Modeling ultrafiltration of gelatin–water suspension by computational fluid dynamics

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A B S T R A C T

In this paper, principles of computational fluid dynamics (CFD) are used to study ultrafiltration (UF) process. Model has been developed by a new technique in which permeation of solvent molecules is introduced to system via appropriate sink terms in conservation equations for computational domain. Experimental data and fittings are applied in model development. Model results have been compared for two and three-dimensional geometries. Finally, a time step and mesh size independent model has been developed in two dimensions for modeling the permeation flux vs. filtration time in a gelatin–water UF system. Final model is able to predict steady-state permeation flux with relative error less than 2%. Accuracy of calculation is investigated through the comparison between mass imbalance and sum of local fluxes. Modeling results show that increase in cross flow velocity (CFV) and trans-membrane pressure (TMP) leads to increase in permeation flux but decrease in solute concentration and rejection of solute particles from membrane surface makes permeation flux increase.

Keywords: Ultrafiltration; Computational fluid dynamic; Concentration polarization; Permeation flux decline

1. Introduction

The widespread application of ultrafiltration (UF) in the industry has made the researchers and industrialists pay attention to the modeling of such processes. Inadequate knowledge of process mechanism and experimental data are examples of limitations in different types of modeling. White box modeling requires adequate knowledge of process mechanisms so it is possible to use white-box methods like computational fluid dynamics (CFD) approach for UF modeling as an almost well-known pressure driven membrane process. UF modeling can be classified in three groups: classical and empirical models, mathematical and CFD models and models based on artificial intelligence.

As empirical and classical models, Cheng and Wu (2001) developed a modified model to consider both effects of osmotic pressure and the boundary layer resistance on permeation flux. Paris et al. (2002) compared results of two-dimensional mathematical modeling with classical models like resistance in series and gel-polarization models. Mohammadi et al. (2005) used experimental data to calculate Lihan-Huang equation parameters and developed the model by adding third parameter for better adjustment between experimental data and model results for gelatin in water suspension. Sarkar et al. (2006) and Bhattacharjee et al. (2006) modeled UF of Kraft black liquor with two irreversible thermodynamic methods, Spiegler–Kedem (SK) and Kedem–Katchalsky (KK). UF module of a rotating disk was also modeled in 2008. (Sarkar and Bhattacharjee, 2008).

Literature review of mathematical and CFD methods in modeling shows that in 1997, a circular channel was modeled via finite element method by coupling Navier–Stockes and Darcy equations (Nassehi, 1998). Huang and Morrissey (1999) used finite element method for modeling a rectangular