EFFECT OF DIFFERENT MATERIALS AND CFD ANALYSIS OF FIN TUBE TYPE HEAT EXCHANGER USED IN AERO ENGINES

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Abstract

In order to maintain the temperature of the fin-tube heat exchangers, this will show potential applications in aero engines for their high efficiency and security as compared with other types of heat exchangers used in different areas, heat exchangers used in aero engines are more compact and it is at much higher temperatures and larger temperature differences. In this work tube type heat exchangers are selected for the present research it has a plain finned tube configuration. Hot air coming from compressor flows across the tube bank while cold fluid that may be fuel oil flows inside the tubes. In this work, three different steel alloy materials were used for the manufacturing of heat exchanger that is GH2132, N07750 and N07718 and the heat transfer rate as well as heat transfer coefficient. N07718 shows the maximum heat transfer in between all considered materials.

Keywords- heat exchanger, fin tube type, steel alloys, heat transfer rate, staggered arrangement

1. Introduction

Enhancing the overall heat transfer performance in heat exchanger equipment, which usually is referred to as heat augmentation or simply intensification, heat exchanger can perform a significant factor in conserving energy and material usage. This even leads to minimizing the manufacturing expenditure of heat exchanging products which in turn employed in numerous conventional, industrial and residential applications. As the energy assets of the earth are reducing and their own costs are rising, design of energy effective heat exchangers offers vital influence on energy conservation. The requirement for revitalizing overall heat performance leads to improving heat enhancement approaches which usually make it easier in equipment size reduction, saving operating costs, and so reducing pumping power in heat exchangers. As a result, based on the goal of the equipment, designers can concentrate on one of these heat enhancement criteria and present these achievements.

To increase the performance of heat exchanger used in aero engines here in this work it find out the effect of different material used for the construction of tubes and fin in heat exchanger. To increase the heat transfer rate here three different materials were used for tube and fins construction and finding out the temperature distribution and pressure drop at four different velocities that is 5, 10, 15, 20 m/s. After finding out the optimum material for given boundary condition, it also calculate the effect of change in fin spacing used for heat transfer. It considered three different fin spacing that is 0.75, 1.1, 1.55 mm and find out the optimum fin spacing for increasing the heat transfer rate.

2. Mathematical Model

Maximum velocity of airflow inside the compact heat exchanger is calculated based on relation given for the staggered tube arrangement in Cengel. The relation used for calculating maximum velocity inside the computational domain is given below.

$$V_{max} = \frac{P_t \times V}{2(P_d - D)} \quad (1)$$

Where, D = diameter of tube, V = velocity of air at inlet, P_t = transverse distance in between the two tubes of same row, P_d = diagonal distance between the center of two tubes of adjacent row. To calculate the Reynolds number of air flowing inside the computational domain, maximum velocity of air flowing inside the domain were considered in a particular case of staggered fin tube type compact heat exchanger [29]. For calculation following relation were used

$$Re = \rho_{air} \times V_{\max air} \times L_c / \mu_{air} \quad (2)$$

Where, ρ_{air}= Density of air, $V_{\max air}$= Velocity of air, μ_{air} = Dynamic viscosity of air. In order to calculate the heat transfer from hot air to fin and tube following relation were use. During the heat transfer from hot air to cold fluid flowing inside the tube, many researchers have found that the thermal resistance during the heat transfer from tube to cold fluid is less as compared to the thermal resistance, during heat transfer from air to tube and fins [6, 22, 29]. So during the calculation of heat transfer and heat transfer coefficient it mainly concern toward the heat transfer from air to fin and tube and neglect the thermal resistance toward the cold fluid domain which is very less as compared to the thermal resistant toward the air side. Due to this, it calculate the local heat transfer coefficient in between air and tube, and not calculating the value of overall heat transfer coefficient. To calculate the heat transfer rate at different velocity following formula used.

$$Q = \dot{m} C_P \Delta T \quad (3)$$

Where, m = mass flow rate of air, C = specific heat of the air, ΔT = change in temperature between inlet to outlet. For calculating the mean temperature difference for particular staggered type arrangement of fin and tube type compact heat exchanger following relation were used as given in the base paper. To calculate ΔT_m following formula mention in the base paper and Cengel and Gajar used.

$$\dot{m} = \rho_{air} \times V_{air} \times A_c \quad (4)$$

$$\Delta T_m = \frac{(T_{in} - T_w) - (T_{out} - T_w)}{ln[(T_{in} - T_w)/(T_{out} - T_w)]} \quad (5)$$

where, T_{in}= Temperature at inlet, T_{out} = Temperature at outlet, T_w =Temperature of the tube wall or fin. To calculate heat transfer coefficient following equations were used

$$Q = hA\Delta T_m \tag{6}$$

Where, h = average heat transfer coefficient (W/m^2-k), A = surface area of domain, ΔT_m = logarithmic mean temperature difference. To calculate the surface area of domain following calculation is use.

$$A = L \times W - (\frac{\pi}{8} \times D^2) \times N \tag{7}$$

Where, L = length of fin, W = width of fin, D = diameter of tube, N = no of tube in computational domain.

3. Validation of CFD Model and Computation

In order to validate the CFD model of heat exchanger used in aero engines, here it first find out the temperature of air at the exit of heat exchanger for different velocity. Here in this work we have considered the four different velocity that is 5, 10, 15, 20 m/s and in each case air exit temperature get calculated and then based on the temperature at the exit here we have calculated the heat transfer rate (q), the value of heat transfer rate calculated with the help of numerical method is then compared with the value of heat transfer rate given in the base paper Lingdong et.al [1]. Here in this analysis it considered the material GH2132 for tube and fins. The thickness of fins for this analysis is 0.1 mm, whereas the gap in between the two fins is near about 1.1 mm.

3.1 Developing Solid Model

In order to achieve the above objective here first it develop the solid model of heat exchanger based on the geometry used given in Lingdong et.al [1] the geometric specification of heat exchanger used in the analysis is defining the tube bank configurations include the tube outside diameter (D), transverse tube pitch (P_t), longitudinal tube pitch (P_l), and number of tube rows (N). They are taken to be D = P_l = 3.0 mm, P_t = 6.0 mm and N = 12 in this research. The plain finned tube configuration involves additional parameters including the fin pitch (F_p) and fin thinkness (d_f), which are specified to be F_p = 1.1 mm and d_f = 0.1 mm. due to the periodicity and symmetry of the heat exchanger geometry for numerical analysis it considered the two dimensional that is 2D airflow passage as shown in the fig. here the solid model of the heat exchanger is prepared in the design modular of Ansys.

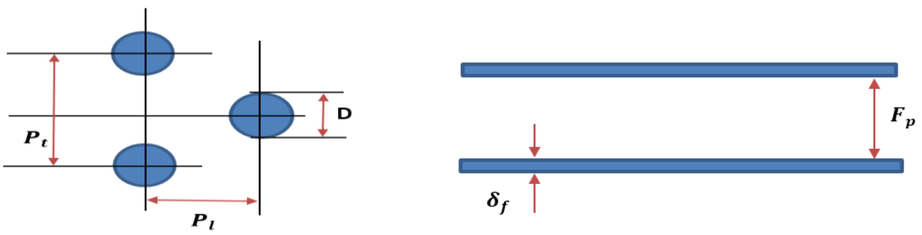
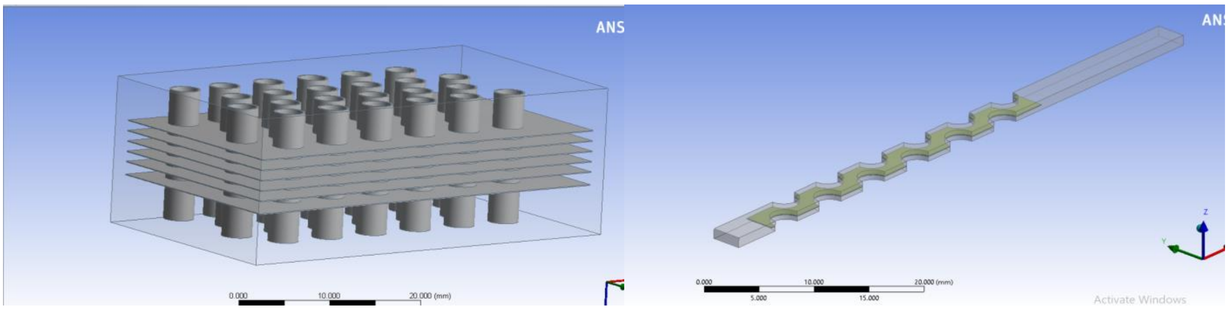


Fig.1 showing the geometric condition of tube



3.2 Air Condition and Air Physical Properties

Air coming from the compressor and entering the heat exchanger in the aero engine operation assume to operate at altitude of 11 km and flies at mach 0.8 as given in Lingdong et.al [1]. During the analysis it considered the local atmospheric temperature and pressure that is calculated as 216.65 K and 22.63 kPa [17]. The inlet total pressure recovery coefficient is assume to be 0.97, the compressor compression ratio considered during the analysis is 25, the compressor efficiency is 0.90, and the air adiabatic index is 1.4, the air temperature and pressure at the inlet of heat exchanger is considered to be same as those at the compressor outlet, and it is considered as 653.99 K and 0.84 MPa [18]. The air velocities at the exchanger inlet (frontal air velocities) are set to range from 5 to 20 m/s, with the tube wall temperature being taken as 298 K.

3.3 Meshing

After developing the solid model of given geometry, it is then discretizing in to number of elements and node because the numerical analysis is completely depends on the number of elements and number of nodes. During the numerical analysis the result were calculated at each node and element. So to discretize the complete solid model in number of small element here it used the different tool to enhance the mesh.

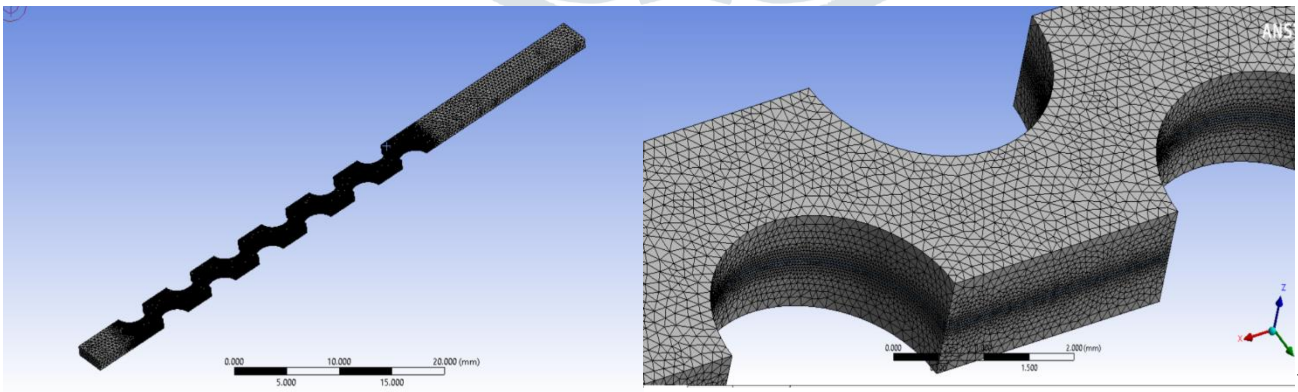


Fig.3

Mesh of the given geometry

3.4 Model used

After performing the mesh, here it selects the model for doing the further analysis. To perform the numerical analysis it is necessary to select appropriate model according to the condition of problem. So in order to find out the appropriate model for the given problem, here it considered the six different model that is K-epsilon Standard, K-epsilon RNG, K-epsilon Realizable, K-omega Standard, K-omega BSL and K-omega SST. Based on the above analysis it is found that there is not much difference in between the different model. But in the entire six models K-epsilon Realizable Standard model is showing the average values as compared to other model, so it is better to prefer this model for further analysis. Here in this work it used the K-epsilon Realizable model for the further analysis.

3.5 Selection of Material

For the initial analysis it uses the GH2132 alloy used in the base paper to perform the analysis work. The material property of GH2132 is mention in above section. For the initial analysis it has taken the material same as that of taken by Lingdong et.al [1]. So here is considering the GH2132 alloy (Fe-25Ni-15Cr) is chosen as the fin material, whose thermal conductivity is set as 14.2 W/ (m^2-K). Properties of material GH2132 that is Density, Specific heat, Thermal conductivity is 7.99 g/cm^3, 447 J/kg-k, 14.2 W/m-C. Properties of material N07750- Density, Specific heat, Thermal conductivity is 8.28 g/m3, 142 J/kg-k, 43.3 W/m-k. Properties of material N07718- Density, Specific heat, Thermal conductivity is 8.19 g/m3, 313 J/kg-k, 32.2 W/m-k.

4. Result

For analyzing the heat transfer rate and heat transfer coefficient of fin tube type heat exchanger through analysis contours of temperature distribution were also calculated. Here in this work, GH2132 material considered for tube and fins manufacturing. The thickness of fins for this analysis is 0.1 mm, whereas the gap in between the two fins is near about 1.1 mm.

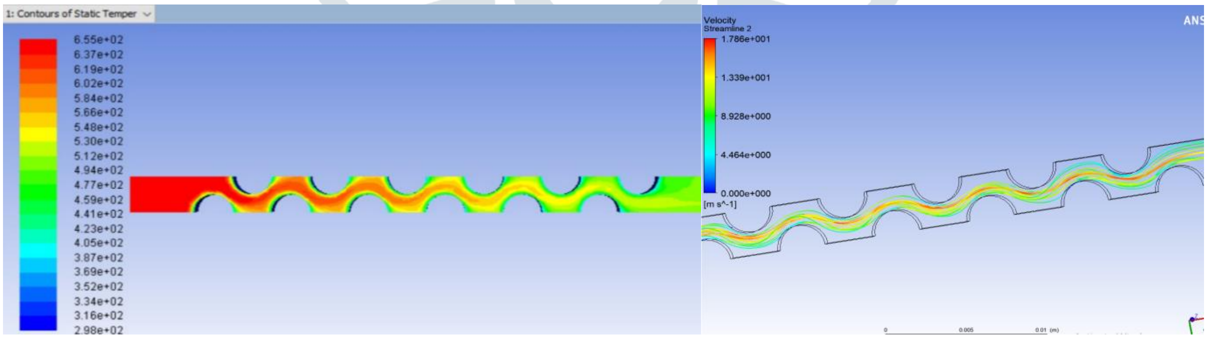


Fig.4 Temperature contour of heat exchanger at 5 m/s velocity- case 1

From the above analysis, it observes that the temperature of air at the exit of heat exchanger is 422 K from the numerical analysis it also finds out the change in velocities and velocity vectors. Comparison of value of heat transfer rate for different velocity of air calculated with the help of numerical analysis to the value of heat transfer rate given in the base paper.

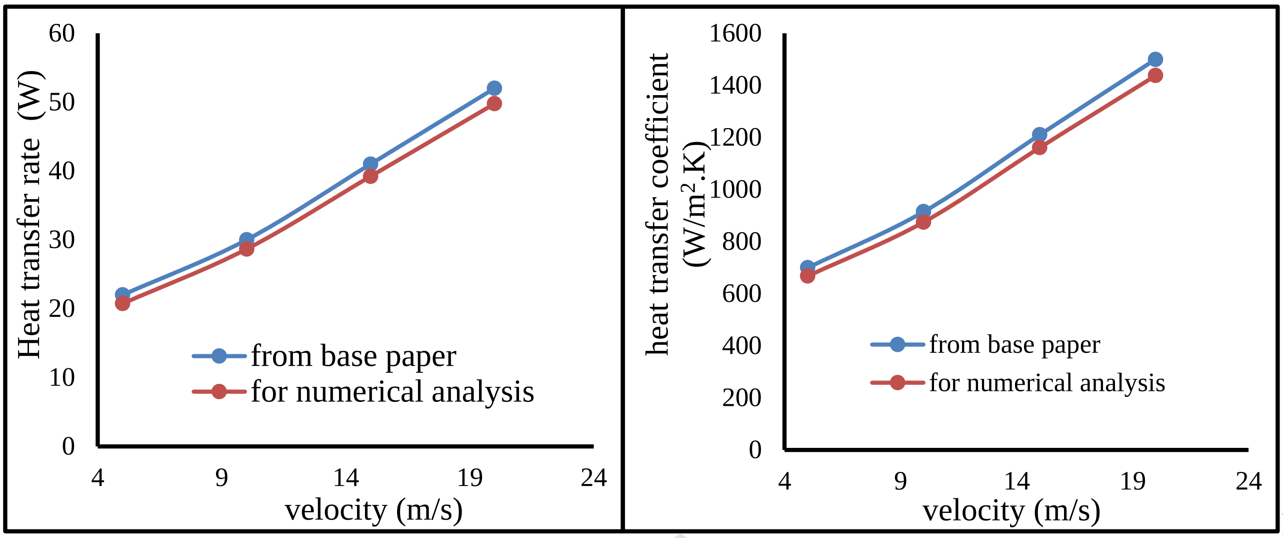


Fig.5

Comparison of heat transfer coefficient and heat transfer rate at different velocity of air

From the above comparison, it is analyzed that the value of heat transfer rate at different velocity of air obtained from the numerical analysis is close to value obtained from the base paper and follow the same trend as follow in the base paper. So after analyzing the graph it shows that the CFD model of heat exchanger that is developing in this work is correct. Value of heat transfer coefficient for different Reynolds number calculated through numerical analysis is closer to the value of heat transfer coefficient for different Reynolds number obtained from the base paper. After validation of the CFD model of heat exchanger, here it optimized the different parameter to enhance the heat transfer rate. To increase the heat transfer rate here in this analysis it has considered the two different materials that are N07750 and N07718, which are also a steel alloy. After finding out the optimum material to enhance the heat transfer rate, here it also analyzing the effect of fin spacing and find out the effect of gap in between the two fins for that is considered three different fin spacing that is 0.75, 1.1 and 1.55 mm.

4.1 For N07750 Material Used for the Tube and Fins

Here in this case it has taken as N07750 material as a material used for the manufacturing of tubes and fins. The material property of this material is mention in chapter 3. Here in case it is analyzed at different velocity of air and find out the temperature of air at the exit of heat exchanger. Here it also considered the four cases at different velocity. The temperature contours for this material at velocity 5 m/s shown in the fig. and calculate the pressure distribution throughout the computational zone. The other boundary condition will remain same as used in Material GH2130.

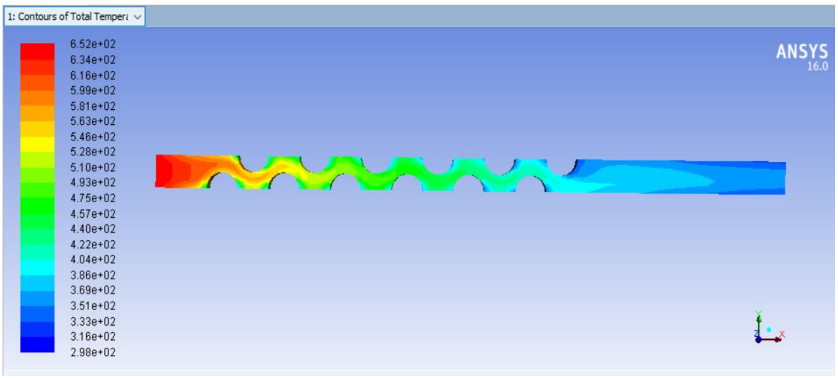


Fig.6 contours of temperature at velocity 5 m/s material N07750

The value of temperature at the exit for velocity 5 m/s is near about 358 K. the temperature contour through the heat exchanger is shown in the above fig. The temperature distribution at the exit of heat exchanger shown in the below fig. for the further calculation average temperature is taken at the exit. Whereas the value of temperature at the exit for velocity 10 m/s is near about 392 K. the temperature contour through the heat exchanger is shown in fig.

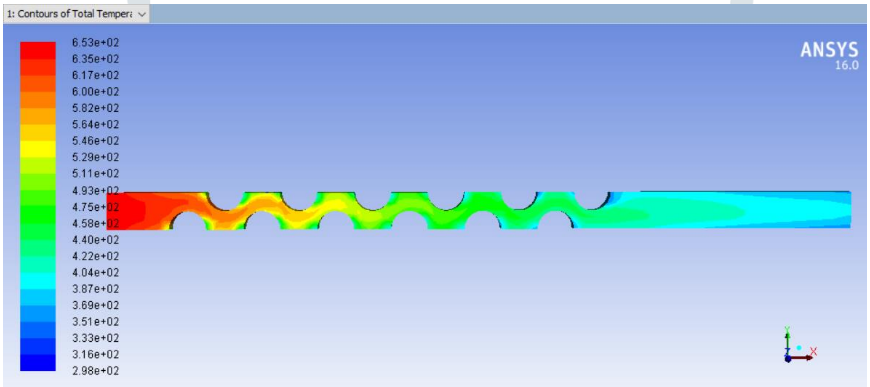


Fig.7 Contours of temperature at velocity 10 m/s material N07750

The temperature distribution at the exit of heat exchanger shown in the below fig. for the further calculation average temperature is taken at the exit. Likewise the above analysis it has calculate the temperature of air at the exit of heat exchanger for different velocity. The value of temperature of frontal air at different velocities is shown in the table.

Table.1 Value of temperature at different velocity

Case	Velocity of air (m/s)	Temperature of air at the exit of heat exchanger
1	5	358
2	10	392
3	15	401
4	20	408

After calculating the value of temperature of air at the exit of heat exchanger here we have calculated the value of heat transfer coefficient for different velocity of air and also calculate the value of heat transfer rate.

4.2 N07718 Material Used for the Tube and Fins

Here in this section it considered the N07718 material for the tube and fins and analyzed the effect of this on the temperature and pressure distribution throughout the computational domain. The material property of N07718 is mention in the chapter 3. The other boundary conditions will remain same as that of section of material GH2130. For this material also it has considered the four different velocities and find out the temperature of air at the exit.

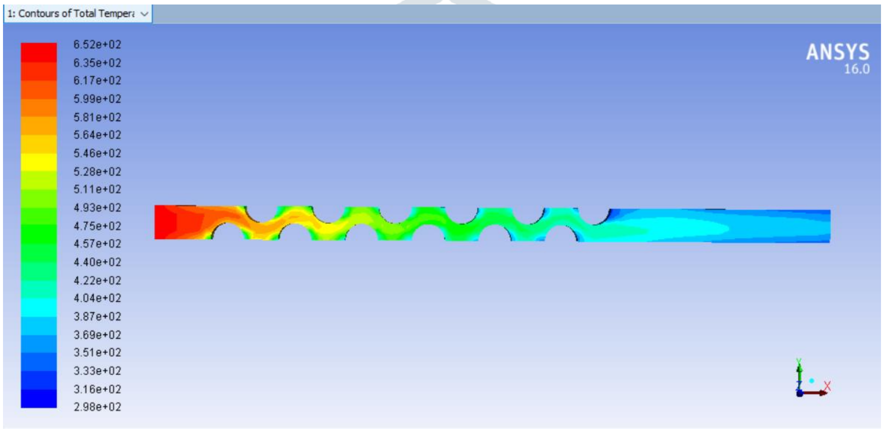


Fig.8 Contours of temperature at velocity 5 m/s material N07718

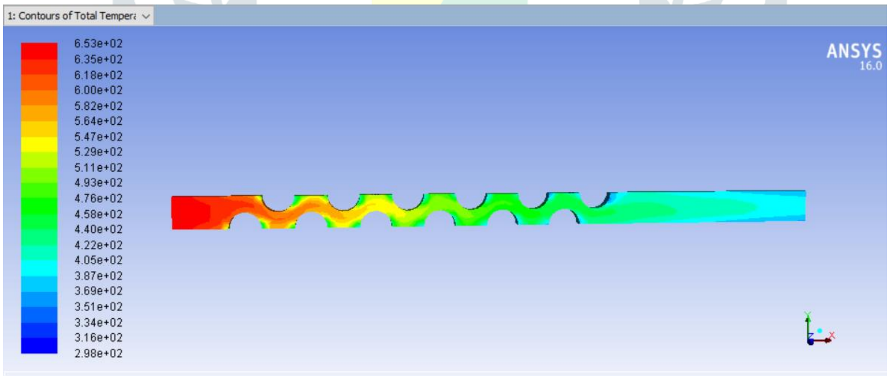


Fig.9 Contours of temperature at velocity 10 m/s material N07718

Average temperature at the exit for velocity 10 m/s is near about 389.5K. Likewise the above analysis we can calculate the temperature at the exit of heat exchanger for velocity 15 and 20 m/s. After analyzing the three different materials, comparison of all this material on the basis of heat transfer rate and heat transfer coefficient were done which is shown in the table below.

Table.2 Comparison of Temperature for Different Material

Case	Velocity of	Heat transfer rate (W)	Heat transfer rate (W)	Heat transfer rate (W)

	air (m/s)	For material GH2132	For material N07750	For material N07718
1	5	20.75	22.76	23.27
2	10	28.67	31.32	33.05
3	15	39.23	42.57	44.87
4	20	49.78	54.12	56.33

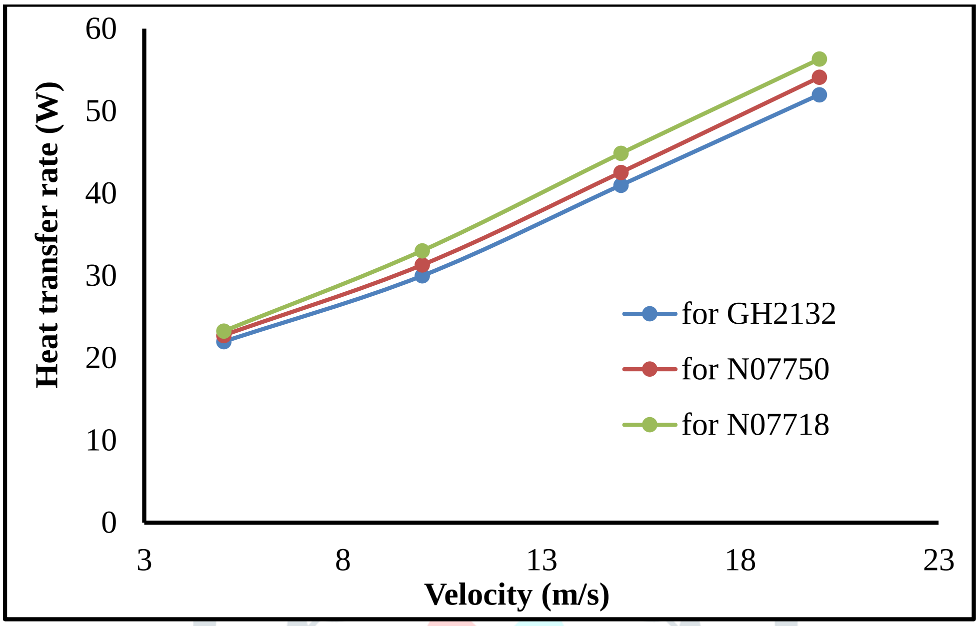


Fig.10 Comparison of heat transfer rate for Different Material

From the above comparison graph, it found that the heat transfer rate is higher for material N07718 as compared to other materials. Through this analysis, it is found that as the material density, specific heat and thermal conductivity changer the heat transfer capacity of the material also changes.

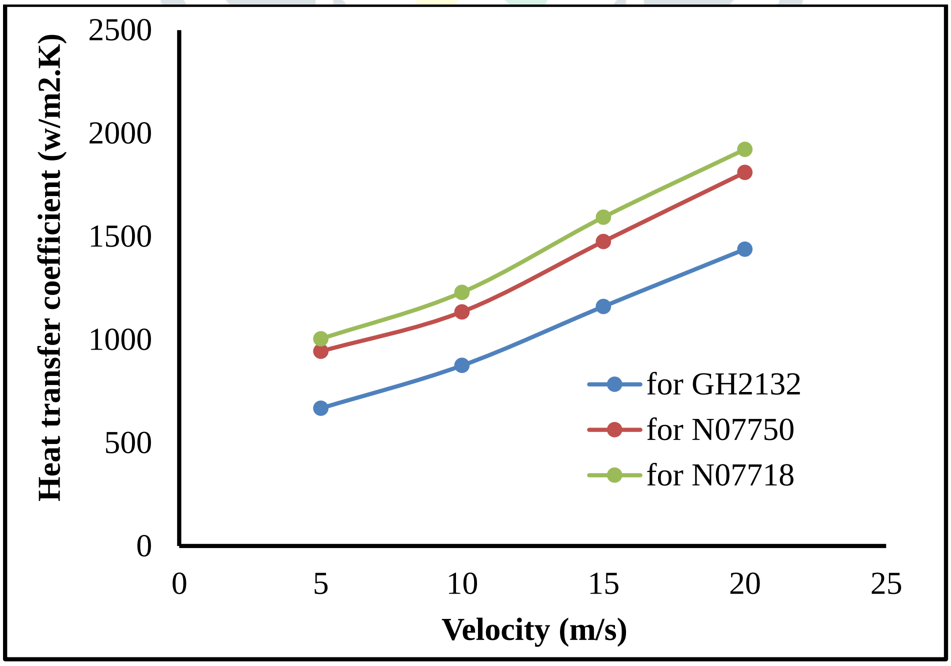


Fig.11 comparison of heat transfer coefficient for different material

After comparing the value of heat transfer rate for different materials here it also compared the value of heat transfer coefficient for different material the value of heat transfer coefficient for different material is shown in the below table

5. Conclusion

Through analysis it is found that material used for the manufacturing of tube and fin affects the heat transfer to calculates the effect of different materials here it consider the different steel alloy which is GH2132, N07718 and N07750. With the CFD analysis of all the three materials, it is finding that the N07718 is showing the highest rate of heat transfer. The airside heat transfer and pressure variation characteristics of plain finned tube heat exchangers are numerically predicted with consideration of the air property variations caused by change in air velocity. Through this analysis it is also observed that rate of heat transfer also depends on the specific heat and density of the material though it is mainly depends on the thermal conductivity of material, but density and specific heat also play some role in it.

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