) facility of FLUENT or source term adjustment for modelling the process. In this study, the process is represented by the cell zone definition. In order to substantiate this proposition, CFD simulation is carried out without using any of the methodologies mentioned earlier.

The objective of this paper is to model Forward Osmosis system with an asymmetric membrane using CFD model. For this ANSYS FLUENT 14.5, CFD based software have been used. The membrane module consists of a thin non-porous skin dense layer called skin, on top of a porous support layer. The porous layer supports the membrane but they reduce the efficiency of the membrane. Multiphase mixture model was used.

1.1. Theory

The general equation describing water flux in an osmotic process is given by

$$Jw = A\cdot(\Delta\pi - \Delta P) \tag{1}$$

where Jw is the water flux through membrane, A is the water permeability coefficient of the membrane, $\Delta\pi$ is the osmotic pressure difference and ΔP the hydraulic pressure differential across the membrane (Fluent 2006; Gruber et al. , 2011).

Osmotic pressure ($\Pi_{OSMOTIC}$) can be calculated by the Van't Hoff equation:

$$\Pi = 2\cdot C_{NaCl}\cdot R\cdot T \tag{2}$$

where R is the gas constant, T is the absolute temperature and C_{NaCl} is the concentration of NaCl (Gruber et al. , 2011).

All CFD software solves seven equations, these are: Equation of conservation of mass, three momentum equations in three directions, Energy equation, Equation of state and Equation of enthalpy.

The Equation of state can be expressed as:

$$P = \rho * R * T \tag{3}$$

where P is the pressure, R is the gas constant,T is the absolute temperature and ρ is the density.

For a mixture, density becomes density of the mixture ρ_{mix}. ρ_a for component A in mixture is expressed as the ratio of mass of component A by total volume of mixture. This represents the concentration c. The equation (3) can be changed as,

$$P = c * R * T \tag{4}$$

This equation is similar to Van't Hoffs equation for osmotic pressure π and is given by