Numerical Analysis of the Effect of Serrated Fin to the Heat Transfer in the Condenser

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Abstract: Condenser is one of the most important components in the power generation industry, which serves to condense the output steam from low-pressure turbine for boiler feed water. Several ways can be used to improve the performance of the condenser, one way is to add a serrated fin on the outer tube to lower the temperature of the outlet. A serrated fin that is used has 0° and 30 segments per period, which is installed on the tube with the diameter of the outer of 0.03175 m. This research was carried out by using the numerical method of CFD 2D to compare the performance of the heat transfer on the tube without and with a serrated fin on the variation speed of 7 m/s and 9 m/s. By inputting the parameters of the inlet of 350.15 °K, the resulting value of the outlet serrated fin tube temperature which is lower than the annular tube (tube without the serrated fin). On the simulation of the serrated fin tube with an inlet velocity of 7 m/s resulting outlet temperature of 343.2 °K, lower than in the simulation on the annular tube which produces the outlet temperature of 344.53 °K.

1 INTRODUCTION

Condenser serves to condense the steam output from the low-pressure turbine into condensate water which is then reused as boiler feedwater. In general, steam power plants use the condenser shell and tube type, which consist of a collection pipe that are located inside a shell. Cooling water originating from seawater will flow in the tube to condense the steam output from the low-pressure turbine flowing in the outer tube.

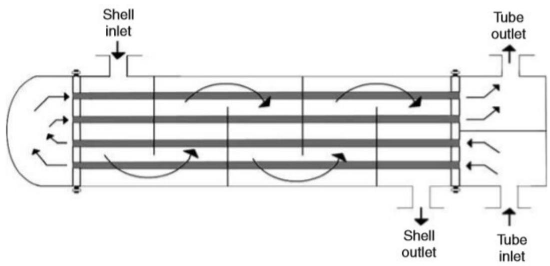

Figure 1: Shell and Tube Heat Exchanger.

The condenser has a very important influence on the whole success of the series of processes in the steam power plant, due to damage to the condenser will result in the failure of mechanics or operational failures that leads to the cessation of unit operation. Besides, the decrease in the performance of the condenser will also have a significant impact on the efficiency of the fuel used.

Therefore, the condenser is required to have performance as optimal as possible. A decline in the condenser performance can be caused by many factors, ranging from the presence of fouling, the design of the tube, to the arrangement of the tube which is less precise. One solution that can be done to improve the performance of the condenser is to ad fin on the outer side of the tube that aims to expand the heat transfer surface. The more surface area and increased turbulence of the fluid, the more the rate of heat transfer will be. Based on research by Dian Nilasari, it is known that the addition of a fin will make the contour of the flow that occurs in the shell side the random. Fin tube consists of several kinds, such as annular, studded, plain, serrated, and others. Various types of the fin can be affixed on the outer side of the tube with some means, such as tension winding using the adhesive bonding, soldered, brazing, welding, or extrusion. Previous research has been done by Reggy Arya Putra by comparing the characteristics of the serrated fin tube and plain tube using numerical methods of Computational Fluid Dynamics (CFD). The result is known that the

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serrated fin has the better heat transfer characteristics, due to turbulence of flow around the tube increased compared with the addition of plain tube. Therefore the author researched by comparing the serrated fin tube with the annular tube to find out how much the influence of the addition of fin on heat transfer performance in the condenser. This study contributes to the investigation of the flow phenomenon across the tubes which is not possible experimentally.

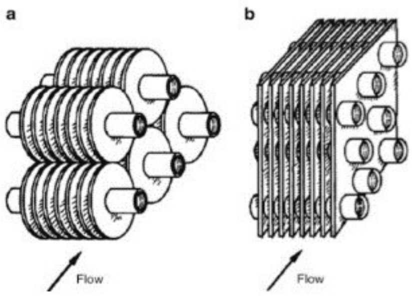


Figure 2: Tube Fin Exchanger Configuration. (a) Individually Finned Tubes. (b) Flat Fin with Continuous Form on an Array of Tubes.

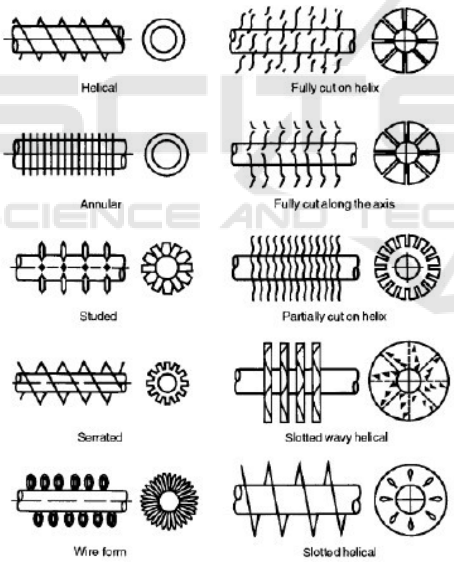


Figure 3: Type Fin Tube.

2 RESEARCH METHODE

The author researched by using the numerical methods of CFD to determine the effect of the serrated fin to the heat transfer. The simulation is performed in dimensionless 2D by comparing the heat transfer that occurs between the annular tube and serrated fin tube at different speeds, 7 m/s and 9 m/s. From this research, qualitative and quantitative data are obtained.

2.1 Tube Design

The making of the design was done in SpaceClaim with the parameters as in Table 1, using the fins with 0° angle in accordance to researched by Lemouedda and Franz.

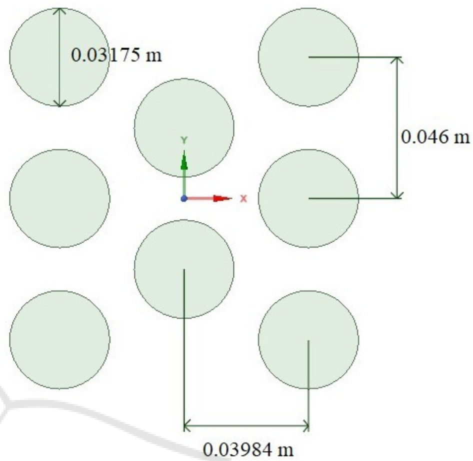


Figure 4: Design of Annulus Tube.

Table 1: Parameter Design of Geometry Serrated Fin Tube.

Design	Design Parameter	
	Value	***Unit***
Tube OD	0.03175	m
Fin High	0.0035	m
Fin Angle	0	°
Fin Width	0.003	
Tube Arrangement	Staggered	
Tube Bank Angle	60	°
Transversal Pitch	0.046	m
Longitudinal Pitch	0,03984	m

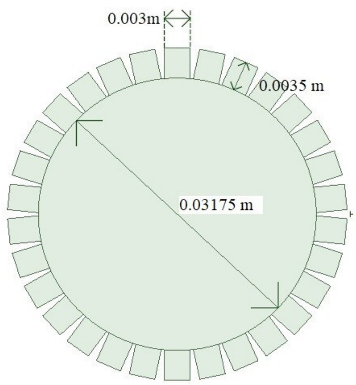


Figure 5: Design of Serrated Tube.

2.2 Meshing

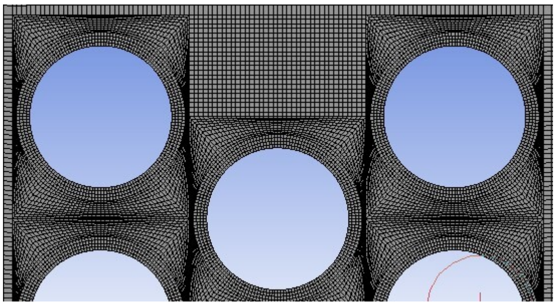


Figure 6: Details of Meshing Annulus Tube.

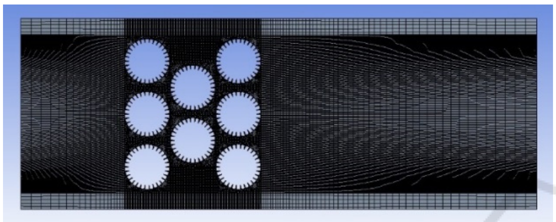


Figure 7: Meshing Serrated Fin Tube.

Meshing is the enumeration of the geometry into small parts that will be done the calculations for computing. Tightly meshing will produce a value close to the accuracy. Since there are significant conditions gradation around the tube, such as decreased temperature, increased speed, and the other, the meshing around the tube area is done very tightly. The meshing type used in the simulation is Quadrilateral-Map. The results of meshing on the simulation can be seen in Figure 6 and Figure 7 While the parameters and the quality of the meshing can be seen in Table 2.

Table 2: Parameter Meshing.

Tube Type	**Parameter Meshing**			
	Element Mesh	***Nodes***	***Orthogonal Quality***	***Skewness Quality***
Annulus Tube	50704	51960	0,92225	0,17515
Serrated Tube	40043	42527	0,9859	6,62E-02

Equation 1 is used to get the value of the temperature of the surface of the tube.

$$T_w = \frac{h_i t_{ave} + h_o D_o/D_i)T_{ave}}{h_i + h_o(D_o/D_i)} \tag{1}$$

Equation is used to get the value of the temperature of the surface fin.

$$T_{wtd} = \frac{h_i\eta_w t_{ave} + [h_i(1-\eta_w) + h_o\eta_w(A_{Tot}/A_i)]T_{ave}}{h_i + h_o\eta_w(A_{Tot}/A_i)} \tag{2}$$

$$\eta_w = \frac{A_{prime} + \eta_f A_{fins}}{A_{Tot}} \tag{3}$$

$$\eta_f = \frac{\tanh(mb_c)}{mb_c} \tag{4}$$

Furthermore, the method of solution used is SIMPLEC and spatial discretization on the second order upwind for all the parameters. To improve accuracy of the simulation, the value 10^{-4} is set in the residual setting element. The latter initialization is done using the method of hybrid initialization, before finally starting the iteration to get the result convergent in steady conditions.

2.3 Processing

In this stage, processing is done by settings the solver model, viscous models, the determination of the type of material, the determination of the boundary conditions, control & monitoring conditions, and initial conditions. In the solver model, it enables the energy equation to support the completion of the heat transfer, which uses the equation 5 of energy transport

$$\frac{\partial(\rho E)}{t} + \nabla.[V(\rho E + \rho) = \nabla.\left[k_{eff}\nabla T - \sum_j h_j J_j + \tau_{eff}.V\right] + S_h \tag{5}$$

While for the turbulence modeling of selected k-RNG (Renormalization Group) for the support of turbulence in the outer side of the tube is using the transport equation 6.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial xj}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial xj}\right] + P_k - \rho\varepsilon$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial xj}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial xj}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}P_k - C^*_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{6}$$

This simulation is using two materials, one is water vapor wich flowing in the shell side, the other is titanium which is used as the material for the tube and the fin. The value of the properties of water-vapor and titanium is analyzed based on the average temperature of the fluid within the shell. Next, boundary condition is determined. The boundary conditions set in this simulation are shown in Table 3.

Table 3: Parameter Boundary Conditions.

Boundary Condition	Boundary Conditions Parameter	
	Type	**Parameter**
Inlet	Velocity	Velocity = 7 & 9 m/s
		Temperature = 350.15° K
Outlet	Outflow	
Tube	Wall	Temperature = 315.13° K
Fin	Wall	Temperature = 315.9° K
Up and Down Wall	Symmetry	

Equation is used to get the value of the temperature of the surface of the tube.

$$T_w = \frac{h_i t_{ave} + h_o(D_o/D_i)T_{ave}}{h_i + h_o(D_o/D_i)} \quad (7)$$

Equation is used to get the value of the temperature of the surface fin.

$$T_{wtd} = \frac{h_i \eta_w t_{ave} + [h_i(1-\eta_w) + h_o \eta_w (A_{Tot}/A_i)]T_{ave}}{h_i + h_o \eta_w (A_{Tot}/A_i)} \quad (8)$$

$$\eta_w = \frac{A_{prime} + \eta_f A_{fins}}{A_{Tot}} \quad (9)$$

$$\eta_f = \frac{\tanh(mb_c)}{mb_c} \quad (10)$$

Furthermore, the method of solution used is SIMPLEC and spatial discretization on the second order upwind for all the parameters. To improve accuracy of the simulation, the value 10^{-4} is set in the residual setting element. The latter initialization is done using the method of hybrid initialization, before finally starting the iteration to get the result convergent in steady conditions.

2.4 Post-processing

The results of numerical simulations will be analyzed qualitatively and quantitatively. The qualitative analysis will be presented in the form of the image velocity and temperature distribution, while quantitative analysis will be presented in the form of a bar chart to determine the effect of serrated fin against heat transfer characteristics, such as Reynolds Number, Nusselt Number, and heat transfer coefficient.

3 RESULT AND ANALYSIS

The research method is a numerical study that is completed computationally with the results of the analysis using fluid mechanics theory and heat transfer.

3.1 Comparison of Speed Distribution for Annulus and Serrated Fin Tube

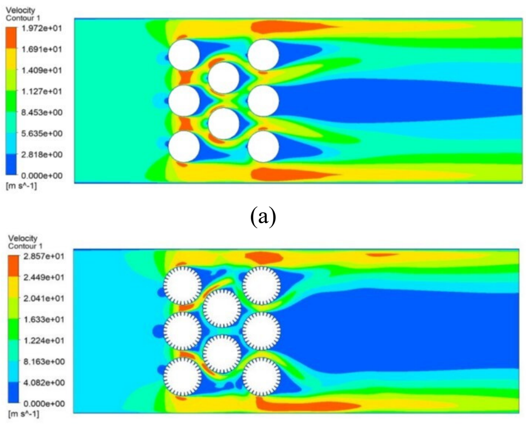


Figure 8: Comparison of Speed Distribution (a) Annulus and (b) Serrated Fin Tube.

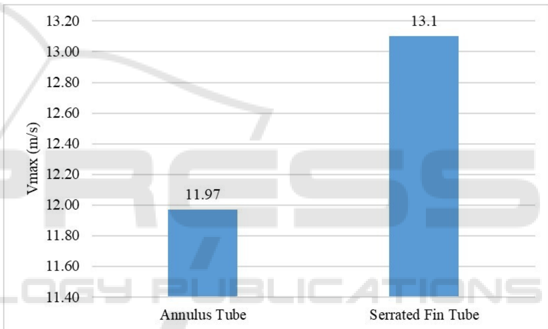
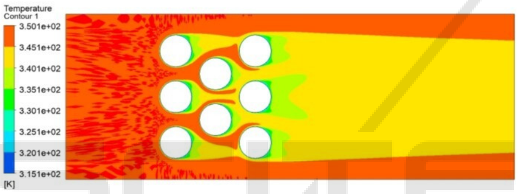


Figure 9: Vmax Comparison Chart for Annulus and Serrated Fin Tube.

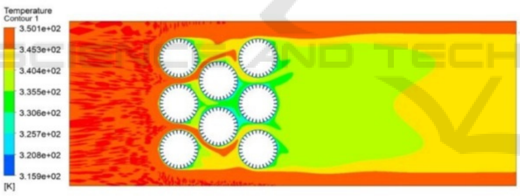
Image of flow speed contour through tube bank is taken at the time of a speed of 7 m/s, both for the simulation of annular tube or serrated fin tube. Based on Fig. 8 obtained qualitative data in the form of a contour image of speed with the indicator red indicates the highest speed and blue color to represents the speed of the lowest. On the simulation of annular or serrated fin tube, maximum speed value is obtained at the area of the transverse rows of the first, which is due to the occurrence of the narrowing of the area. While on the part of the transverse rows of the second and third has been a decreased in the speed of the fluid flow caused by flow colliding with the tube in the front (Shah and Sekulic, 2007). Based on Fig. 8 the back of the tube is blue, both on the tube line of the first, second or third, which is caused by the flow of fluid that has passed through the pipe having the separation of the flow and creates a wake, which is the area that a deficit of momentum.

The value of Vmax between the annular tube and serrated fin tube will be presented quantitatively in Fig. 9 Based on the simulation results, the addition of the serrated fin has a Vmax of 13.1 m/s, which is larger compared to the annular tube, which produces Vmax value only at 11.97 m/s. The high value of the Vmax in the simulation of the serrated fin tube due to the existence of the fin on the outside of the tube will enlarge the heat transfer surface and narrow the distance of the transverse and longitudinal between the tube, causing heat transfer occurring to be better (Bergman et al.). The existence of the serrated fin will also further randomize the flow of the fluid, which causes the value of Reynolds Number is also greater. The more random or turbulent fluid flow, then the heat transfer that occurs would be even better.

3.2 Comparison of Temperature Distribution for Annulus and Serrated Fin Tube



(a)



(b)

Figure 10: Comparison of Temperature Distribution (a) Annulus and (b) Serrated Fin Tube.

Image of the temperature contours which passes through the tube bank is taken at the time of a speed of 7 m/s, both on the simulation of the annular tube or serrated fin tube. Based On Fig. 10 obtained qualitative data in the form of image contour of temperature with indicator red color represents the highest temperature and the blue color to shows lowest temperature. On the simulation, the inlet temperature parameters input is 350.15°K with the temperature conditions uniform, either for the simulation of annular tube or serrated fin tube. While cooling water temperature is low within the tube, enabling the decrease of the temperature at the outlet side because there was a heat transfer arround the tube bank, which heat will flow from the high temperatures heading to the low temperatures. Based on Fig. 10 obtained qualitative data in an annular tube is dominated by the yellow color on the outlet, thus indicating that fluid wasted still have high temperatures. Different from the qualitative data serrated fin tube which is dominated by light green color on the side of the outlet, which indicates that the fluid has a lower temperature because it has happened more heat transfer around the tube bank.

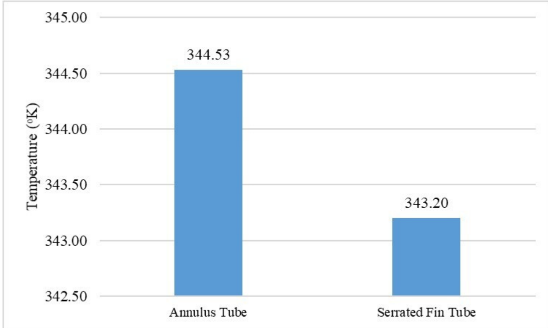


Figure 11: Temperature Comparison Chart for Annulus and Serrated Fin Tube.

Based on Figure 11 obtained quantitative data outlet temperature of the annular tube is 344.53 °K, which means it has 5.62 °K difference from the temperature of the inlet. While the outlet temperature serrated fin tube is 343.20 °K, the difference 6.95 °K from the temperature of the inlet. Thus, it means the installation of serrated fin tube makes heat transfer around the tube bank better, because of the serrated fin will make the surface of the heat transfer is more extensive if compared to the annular tube. The greater the area of the heat transfer surface, the better the heat transfer occurs.

3.3 Analysis of the Effect of Speed on Reynold Numbers for Annulus and Serrated Fin Tube

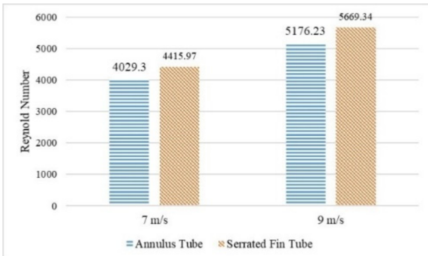


Figure 12: Reynold Number Comparison Chart for Annulus and Serrated Fin Tube at 7 m/s and 9 m/s Speed.

In this simulation, the speed is varied by 7 m/s and 9 m/s respectively, both on the annular tube or serrated fin tube, to determine the effect of speed changes against the Reynolds Number. The Reynolds Number is a dimensionless number used to determine the type of fluid flow that occurs. The Reynolds Number is also defined as the ratio between inertia force with the viscosity force in the boundary layer speed. The low Reynolds Number value will cause the force of inertia is not so significant compared to the viscosity force. While the high Reynold Number value has high inertial force, which has more significance than viscocity force. The high value of the Reynolds Number will make boundary layer of the fluid thinner because it is depressed by the force of inertia. The thinness of the boundary layer will increase the amount of fluid that is high speed so that the process of heat transfer will occur faster. The value of Reynolds Number is also very dependent on the value of Vmax, the greater the value of the maximum velocity then the value of the Reynolds Number will be even greater.

$$ReD = \frac{\rho\ x\ v \max x\ d}{\mu} \tag{11}$$

$$V_{max} = \frac{ST}{2(SD-D)} V \tag{12}$$

Based on Figure 12 The obtained value of Reynolds Number is different in the simulation of annular and serrated fin tube. Simulation of serrated fin tube generates large Reynolds Number, each worth 4415.97 at a speed of 7 m/s and 5669.34 on the speed of 9 m/s. While the simulation of the annular tube produces only the value of the Reynolds Number of 4029.3 at a speed of 7 m/s and 5176.23 on the speed of 9 m/s. The high Reynolds Number in the simulation of the serrated fin tube shows that the addition of a serrated fin on the outside of the tube will make the fluid flow more random. When the inlet velocity increases, then the value of Vmax will be greater, so also with the Reynolds Number.

3.4 Analysis of the Effect of Speed Changes on Nusselt Numbers for Annulus and Serrated Fin Tube

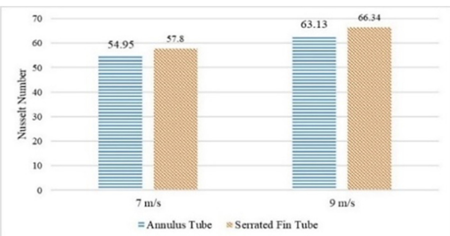


Figure 13: Nusselt Number Comparison Chart for Annulus and Serrated Fin Tube at 7 m/s and 9 m/s Speeds.

Based on Figure 13 the known Nusselt Number will change along with the increase of speed. A Nusselt Number is a dimensionless number of the ratio of heat transfer by convection and conduction on the boundary condition of the fluid. Increasing speed will increase the value of the Reynolds Number because the thickness of the boundary layer is getting thinner so the amount of high speed fluid is increasing. The depletion of the boundary layer of the fluid will cause an increase in the value of the Nusselt Number, and vice versa. Therefore, the increasing Nusselt Number will also make the heat transfer the better. The value of Nusselt Number is also influenced by the Prandtl Number.

$$\mathrm{Nu}_D = 1{,}13\ \mathrm{C1\ ReD_{maxm}}\ Pr^{\frac{1}{3}} \begin{bmatrix} & N_L > 10 & \\ 2000 \ \leq & Re_{D,max} & \leq 40000 \\ & P_r \geq 0{,}7 & \end{bmatrix} \tag{13}$$

	S_T/D							
	1.25		1.5		2.0		3.0	
S_L/D	C_1	m	C_1	m	C_1	m	C_1	m
Aligned								
1.25	0.348	0.592	0.275	0.608	0.100	0.704	0.0633	0.752
1.50	0.367	0.586	0.250	0.620	0.101	0.702	0.0678	0.744
2.00	0.418	0.570	0.299	0.602	0.229	0.632	0.198	0.648
3.00	0.290	0.601	0.357	0.584	0.374	0.581	0.286	0.608
Staggered								
0.600	—	—	—	—	—	—	0.213	0.636
0.900	—	—	—	—	0.446	0.571	0.401	0.581
1.000	—	—	0.497	0.558	—	—	—	—
1.125	—	—	—	—	0.478	0.565	0.518	0.560
1.250	0.518	0.556	0.505	0.554	0.519	0.556	0.522	0.562
1.500	0.451	0.568	0.460	0.562	0.452	0.568	0.488	0.568
2.000	0.404	0.572	0.416	0.568	0.482	0.556	0.449	0.570
3.000	0.310	0.592	0.356	0.580	0.440	0.562	0.428	0.574

Figure 14: Constant Value C1 and m.

Based on Figure 13 it can be known that the Nusselt Number on the simulation of the serrated fin tube is good compared with the annular tube, both at a speed of 7 m/s or 9 m/s. On the simulation of the annular tube with a speed of 7 m/s produces only the Nusselt Number of 54.95 and at a speed of 9 m/s will produce a Nusselt Number of 63.13. While in the simulation of the serrated fin tube will produce a Nusselt Number of 57.8 at a speed of 7 m/s and will be increased to 66.34 at a speed of 9 m/s. Thus it can be concluded that the addition of a serrated fin on the outside of the tube will produce large Nusselt Number and the heat transfer that occurs in the tube bank is better.

3.5 Analysis of the Effect of Speed Changes on the Convection Coefficient for Annulus and Serrated Fin Tube

In theory the greater the value of the coefficient of convection means better heat transfer. There are two types of convection which occur, namely natural

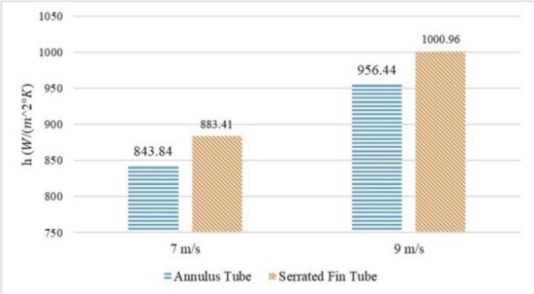


Figure 15: Graphic Comparison of Convection Heat Transfer Coefficients for Annulus and Serrated Fin Tube at 7 m/s and 9 m/s Speeds.

convection and forced convection. Natural convection occurs if there is no fluid velocity that affects the heat transfer process. While forced convection occurs when the heat transfer process is influenced by the speed of the fluid occurs in the vicinity. In this simulation occurs forced convection heat transfer, because of the speed of the input on the inlet. Heat transfer by convection occurs because water-vapor that has a higher temperature will release heat to the walls of the fin or the tube that have lower temperatures. The value of the coefficient of convection is also affected by the Reynolds Number. The greater the value of the Reynolds Number, the greater the process of convection that occurs. Besides, the value of the coefficient of convection is also affected by the Prandtl Number and thermal conductivity of water vapor. The Prandtl Number is defined as the ratio of diffusivity of momentum to diffusivity thermal, while thermal conductivity is defined as the rate of heat transfer by conduction through the area of the cross-section of the unit material.

$$H_{kforced} = \frac{(0.4\ x\ R_e{}^{0.5}) + (0.06\ x\ R_e{}^{0.5})\ x\ P_r{}^{0,4}\ x\ K^{0.25}}{D} \quad (14)$$

Based on Figure 15 it is known that the addition of the serrated fin will result in the better value of the coefficient of convection heat transfer compared to the annular tube, both at a speed of 7 m/s or 9 m/s. On the simulation of the serrated fin tube with a speed of 7 m/s the convection heat transfer coefficient is produced at 883.41 $\frac{W}{m^2°K}$, and increased to 1000.96 $\frac{W}{m^2°K}$ at a speed of 9 m/s. While in the simulation the annular tube produces the convection heat transfer coefficient is produced at 843.84 $\frac{W}{m^2°K}$ at a speed of 7 m/s and increased to 956.44 $\frac{W}{m^2°K}$ at a speed of 9 m/s. Thus the addition of a serrated fin on the side of the outer tube can increase the occurrence of heat transfer, which is proven by the increasing coefficient of heat transfer by convection.

4 CONCLUSIONS

Based on the simulation results, it can be concluded that the addition of a serrated fin on the side of the outer tube can improve the heat transfer that occurs around the tube banks because the outlet temperature is low. With the same temperature inlet input 350.15 °K, at a speed of 7 m/s the simulation of an annular tube produces only the outlet temperature of 344.53°K, while in the simulation of the serrated fin tube produces the outlet temperature of 343.2 °K. Besides, the use of serrated fin tube can also increase the Reynolds Number, Nusselt Number, and convection heat transfer coefficient around the tube bank. On the simulation of the serrated fin tube with a speed of 7 m/s produced a Reynolds Number of 4415.97, Nusselt Number of 57.8, and the convection heat transfer coefficient of 883.41$\frac{W}{m^2°K}$. While in the simulation of the annular tube with a speed of 7 m/s only produces a Reynolds Number of 4029.3, Nusselt Number of 54.95, and coefficient of convection heat transfer by 843.84 $\frac{W}{m^2°K}$. To further improve the heat transfer performance of the serrated fins, further research could increase the number of segments in each period to expand the heat transfer surface. The more surface area of an object, the better the heat transfer that occurs.

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