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A three-dimensional unsteady hydrodynamic profile of a reciprocating membrane channel

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ABSTRACT

Dynamic membranes have successfully increased the membrane surface shear stress and extended the use of membranes into many applications, including highly viscous fluids. High shear stress has been shown to reduce concentration polarization and membrane fouling. The effect of applying reciprocating movement to a channel filled with a corrugated spacer was studied in this paper by using computational fluid dynamics (CFD). The velocity of the spacer-filled channel changed sinusoidally as a function of time and the motor rotation speed. The average shear stress on the membrane was found to increase exponentially with the membrane velocity. Generally, there were five types of flow involved in the reciprocating motion, including Poiseuille flow, Couette–Poiseuille flow, plug flow, vibratory shear enhanced process (VSEP) flow and opposite-direction Couette–Poiseuille flow. We concluded that the reciprocating motion increased the membrane surface shear stress sinusoidally in the corrugated spacer-filled channel; the transmembrane pressure also changes sinusoidally with the reciprocating motion.

1. Introduction

Spiral-wound membrane (SWM) modules are widely used in various industries. They offer a higher packing density than plate and frame modules and also have better fouling resistance than hollow fiber modules, which is an advantage that should be utilized by industry. The main problem faced by membrane applications is concentration polarization in the membrane processes. A gel layer is formed because of the concentration polarization, which causes the flux to decrease. Therefore, the back diffusive transport of solute away from the membrane surface is important for reducing the concentration polarization (CP) [1]. The high shear stress formed on the membrane surface has been proven to reduce the CP [2,3] and also the cake-layer formation [4] by increasing the back transport of the solute back to the main stream. CFD is being used to evaluate the performance of the spacer in SWM modules [5,6]. The feed spacer design and the mesh angle have been studied to find the optimum spacer design [7,8] and mesh angle [9] that can give the optimum performance between the shear stress created on the membrane surface and the subsequent pressure drop across the spacer-filled channel.

Dynamic membrane has been proven can create higher shear stress on the membrane surface and reduce fouling compared to stationary membrane filtration [10] and successfully increases both the permeate flux [11] and the membrane selectivity [12]. The high shear stress created is independent of the feed flow velocity [13] and thus enables various types of fluids to be treated using dynamic membranes [14]. An additional shear wave which is able to lift the solid and the foulants from the membrane surface is also formed in vibratory shear enhanced process (VSEP) vibrating membranes [15].

Some studies have revealed that the permeate flux obtained from a rotating disk equipped with vanes is higher than the VSEP [16,17] because of the very high shear stress, which reduced the CP to much lower levels. Moulai-Mostefa et al. have found out that the permeate flux decreases with time but that there is no fouling limitation in rotating disks with vanes. It has also been shown that disks with vanes can further increase the permeate flux compared with a smooth disk with the same disk angular velocity, ω, because of the increase in the fluid core velocity, k, which causes a higher shear stress [18] because wall shear stress is proportional to $(k\omega)^{1.8}$ [19]. Sen et al. has found out that the vanes with different arrangements and geometries used as turbulence promoters can be optimized to obtain moderate permeate flux and low energy consumptions [20]. However, the central part of the rotating disk filtration system has a lower permeate flux compared with the periphery, but this is only significant at rotation speeds higher than 1500 rpm. The peripheral pressure is raised during filtration because of the increase in the fluid density and the viscosity [21]. The power consumption in rotating disk filtration increases with rotation speed, but the specific energy per cubic meter of permeate decreases because of the

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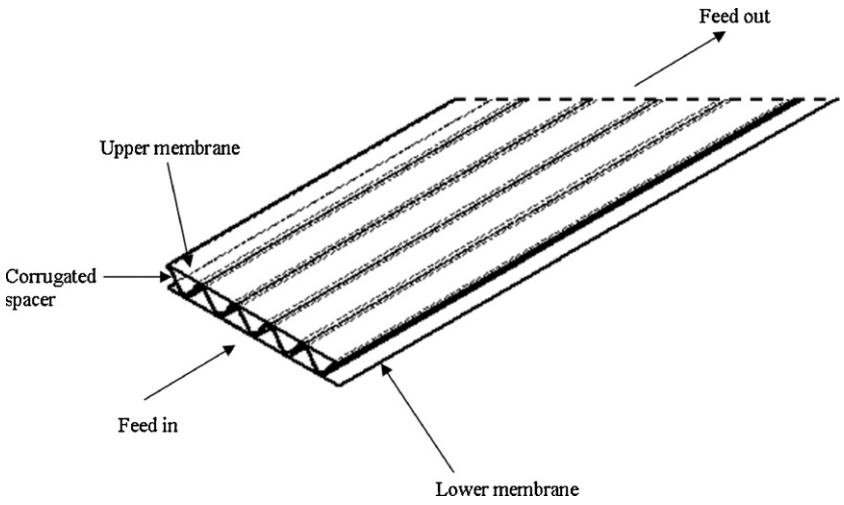

Fig. 1. Corrugated spacer membrane channel.

large increase in the permeate flux when the disk is equipped with vanes [19,22].

Dynamic membrane reduce the operating cost as the specific energy per cubic meter of permeate decreases [23,24] but the use of dynamic membranes in industrial applications is limited because of the complexity of the system and the limited membrane area [25]. Besides that, the VSEP also cannot be operated at its resonance frequency for long periods because of the risk of premature wear and membrane displacement [26]. This limits the VSEP from being operated at its optimum performance settings.

In this paper, the concept of a dynamic membrane has been integrated into the SWM module so that the CP problem can be solved. This paper investigates the effect of a reciprocating corrugated spacer channel on the membrane wall shear stress by using a corrugated spacer with membranes on top and bottom, as shown in Fig. 1.

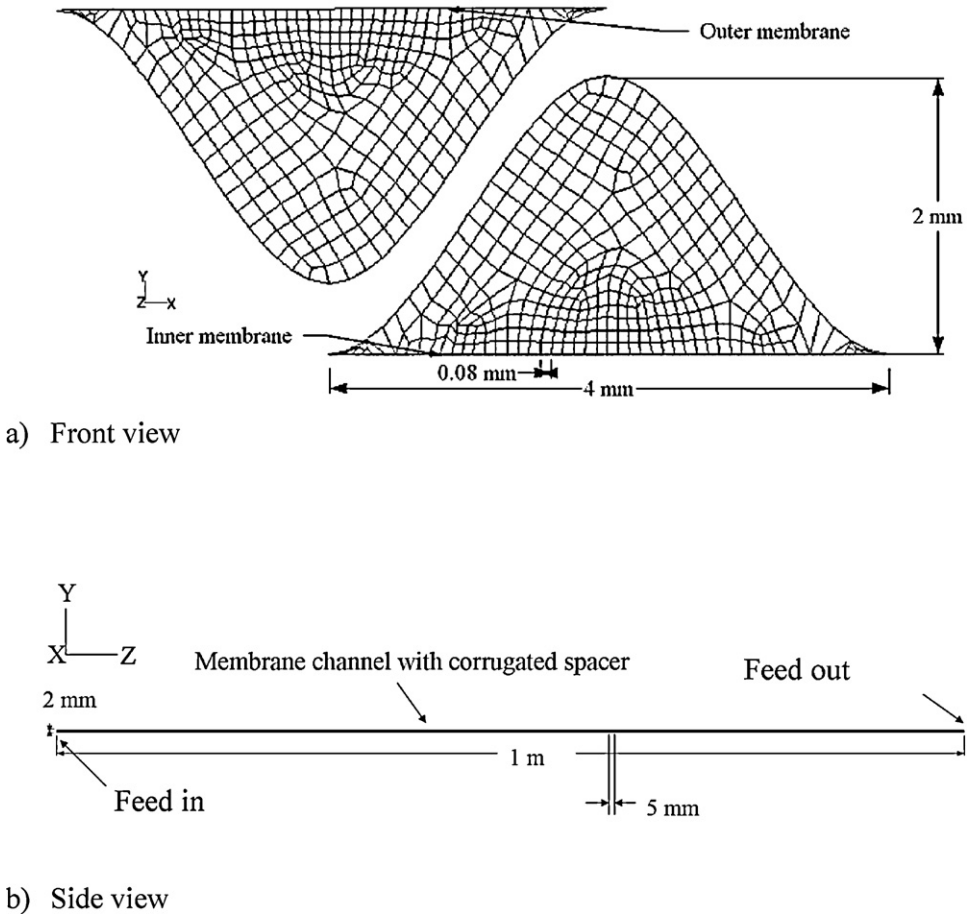

Fig. 2. Mesh of the small channel in the spacer.