GSJ: Volume 10, Issue 6, June 2022, Online: ISSN 2320-9186
www.globalscientificjournal.com

EFFECT OF PORE DIAMETER OF PERMEABLE MEMBRANE ON THE BIOFLUID FLOW IN MICROCHANNEL

Nur Kaliwantoro1), IGNK Yudhayadi2), Rudy Sutanto3) , Sujita4)

1,2, 3, 4 Department of Mechanical Engineering, Faculty of Engineering, Mataram University, Mataram, Indonesia.
E-mail: nurkaliwantoro@unram.ac.id

KeyWords
CFD Simulation, pore size, biofluid, microchannel, permeable membrane.

ABSTRACT

Hemodialysis is an artificial kidney replacement therapy that aims to get rid of the remnants of metabolic products and correct the disruption of fluid and electrolyte balance between blood compartment and dialysate fluid. Permeable membranes in the dialyzer which acts as an artificial kidney through the diffusion process. The performance of a hemodialyzer is largely determined by the mass transfer in the dializer unit. The mass transfer itself is strongly influenced by permeable membrane pores. Research on the influence of membrane pores on relative mass transfer is still limited. For this reason, a simulation was conducted to vary the influence of membrane pore diameter with sizes of 0.4 µm, 1 µm and 3 µm and varying inlet pressures of 80 mmHg, 100 mmHg, and 120 mmHg. The simulation was carried out aiming to determine the mass transfer, shear stress, Reynold's number, and pressure drop using infusion fluid with a flow rate of 40 ml / min.

The results showed that greater the pore diameter and membrane entry pressure will cause the greater mass transfer that occurs. In testing with NaCl, the highest diffusion coefficient was obtained at a pore of 3 µm with an inlet pressure of 120 mmHg of 2.7 x 10-7 m^3 / s, and the smallest diffusion coefficient at a pore of 0.4 µm with an inlet pressure of 80 mmHg of 4.4 x 10-8 m^3 / s. For the shear stress characteristics found that the greater the pore and the inlet pressure, the greater the shear stress. In the test of pressure characteristics, it was found that the greater the pore and inlet pressure, the decrease in pressure passing through the membrane will be greaterIn the test of the flow characteristics, it was found that the larger the pore, the greater Reynold's number.

The first page should be used only for Title/ Keyword/ Abstract section. The main paper will start from second page.

INTRODUCTION

Hemodialysis is the process of cleansing the blood by the accumulation of waste of waste. Hemodialysis is used for patients with late stages of renal failure or acutely diseased patients who need a short time dialysis [1]. In haemodialysis, there is a process of removing metabolic waste substances such as ureum and other toxic substances, by flowing blood through a dializer containing a selective-permeable membrane. The performance of hemodialyzer is highly determined by the mass transfer in the dialyzer. Some significant parameters of the mass transfer in the dialyzer are fluids velocity, pressure of the blood and dialysate and pore size of the membrane.[2; 3; 4]. Besides that mass transfer also affected by the diameter of the membrane pore as found in the experimental study of dengue virus-infected vero cell line by Kaliwantoro [5]. Although study of the fluid velocity has been held by many researchers, but many aspects have not been explored yet.

METHOD

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:

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

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

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 micrometer 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. In this work, membrane was represented by numbers of rectangular. The presence of the gap reflects "the pore" of the membrane which allows the fluid enters it and finally falls to the bottom surface.

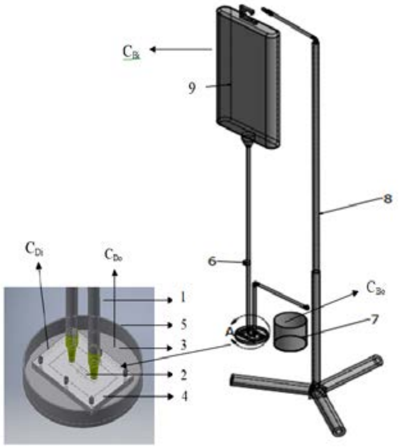
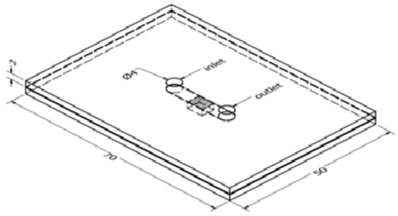


Figure 1. Experimental setup referred by simulation



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

Figure 2. Model of parallel flow chamber

RESULTS AND DISCUSSION

FLOW CHARACTERISTIC ON THE SURFACE OF THE MEMBRANE

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

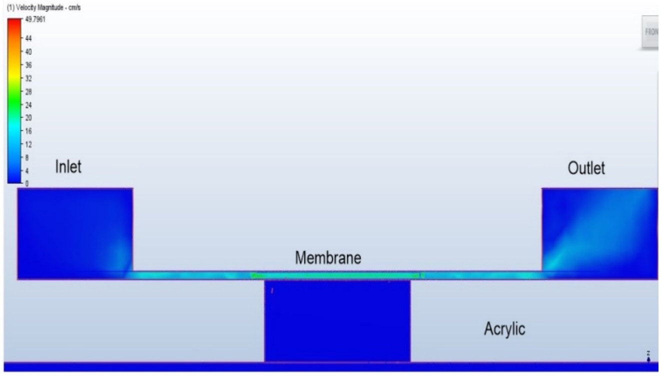


Figure 3. Side view of velocity profile

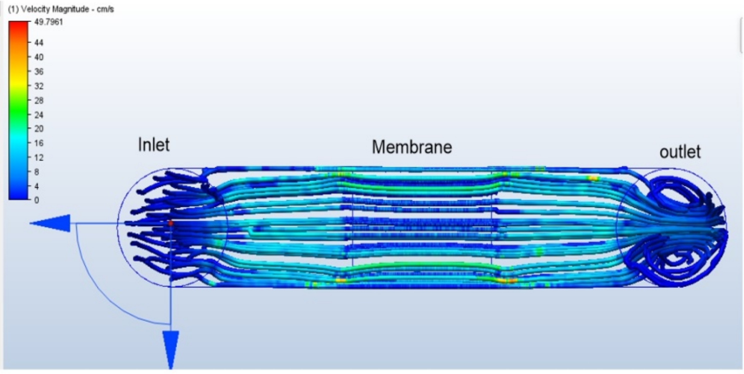


Figure 4. Top view of velocity profile.

Figure 3 presents the side view of velocity profile from the inlet, membrane test section and the outlet side. It can be seen that there is an increase in the biofluid velocity from the inlet side to the area near the pore which is marked by dark blue to light blue. This happens because the cross-sectional area of the parallel plate is smaller than the cross-sectional area of the inlet and outlet. When the biofluid passes through the pores, its speed decreases, which is indicated by a dark blue color change. This happens because of a change in the direction of flow where some of the fluid moves towards the pores and the rest moves over the membrane. Then after passing through the pores, the velocity of the biofluid increases again because there is no change in flow and the fluid flows more smoothly because there are no more pores.

From the figure 4 that shows the top view of the velocity profile, it is also showed that the fluid velocity decreases as it flow toward the membrane region and rise again as it left the membrane region. Some yellowish color at the both sides of the membrane region indicates the higher velocity than the fluid flow inside the membrane region. Again, its is occurs due to some fluid turn its flow into the pore track on the membrane.

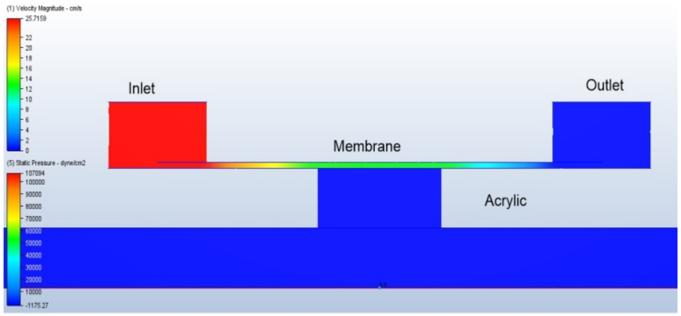


Figure 5. Pressure distribution on the test section

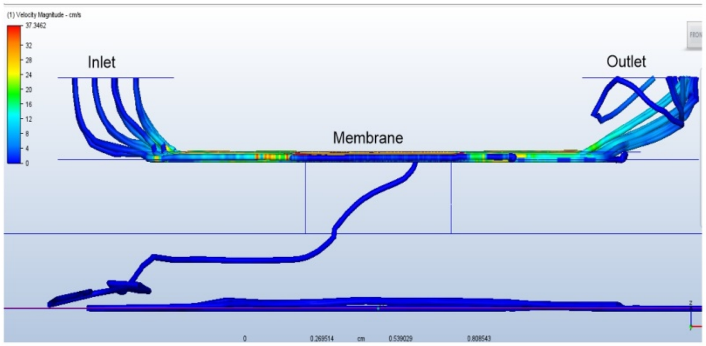


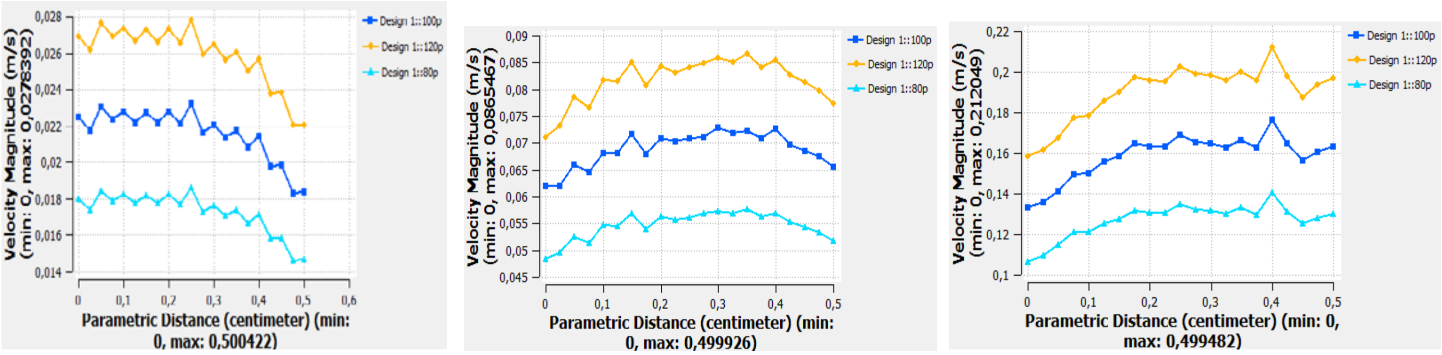
Figure 6. Path of fluid across the membrane

Based on Figure 5 it can be seen that the difference in fluid pressure between the inlet, membrane region and outlet. The red color in the entering zone indicated high fluid pressure. The fluid pressure then decrease gradually toward the outlet region. It is aslo showed that a significant difference between the fluid on the upper side and downside of the membrane. Such pressure difference that govern the fluid to move across the pore of the permeable membrane.

Path of the fluid particle across the pore membrane is shown by Figure 6. The diagonal track occurs due to the counter fluid flow between the upperside and downside of the permeable membrane. The same dark blue color in the membrane region and downside reservoir indicated the low velocity profile on those region.

EFFECT OF THE PORE DIAMETER ON THE FLUID VELOCITY

Diameter has very significant role in affecting the fluid flow on the permeable membrane. Comparison of velocity magnitude between membranes that have pore size of 0.4 µm, 1 µm and 3 µm are shown in Figure 7 belows



Pore size 0.4 µm, Pore size 1 µm Pore size 3 µm

Figure 7. Comparison of velocity magnitude on the membrane surface

Based on Figure 7 shows that the speed of the biofluid flowing on the surface of the membrane is fluctuative due to the presence of a pore. Those pores cause some of the biofluid change its direction, flows into the pore microchannel, while the rest flows over the membrane. Such phenomenon then distort the velocity profile as shown in the above pictures. In this study it is found that the maximum fluid velocity flow that passes over the membrane with a pore size of 0.4 µm, 1 µm and 3 µm are 0.0302 m/s; 0.0725 m/s and 0.1352 m/s , each at a pressure of 120 mmHg. It is also found that the higher the pressure the higher the velocity of the fluid flowing over the permeable membrane. In the calculation, it is also found that the highest diffusion coefficient was obtained at a pore of 3 µm with an inlet pressure of 120 mmHg of 2.7 x 10-7 m^3 / s, and the smallest diffusion coefficient at a pore of 0.4 µm with an inlet pressure of 80 mmHg of 4.4 x 10-8 m^3 / s.

Conclusion

In this study it is found that the velocity profile of fluid flow over porous permeable membrane is highly affected by the pore size. The bigger the pore diameter the higher velocity magnitude. Bigger pore diameter also causes the higher diffusion coefficient. Pressure has linear trend with the fluid velocity over the surface of the membrane.

Acknowledgment

The authors wish to thank Indra Gunawan that has helped for completing this research study.

References

[1] Ronco, C, Ghezzi, P.M., Brendolan, A, Crepaldi, C, La Greca, G, “The haemodialysis system: basic mechanisms of water and solute transport in extracorporeal renal replacement therapies”, Nephrol Dial Transplant 13 [Suppl 6]1998: 3–9
[2] Uhlenbusch-Körwer, E. Bonnie-Schorn, A. Grassmann, J. Vienken, Understanding Membranes and Dialysers
[3] Kerr, PG, Review: Membranes for haemodialysis, Nephrolog vol 15, 2010
[4] Nur Kaliwantoro, Marsetyawan HNES, Indarto, Mohammad Juffrie, Rini Dharmastiti, CFD Simulation of Plasma Leakage and Fluid Flow on Dengue Virus Infected - Endothelial Cells, ARPN Journal of Engineering and Applied Science, Vol 11 No. 2, 2016
[5] Eloot S., Experiment and Numerical Modelling of Dialysis, PhD Disssertation, Ghent University, 2004

[1] https://www.republika.co.id/berita/gaya-hidup/info-sehat/18/05/06/p8ap02399 jumlah pasien-penyakit-ginjal-kronis-terus-meningkat
[2] Ronco, C, Ghezzi, P.M., Brendolan, A, Crepaldi, C, La Greca, G, “The haemodialysis system: basic mechanisms of water and solute transport in extracorporeal renal replacement therapies”, Nephrol Dial Transplant 13 [Suppl 6]1998: 3–9
[3] Uhlenbusch-Körwer, E. Bonnie-Schorn, A. Grassmann, J. Vienken, Understanding Membranes and Dialysers, 2004
[4] Kerr, PG, Review: Membranes for haemodialysis, Nephrolog vol 15, 2010
[5] Nur Kaliwantoro, Marsetyawan HNES, Indarto, Mohammad Juffrie, Rini Dharmastiti, CFD Simulation of Plasma Leakage and Fluid Flow on Dengue Virus Infected - Endothelial Cells, ARPN Journal of Engineering and Applied Science, Vol 11 No. 2, 2016
[6] Eloot S., Experiment and Numerical Modelling of Dialysis, PhD Disssertation, Ghent