Effect of Biofluid Viscosity on the Fluid Flow and Mass Transfer Through Permeable Membrane of Microchannel

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Abstract. Hemodialysis is an artificial kidney replacement therapy that aims to control blood pressure and balance important minerals, such as potassium, sodium, and calcium, in the blood. The osmotic and ultrafiltration processes in the hemodialyzer were affected by the blood viscosity flowed through the permeable membrane of microchannels. In this simulation study the dialyzer was modelled as a microchannel formed by two parallel permeable membrane with pore size of 3 μm and 10 μm of membrane thickness. The distance of the two parallel membrane was 20 μm. The biofluid with viscosity of $4{,}0 \times 10^{-3}$ pa.s; $4{,}5 \times 10^{-3}$ pa.s; and $5{,}0 \times 10^{-3}$ pa.s was then flowed through the microchannel at the flow rate of 10 ml/s. Below the membrane there was counter flow dialisate at flow rate of 20 mm/s. The result showed that the higher the viscosity, the lower the biofluid velocity flowed through the membrane pore. For the above variations, the fluid flow in the pore were found of 0.00013748 m/s; 0.00010341 m/s and 0.00009766 m/s, each. The corresponding pressure on the membrane surface were 4995.964 Pa; 4994.142 Pa; and 4995.890 Pa, each. While the pressure in the pore were a bit higher of 5098.484 Pa; 5084.181 Pa; and 5057.133 Pa, each.

Keywords: viscosity · flow · microchannel · permeable · membrane

1 Introduction

Recently, chronic kidney disease (CKD) has become one of the top health problems in many countries, including Indonesia. In 2018 the total CKD cases are reported up to 150000 patients [1]. The cost for each hemodilayzed therapy per persons at around Rp. 1.000,000.-, and must be done 8 times monthly as an ideal therapy. The cost of CKD medication that must be paid by government is the second of the highest after heart therapy. One of the factor that has significant contribution on the high cost of CKD medication is the expensive price of the hemodialyzer, as well as the expensive

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of its maintenance and operational cost. Such condition causes many patients cannot be covered by the hemodialysis therapy service.

The flow from within the permeable membrane is largely determined by the viscosity of the blood of patients who are undergoing hemodialysis therapy [2]. Viscosity of one's own blood varies greatly depending on many things including age, patient lifestyle, the patient's health, and so on. Therefore, studies are needed for studying the effect of viscosity on flow patterns and time transfer across permeable membrane. In relation to previous condition, a simulation study of the effect of viscosity will be carried out fluid to the flow pattern and mass transfer in the permeable membrane. Simulation performed using autodesk computational fluid dynamics (CFD) software.

2 Methods

2.1 Governing Equation

The general mathematical statements of fluid flow are the conservation equations: mass, momentum and energy. Since biofluid in the microchannel segments is adiabatic, the energy equation can be ignored, leaving the continuity and momentum equations as the governing relations for flows of interest in the present study. The Navier–Stokes equations were solved over the domain using a finite volume method with the code developed in commercial CFD software. The equations were applied with constant viscosity and density, without body force, while the blood is assumed as incompressible and steady flow.

The diffusion parameter was determined using the equation:

$$D = \frac{Q_{Bi}(C_{Bi} - C_{Bo})}{(C_{Bi} - C_{Do})} \tag{1}$$

where:

D = Diffusion (ml/minute)
C_{Bi} = Concentration of inlet biofluid
C_{Bo} = Concentration of outlet biofluid
C_{Do} = Concentration of outlet dialysate

2.2 CFD Model

The model developed based on the experiment using infusion biofluid that flowed in the parallel plate flow chamber. Permeable membrane with pore size of 3 μm with dimension of 4 mm x 10 mm was placed on the bottom edge of the parallel plate flow chamber. Infussion fluid was then flowed at the rate of 10; 20; 30 and 40 ml/second. While the dialysate was flowed at the double rate. In the simulation, the number of pore was limited to 100 hole. The hole was distributed uniformly in the area of 4 mm x 100 above. The biofluid used was infusion fluid that usually given to patient (Figs. 1 and 2).

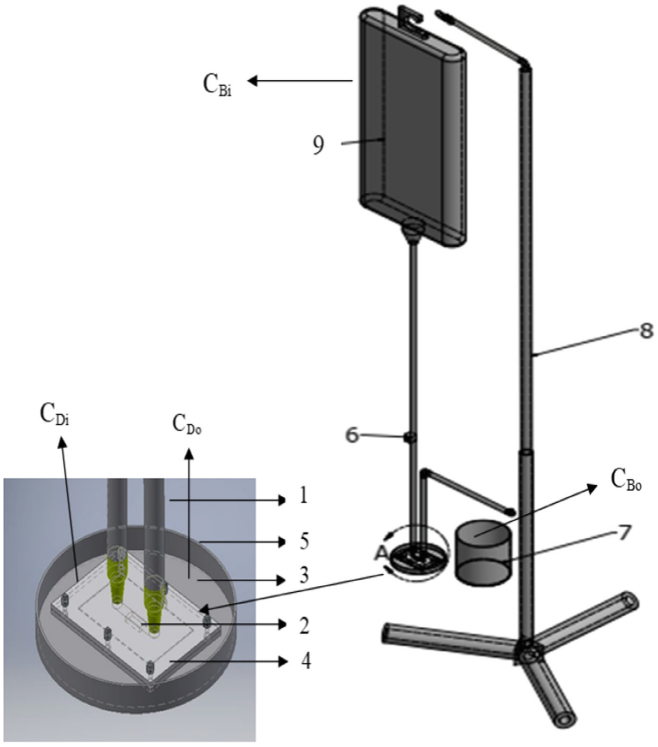
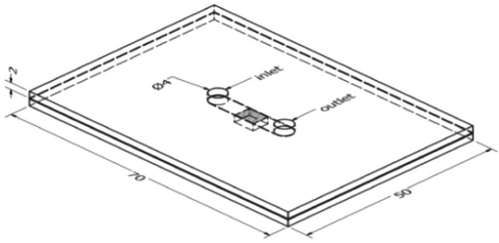


Fig. 1. Experimental setup.



Physycal value for the model.

Membrane thickness		= 10 micrometer
Pore diameter		= 3 micrometer
Membrane dimension		= 4 mm x 10 mm
Number of pores		= 100
infusion fluid	ρ	= 1050 kg/m³
	μ	= 1,066 m²/s
	ν	= 0,0010028 m²/s
Dimension of PPFC		= 50 mm x 70 mm

Fig. 2. Test section.

3 Result and Discussion

3.1 Velocity Profile of the Biofluid on the Membrane Surface

Mass transfer through the permeable membrane is highly affected by the velocity of the biofluid flowing through the microchannel. Figure 3 showed the velocity contour of the biofluid. While Fig. 4 showed the biofluid route in the microchannel of the parallel plate flow chamber.

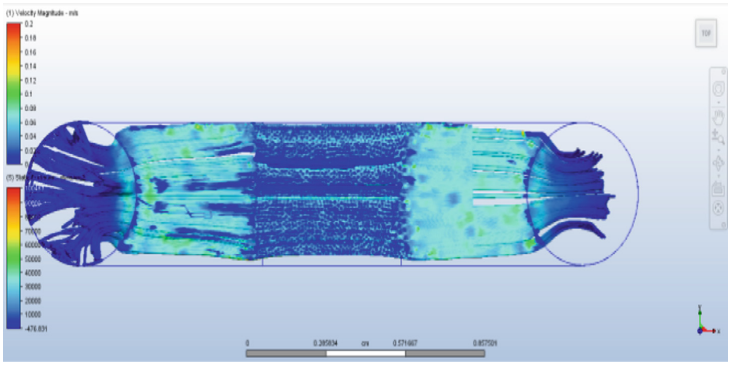


Fig. 3. Velocity contour on the membrane surface.

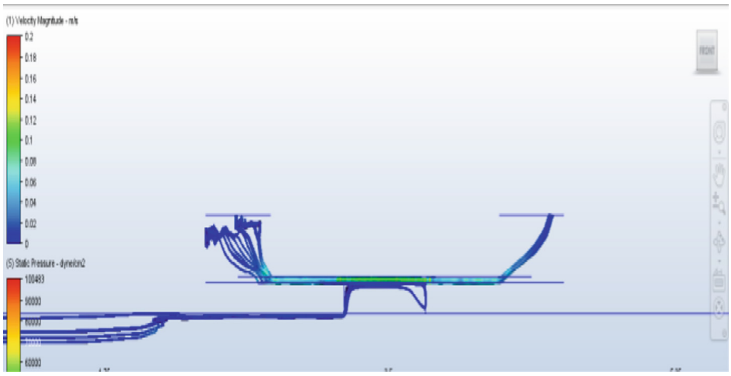


Fig. 4. Counter flow route of the biofluid in the microchannel.

The velocity in the inlet region is slower and become faster in the area before the membrane due to the smaller cross area between the upper and lower plate of the parallel plate flow channel. In the next route, the biofluid flow slower again in the permeabale membrane region. The slower velocity in the membrane region occurs due to the leakage of some biofluid to the lower compartement as shown in Fig. 4.

The velocity profile across the microchannel was shown in Fig. 5. The profile shows lower velocity in the beginning of the microchannel, rises slightly to the center, and reduced slightly again until reaching the last region of the membrane. The velocity profile is the same for the four various fluid capacity.

3.2 Velocity Profile in the Membrane Pore

The pore observed in this research has diameter of 3 μm. While the thickness of the membrane was 10 μm. When flowed in the permeable membrane, some of the biofluid leaks to the lower compartement through the pore with velocity of 0.06 m/s up to 0.085 m/s, as shown in Fig. 6. Those velocities are about 4 times higher than the velocity of the biofluid flowed on the membrane surface.

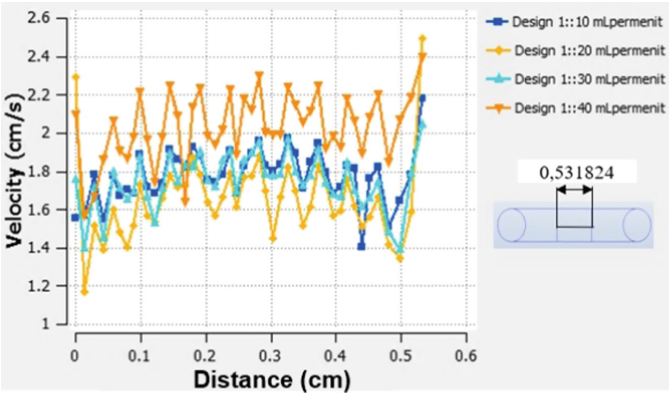


Fig. 5. Velocity profile of the biofluid flow on the membrane surface.

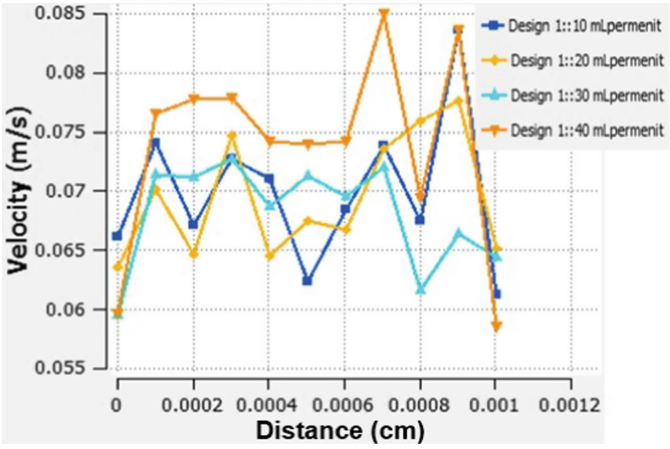


Fig. 6. Velocity of the biofluid flow in the pore.

The velocity contour as shown in Fig. 6 and Fig. 7 indicated that the highest velocity occurs at the center diameter of the pore. The figure shows that the velocity is lower at the beginning of the pore, rise slightly up to 80% of the channel, and reduce again until,the end of the channel. This results matches well with the published dengue infection work [4].

3.3 Pressure Distribution in the Membrane Pore

As shown in Fig. 8, the pressure of the biofluid reduced deeply when flowing in the microchannel permeable membrane. Such profile is identic for the four fluid capacity observed in the recent work. This finding occurs due to the combination of relatively high viscosity of the biofluid, as well as the narrow cross section of the microchannel.

The observation of the pressure in the pore also resulted the same profile to the pressure distribution on the membrane surface. But the range of the pressure in the pore

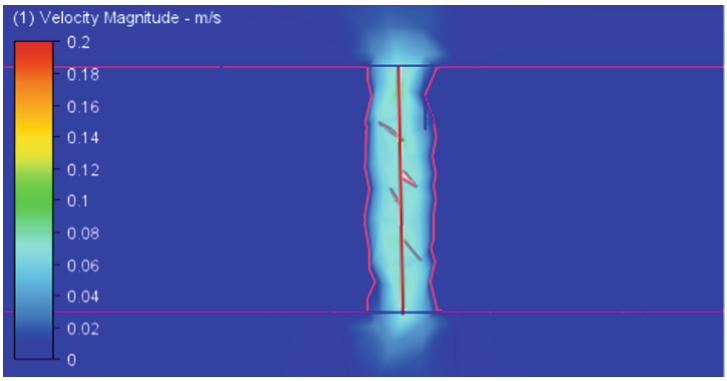


Fig. 7. Velocity contour of the biofluid flow.

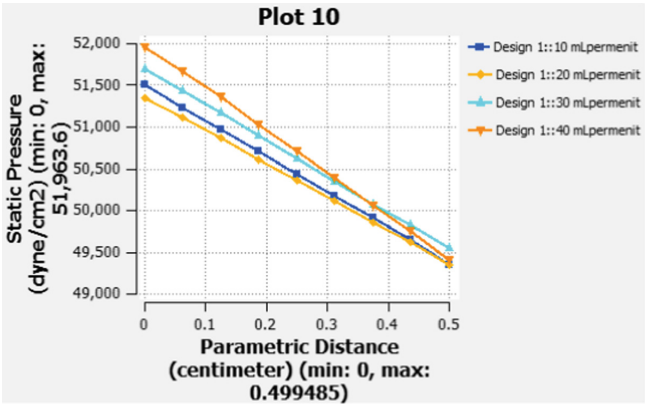


Fig. 8. Pressure distribution in the pore.

only 1000 Pa to 5000 Pa, compare to 49500 to 52000 Pa, observed on the membrane surface. It is means that the pressure in the pore only about 2,5% of the pressure in the membrane surface.

4 Conclusion

1. The higher the velocity of the biofluid, the higher the mass transfer and shear stress occurred on the hemodialysis process.
2. The pressure on the membrane surface is higher than the pressure in the pore of the membrane.
3. The higher the dialisate flow, the higher the mass transfer occurs.

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