SIMULATION MODEL OF FLUID FLOW AND TEMPERATURE DISTRIBUTION IN POROUS MEDIA USING CYLINDRICAL, CONVERGENT AND DIVERGENT NOZZLES

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ABSTRACT: Simulation of heat transfer in porous media is performed to determine the model of fluid flow and temperature distribution in the test section using the cylindrical, convergent and divergent nozzles. The purpose of this simulation is to determine the effect of fluid velocity to the distribution of temperature in a porous medium using a variation of the nozzle. The simulation used the fluid velocity of 1.5 m/s with the incoming fluid temperature of 30^0C, a temperature of lower plate as a heat sink is kept constant at 10^0C. The material of porous media is the oil palm shell charcoal, which the porosity of 30%, the thermal conductivity of 6:21 W/ mK, and the density of 0.75593 g/cm^3. The result shows that the cylindrical, convergent and divergent nozzles are able to distribute the fluid flow and temperature in porous media. The highest heat flux of 124.2 W/m^2 is obtained when the convergent nozzle is used. While the highest value of Reynolds number of 754.4797 is obtained when divergent nozzle is used.

Keywords: Heat transfer, porous media and nozzle

1. Introduction

Recently the porous media from oil palm shell charcoal has not been yet widely used as the temperature distribution medium (Sembiring and Sinaga, 2003). This natural material has been used as a substitute for silica gel and glass bead (Siswanto, 2012), and moisture absorbent. The oil palm shell charcoal is one of the natural ingredients that is expected to be an alternative moisture absorbent. The benefits of using the material are: it is widely available in Indonesia and easy to recycle (Budi, 2011; Department of Industry, 1983; Maryono, Sudding, and Rahmawati, 2013; Pramono, 2010). Therefore it is necessary to study a simulation model of fluid flow and temperature distribution in the oil palm shell charcoal using cylindrical, convergent and divergent nozzles. Using the model, we could assess the equalization flow and the heat transfer to know the quality of absorption. The purpose of this study is to determine the model of fluid flow and temperature distribution in porous media using cylindrical, convergent and divergent nozzles. In this study we examine the use of cylindrical, convergent and divergent nozzles to determine the fluid equalization and the temperature distribution in porous media within the test section and flow rate into the same nozzle so that the differences in flow velocity in three nozzles are known. By observing the difference of flow velocity, the laminar and turbulent flows could be examined. The results of this study are expected to be used to provide a better understanding of porous media from oil palm shell charcoal for widespread application.

2. Literature Review

The heat transfer treated in this simulation is the heat transfer caused by convection and conduction. The heat transfer by conduction is the heat transfer process in which the heat flows from regions of high temperature to the low temperature in a medium either solid, liquid or gas, or between different media that intersect directly. If there is a temperature gradient on a body, there will be a transfer of energy from the high temperature to the low temperature. It can be said that the energy moves by conduction and the heat transfer rate (Q_d) is proportional to the normal temperature and expressed as [3]

$$Qd = -k \times A \times (T_1 - T_2) / \Delta x \quad (1)$$

where k is the thermal conductivity factor, A is the surface area; (T_1-T_2) is the change in temperature and Δx is the thickness of the material (Zenitha, Siswanto, Choiron, 2013).

Convection heat transfer is the process of energy transfer between a solid surface and a liquid or gas fluid flow that intersect. The heat transfer rate by convection (Qc) is expressed as

$$Qc = -h \times A \times (T_s - T_\infty) \quad (2)$$

where h is he heat transfer coefficient, A is the surface area, T_s is the solid surface temperature, T_∞ is the fluid temperature.

The heat transfer by conduction and convection is improved by increasing the surface area of heat transfer. Relating to the addition of the outside surface, a new model with similar functions could be developed to increase the heat transfer in porous media from the palm shell charcoal. The porous media from oil palm shell charcoal have holes scattered, thus creating the cavities that can be bypassed by the fluid. Using the cavity in porous media can enlarge the surface area of greater heat transfer and flow distribution in porous media can be considered equitable. The oil palm shell charcoal has a porosity of 30%, so that cavities can be traversed by the fluid and able to perform the heat transfer evenly.

The experimental research on laminar condensation in porous media to determine the treatment effect of ambient temperature on the flow dynamic lateral migration of condensate in porous media with different humidity already been done before (Siswanto, Hiroshi, Katoh, 2011).

In the laminar flow, fluid particles move along the track is smooth and smooth in layers with a sliding layer on adjacent layers. In this flow, the shear stress is proportional to the rate of change of viscosity and fluid motion angular shape. The laminar flow viscosity reduces turbulent but is not stable when it comes to a combination of low viscosity or high speed.

In the turbulent flow, fluid particles move in the irregular trajectories, resulting in the exchange of momentum from one part to another part of the fluid in a manner similar to the transfer of molecular momentum. To determine the type or characteristics of the fluid flow, the Reynolds number is used, which depends on the speed, flow geometry, surface roughness, nozzles used and the position of the inlet fluid flow into the nozzle. The turbulent flow Reynolds number is greater than the critical Reynolds number, while the flow has a Reynolds number laminar smaller than the Reynolds number (Merle, David, 2008).

3. Methodology

This research conducted the quasi-experimental or simulation using ANSYS 14.5 software. The installation of test section of porous media used in this study is shown in Figure 1, where the dimensions are the length of 200 mm, the width of 50 mm, and the height of 50 mm. The porous media filled the volume of 200 mm x 250 mm x 250 mm on the bottom arrangement, while the upper volume is drained by the fluid. The test section model and porous media are developed, and then perform meshing on the model that has been developed to define the boundary conditions where the determination of the parameters and restrictions that may occur in the simulation.

Figure 2 depicts the boundary condition of the inlet, i.e. the inlet velocity using the cylindrical, convergent and divergent nozzles. The processing stage is a stage for running to get the results that will be analyzed. Before the stage, it has to fill some parameters such as speed of 1.5 m / s with the incoming fluid temperature of 30^0C and the bottom plate temperature as a heat sink and the threshold temperature is kept constant at 10^0C. The material used in this simulation is the porous media where the data is taken from oil palm shell charcoal having the porosity of 30%, the thermal conductivity of 6.21W /m.K with the density of 0.75593 g / cm^3.

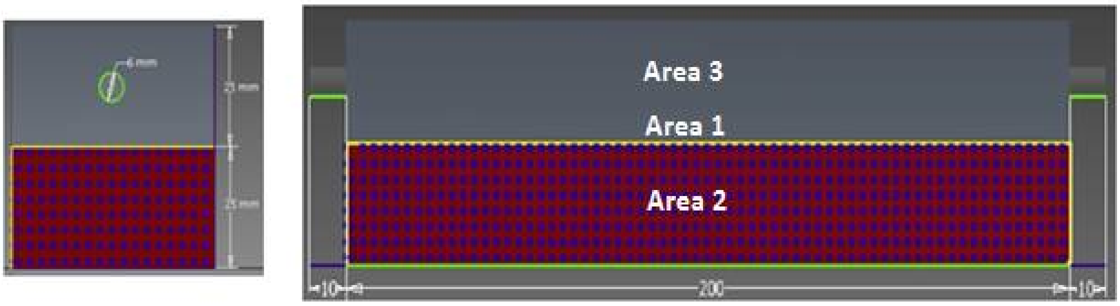

Figure 1 Test section

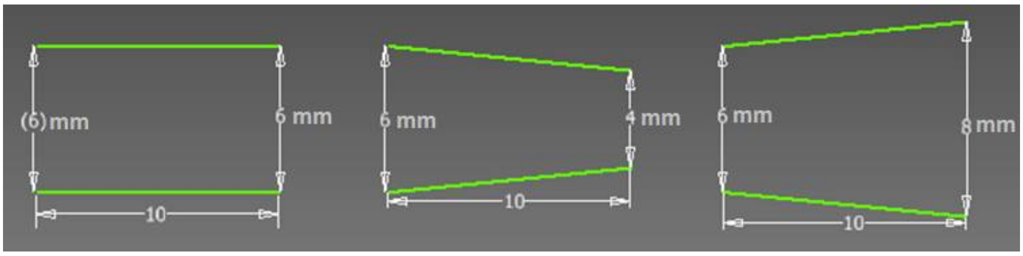

Figure 2 The cylindrical, convergent and divergent nozzles

4. Results and Discussion

4.1 Temperature Distribution

The visualization of temperature distribution in the space contour of test section is divided into three areas: area-1, area-2, and area-3 with a distance of 0-200 mm from the influx of fluid through the fluid discharge, where the location of area-1 is on the whole surface of the porous media, area-2 is located inside the porous media, and area-3 is located above the porous media which aligned with the nozzle, at the entry point of the fluid. The visualizations of temperature distribution for the cylindrical, convergent and divergent nozzles are shown in Figure 3, 4, and 5 respectively.

The figures show that the temperature distribution in each area forms the diverse contours. The temperature of the parts which is far away from the nozzle is lower than the one closer to the nozzle. This phenomenon is caused by the heat transfer between fluid and porous media in the test section. The visualization of temperature distribution shows that there is a color gradation forms a valley in the porous media on a distance far away from the nozzle. The color gradation from yellow to green show that in the porous media, the temperature decreases along the increasing of distance in the test section. It also occurs in the fluid, i.e. the temperature decreases along the fluid flows.

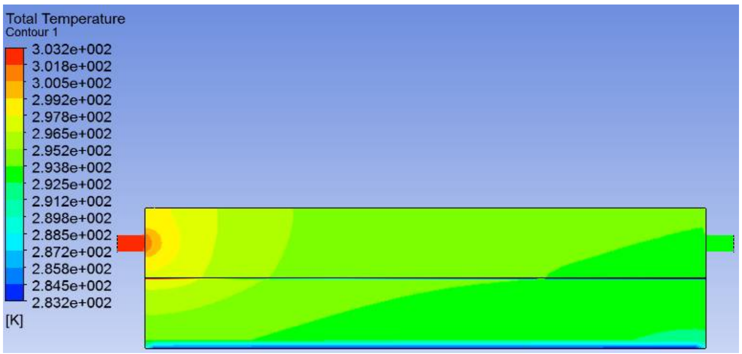

Figure 3 Visualization of temperature distribution using cylindrical nozzle

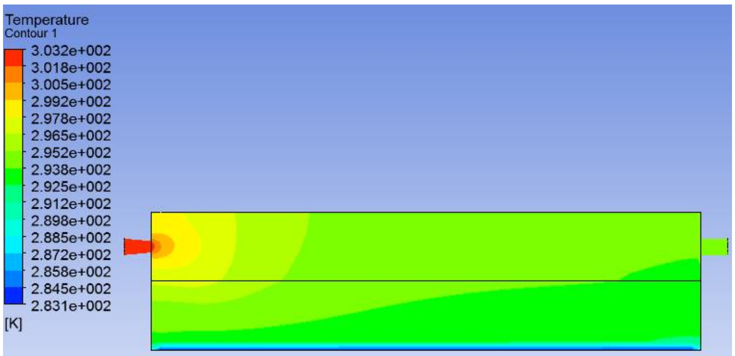

Figure 4 Visualization of temperature distribution using convergent nozzle

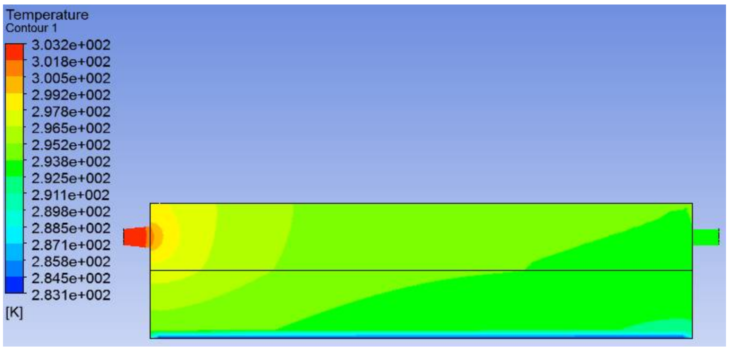

Figure 5 Visualization of temperature distribution using divergent nozzle

4.2 Fluid Flow

The visualizations of fluid flow cylindrical, convergent and divergent nozzles are depicted in Figure 6, 7, and 8 respectively. The figures show that the flows do not grow fully from the fluid inlet into the nozzle. It is caused by the vortex at the inlet in every nozzle. The vortex does not occur in the divergent nozzle due to the different shape of the nozzle. The vortex in the porous media shows that the fluid velocity in the porous media is higher than the one in the area above the porous media.

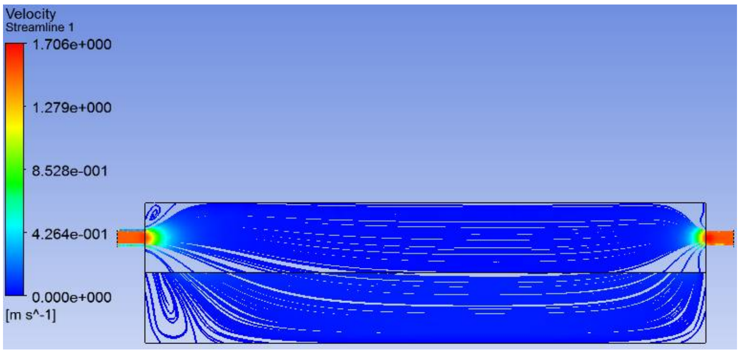

Figure 6 Visualization of fluid flow using cylindrical nozzle

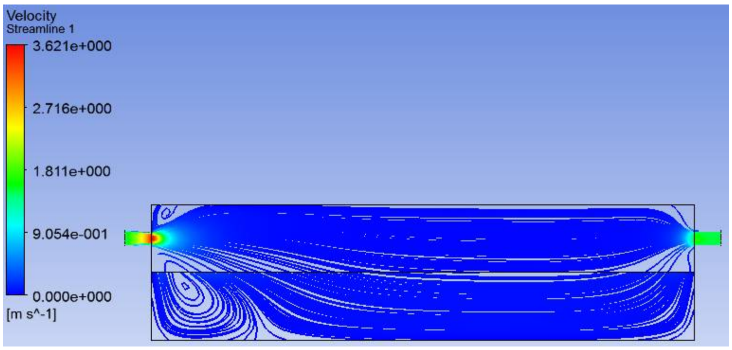

Figure 7 Visualization of fluid flow using convergent nozzle

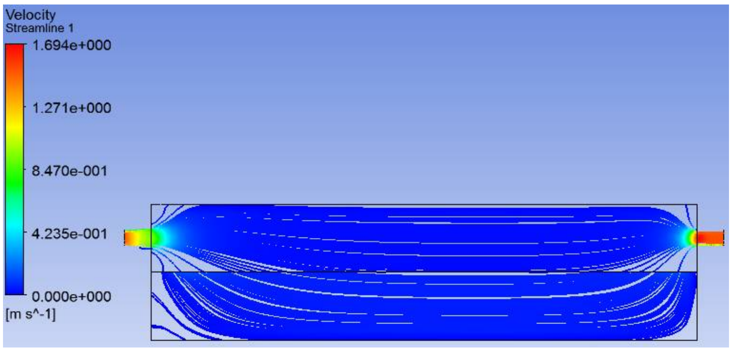

Figure 8 Visualization of fluid flow using divergent nozzle

4.3 Temperature Distribution of Each Area

The temperature distributions of area-1, area-2, and area-3 are depicted in Figure 9, 10, and 11 respectively. In the figure, X_t is the length of a point, while X_{max} is the total length. The figures show that the temperature distribution decreases when the measurement is taken at the point far away from the nozzle. The decrement of temperature is caused by the heat transfer in the porous media and the shape of nozzle. From Figure 11, it is obtained that at the last point, the fluid temperatures are almost the same for three nozzles. This result shows that the heat is transferred in the porous media effectively, as indicated by the decreasing of temperature.

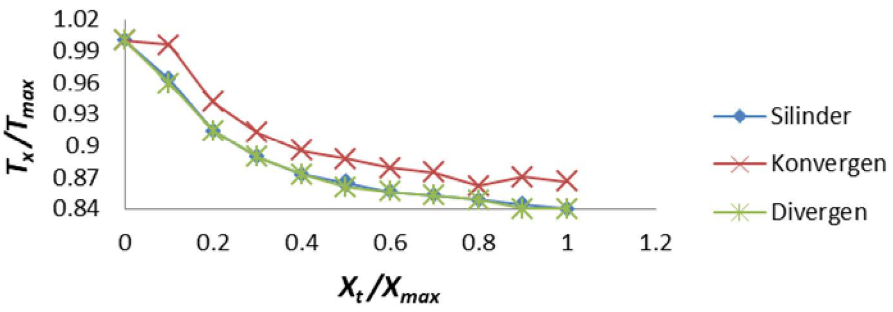

Figure 9 Temperature distribution in area-1

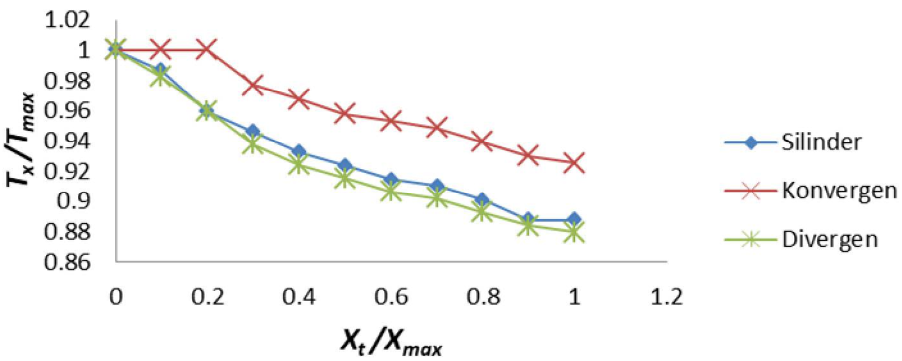

Figure 10 Temperature distribution in area-2

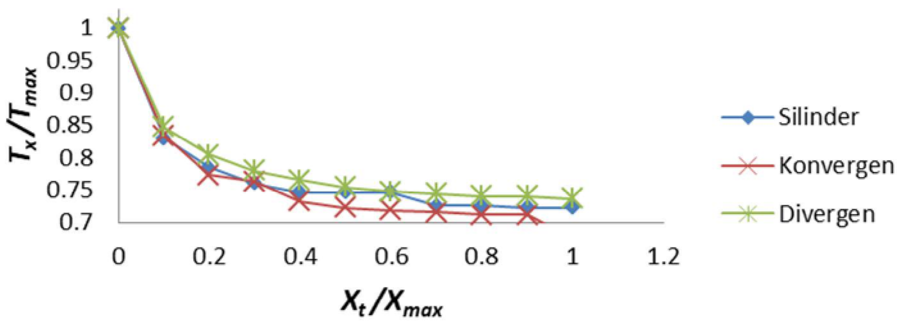

Figure 11 Temperature distribution in area-3

4.4 Reynolds Number

Figure 12, 13 and 14 show the relationship between the Reynolds number and the area of test section using the cylindrical, convergent and divergent nozzles respectively. For all area-1, area-2 and area-3, the Reynolds number increases when the area of test section increases. The figures show that the Reynolds number in area-2 is greater than the one in area-1 and area-3. It is caused by the fact that area-2 is located in the surface of porous media so that the friction factor increases due to the different media. The high friction factor on the divergent nozzle causes the high Reynolds number, i.e. 754.4797 that is below the critical value, so that the flow is the laminar flow.

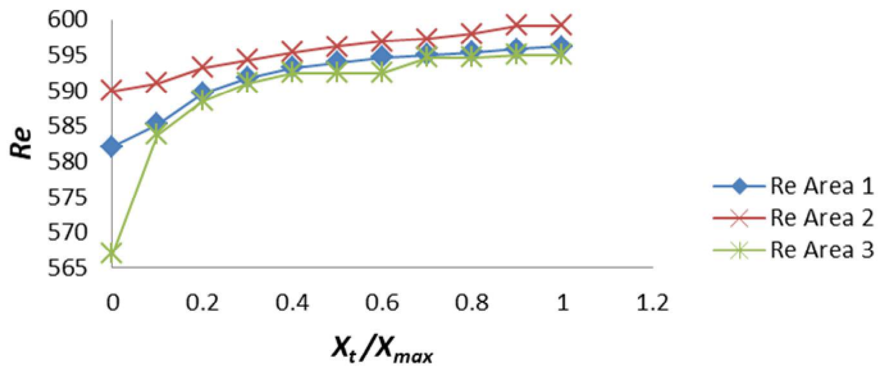

Figure 12 Reynolds number with cylindrical nozzle

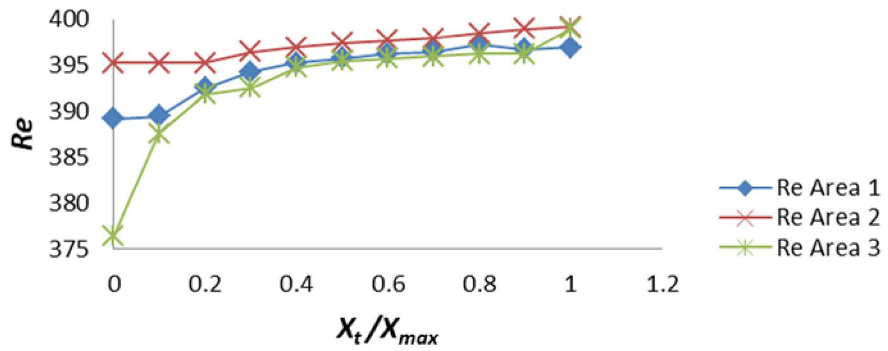

Figure 13 Reynolds number with convergent nozzle

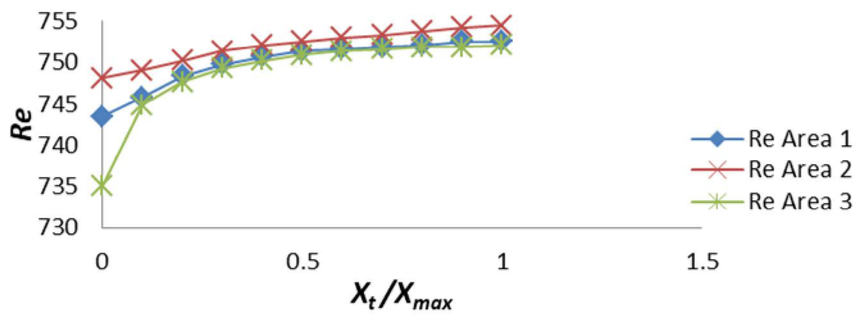

Figure 14 Reynolds number with diverging nozzle

4.5 Heat Flow

Heat flow in the porous media for cylindrical, convergent and divergent nozzle is shown in Figure 15. In the figure, the heat flow in the porous media along the surface lies between area-1 and area-2 is the heat transfer by convection, and the conduction occurs in the test section using the porous media. The heat flow is caused by the heat transfer in the surface of area-2 and the temperature difference between the fluid and the porous media. As shown in the figure, the heat transfer in the porous media using three nozzles tends to decrease.

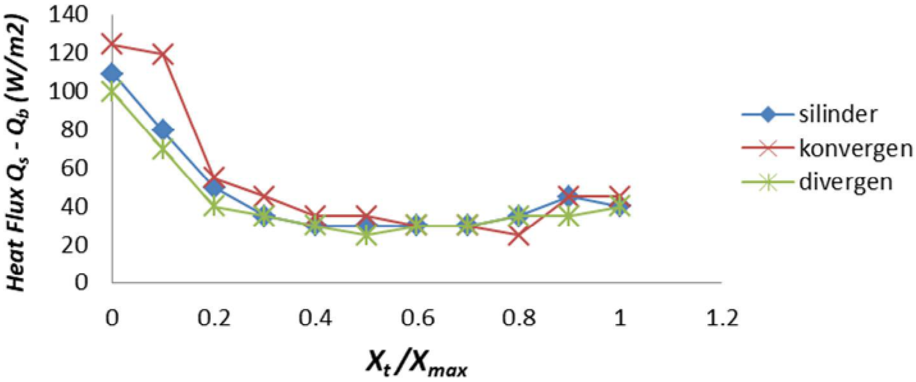

Figure 15 Heat Flux Porous Media

4.6 Nusselt Numbers

The Nusselt number is used to calculate the ration of heat transfer by convection and conduction. The Nusselt numbers using cylindrical, convergent, and divergent nozzles are depicted in Figure 16, 17, and 18. The high value of Nusselt number denotes that the heat transfer is dominated by the convection. Since the number is proportional to the length of porous media, the value increases along the increment of the length as verified in the figures.

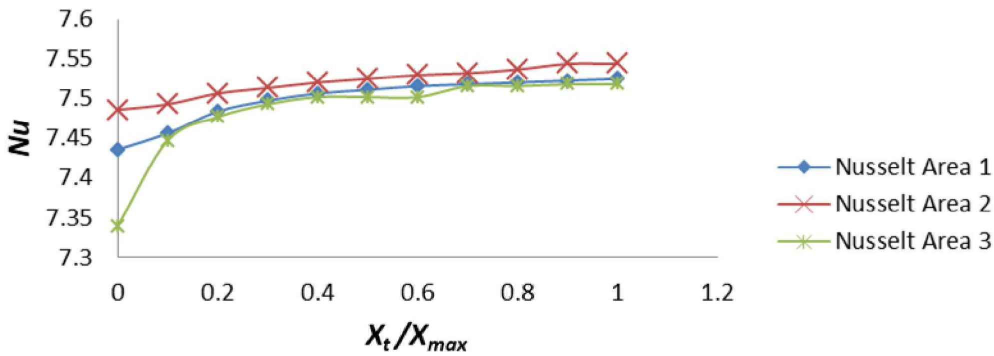

Figure 16 Nusselt number with cylindrical nozzle

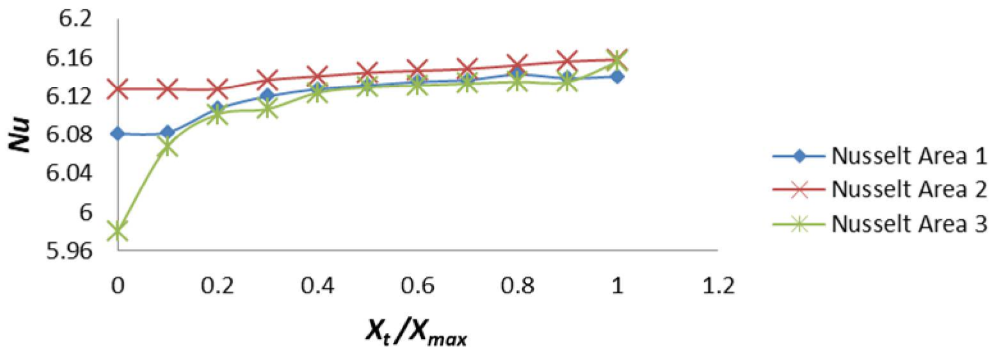

Figure 17 Nusselt number with convergent nozzle

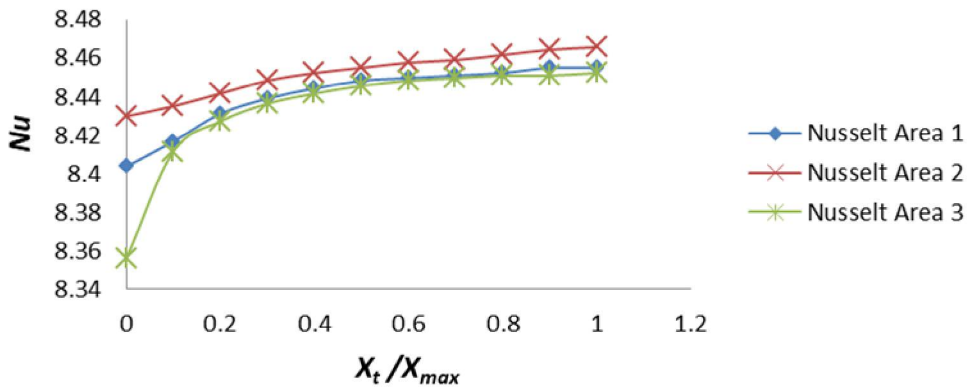

Figure 18 Nusselt number with divergent nozzle

4.7 Grashof Numbers

The relationship between the ratio of Grashof number to Reynolds number (Gr/Re^2) and the length of porous media is depicted in Figure 19. Comparing Figure 9, 10, 11 and Figure 19, it is obtained that the relationship between (Gr/Re^2) and the temperature is inversely proportional, in the sense that when the increment of length of porous media causes the decrement of temperature, it will increase (Gr/Re^2). Figure 19 also shows that the value of (Gr/Re^2) is affected by the nozzle's type.

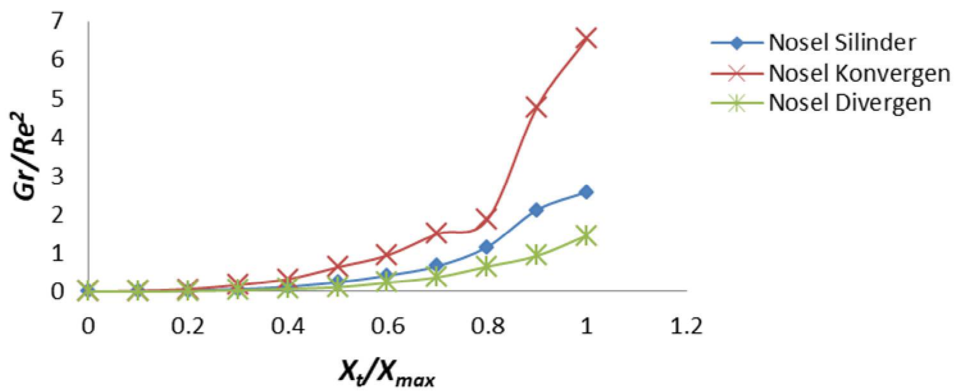

Figure 19 Relationship between ***Gr/Re^2*** **and the length of in porous media**

5. Conclusions

The model of fluid flow and temperature distribution of porous media from oil palm shell charcoal has been simulated. In the simulation, three types of nozzles (cylindrical, convergent, and divergent) are examined. The simulation results showed that the cylindrical, convergent, and divergent nozzles are able to distribute the fluid flow and temperature to the porous media. Using the model, the application of porous media from oil palm shell charcoal as the heat transfer media such as the moisture absorbent could be adopted properly.

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