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CFD Study of Mass Transfer in Spacer Filled Membrane Module

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ABSTRACT

The present paper is devoted to investigate the mass transfer in two dimensional spacer filled channels. Three different configurations of the cylindrical spacers are considered with different channel Reynolds number and mesh length. Different size and shape of formation of recirculation region, upstream and downstream of the spacers are closely observed. This recirculation regions have an important role in enhancing the mass transfer in the reattachment region. CFD simulations show that the submerged spacers have the highest efficiency with highest wall shear stress and mass transfer enhancement whilst the cavity spacer have the least performance.

Key words: Concentration polarization, Mass transfer enhancement, Reattachment length

1. Introduction

In membrane processes accumulation of rejected species near the feed side of the membrane (concentration polarization) causes reduction of permeate flux and deterioration of permeate quality. Accumulation of rejected species can be suppressed by creating back mixing from the membrane to the bulk of the liquid.

This paper describes the CFD model and provides a discussion of mass transfer of a spacer filled two dimensional channel. The effects of single and multiple filaments on the mass transfer is presented. Effects of the types of spacers, channel Reynolds number, mesh length on the flow field, mass transfer enhancement and pressure loss along the channel is discussed based on the numerical simulations of the flow field.

2. Problem Description:

Spacer geometry, the channel geometry, typical grid generated for numerical simulation,the methods of numerical modeling etc. has been depictedin details in [1].

Spacers come in various forms that are comprised of a net-like arrangement of filaments aligned parallel, transverse or at an angle to the module axis. Different diameters, various mesh lengths are observed in commercially available spacers. In the present work,flows in narrow channels with cylindrical obstructions is investigated to improve fundamental understanding of mass transfer. In order to elucidate the likely extent of flow disturbance, the CFD simulations focused on the effect of cylindrical obstructions positioned normal to the flow. This corresponds to transverse filaments, and allows two-dimensional simulations. Three arrangements are simulated as shown in Fig (1).

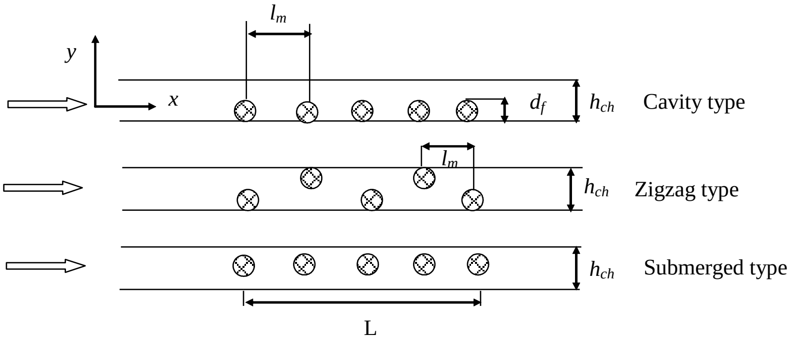


Figure 1.Various

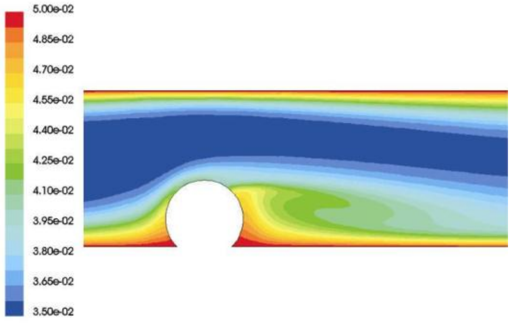
arrangements ofTransverse filaments

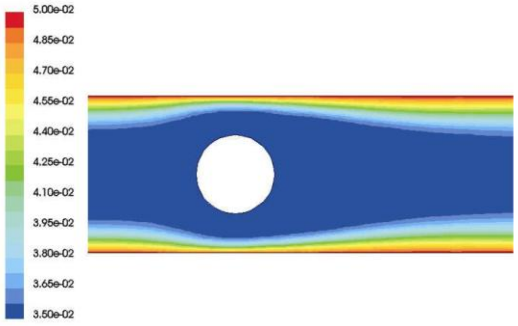
(i) Simulation of spacers touching the same channel wall, (ii) Simulation of spacer cylinders touching alternately adjacent to the top and bottom wall, (iii) Simulations of spacer cylinders immersed in the channel. The computational domain is set up with a channel entrance length of 10 times the filament diameterwhile the exit length is at least twice the entrance length to avoid any effects of the channel exit on eddy formation behind the filaments. The inlet velocity is specified uniform and as normal to the channel entrance and the flow is fully developed before reaching the first upstream filament. The wall is assumed to be non permeable to analyze the hydrodynamics between two sequential filaments because permeate recoveries are usually low for membrane applications. All simulated channel configurations had an identical channel height. Parametric studies of the dimensionless mesh length l_m/h_{ch}, the channel Reynolds number Re_{ch} are performed to cover the range of spacer dimensions used in commercial spiral-wound membrane modules and in other studies examining spacers. The channel Reynolds number Re_{ch} is defined as: $\mathrm{Re}_{ch} = d_h u_{ave} / \nu$ where d_h is the hydraulic diameter for spacer filled flow channel. A schematic of the flow channel is presented in Fig. 3.

3.1 Concentration profile in Narrow channels with transverse filaments:

Concentration profiles for single filament adjacent to the bottom wall and submerged in the center of the channel are presented in Figure 2 (a,b). It was shown earlier that for single filament adjacent to the bottom wall a small recirculation region forms in front of the filament and a large one forms behind the filament. Because of the formation of these recirculation regions, the concentration boundary layer is disturbed at both the top and bottom wall. As a result of the flow recirculation, concentration within the recirculation region is increased near the bottom wall. Higher velocity at the top of the filament and higher value of wall shear stress disturb the formation of the concentration boundary layer at the top wall.

For a spacer submerged in the center of the channel, concentration boundary layer at both top and bottom wall are altered because of the velocity acceleration as well as the formation of the secondary flows. Higher velocity at top and bottom of the filaments leads to an enhancement of wall shear stress at both walls, which also results in a change of near wall scalar transport.





(b) (a)

Figure2(a,b):Concentration profiles (a) for a single filament adjacent to the bottom wall, (b) for a single filament submerged in the center of the channel, Re_{ch} =300,Sc=100, d_f/h_{ch}=0.5.

3.2Mass transfer Enhancement in Spacer-Filled Channel:

In order to estimate the mass transfer enhancement, the efficiency of the spacer is calculated by:

$$\eta_{mt} = \frac{\Delta c_{spacer}}{\Delta c_{slit}} \qquad (2)$$

where η_{mt} is the efficiency of the spacer and $\Delta c_{spacer}$and Δc_{slit} are the concentration increase along the spacer-filled channel and the slit (empty channel), respectively. Calculations are performed for an empty channel (slit) to obtain the value of Δc_{slit}.

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