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CFD analysis of a shell and finned tube heat exchanger for waste heat Recovery applications

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Abstract: The energy available in the exit stream of many energy conversion devices such as I.C engine gas turbine etc goes as waste, if not utilized properly. The present work has been carried out with a view to predicting the performance of a shell and finned tube heat exchanger in the light of waste heat recovery application. The performance of the heat exchanger has been evaluated by using the CFD package fluent 6.3.16 and has been compared with the available experimental values. An attempt has also been made to predict the performance of the above heat exchanger by considering different heat transfer fluid and the result so obtained have been compared. The performance parameters pertaining to heat exchanger such as effectiveness, overall heat transfer coefficient, energy extraction rate etc, have been reported in this work.

Key words: Waste heat recovery, Heat transfer Fluid, finned tube heat exchanger, Diesel engine exhaust

1. INTRODUCTION

Energy is an important entity for economic development of any country .At present scenario the rapid industrial growth is the main reason for the crisis of energy and also for pollution. Diesel engine are now widely used device in all industrial application starting from gas turbine power plant .Nearly about 2/3 rd of energy are now wasted through the exhaust gas which is indirectly cause of global warming and overall energy requirement . Depending on the temperature level of exhaust stream and proposed application, different heat exchanger devices, heat pipes combustion equipments has been employed to facilitate the use of recovered heat. Previously Shell and tube heat exchanger was widely used as industrial heat transfer equipments. Here only plain tube was used with assembling of fins. But now a day's modified tube are using for proper exchanging of heat just like finned tube. Selecting the castor oil as HTF is that it has higher heat transfer coefficients than the gasses. And also it minimizes the size of the heat exchanger. Castor oil is a one type of bio-fuel which is formed from Veranda trees. It has better thermal properties than the water [1]. The trade in castor oil as an item of commerce goes back to antiquity. The oil is obtained from extracting expressing the seed of a plant which has the botanical name Ricinus communis of the family Eurphorbiacae (kirk- Othmer, 1979)[2]. The oil is not only a naturally- occurring resource, it is inexpensive and environmentally friendly. Castor oil is viscous, pale yellow non-volatile and non-drying oil with a bland taste and sometimes used as a purgative. It has a slight characteristics odor while the crude oil tastes slightly acrinauseating after-taste[3]. Relative to other vegetables, it has a good shelf life and it does not turn rancid unless subjected to excessive heat. India is the world largest exporter of castor oil. Finned tube heat exchanger has selected as it has high compactness. Extended surfaces has provide for better heat transfer rate in the exchanger. Water is well nominated heat transfer fluid in industries. But better effectiveness can be achieved when some experimental fluid like castor oil is applied [4]. However much heat could be recovered and losses can be minimized which is shown in this paper. Desai and Bannur[5]have performed experiments in a twin cylinder diesel engine, to recover heat from engine exhaust using a shell and tube heat exchanger. Morcos[6]has studied the performance of shell and dimpled tube heat exchanger for waste heat recovery. Here the exchanger duty, overall heat transfer coefficient effectiveness and tube side friction factor are investigated on the tube surface geometry. He also discussed regarding the flow pattern in the tube at various Reynolds number. Anderson and Robert Nation [7] have worked on heat exchanger using two different liquids operating at different pressure and temperature. V.Pandiyaranjan, and E.

Malan[8] has worked on a finned tube heat exchanger and reported regarding heat exchanger effectiveness and other parameters .

2. EXPERIMENTAL INVESTIGATION

The major criterion in the design of waste heat recovery system is the proper selection of heat exchanger with optimum conditions. In the present investigation, the objective is to extract heat from the exhaust gas. This could be achieved either by embedding the heat exchanger coil surface in-side the storage tank where the storage material is present and allowed to pass through the exhaust gas through the heat exchanger coil or providing a separate heat exchanger through which HTF is circulated to extract heat from the exhaust gas and deliver it to the storage medium present in the TES tank The HRHE is fitted into the exhaust pipe of the engine. The exhaust gas from the engine is allowed to flow either to the heat exchanger or to the atmosphere by using valves. Castor oil circulated through tube side of the heat exchanger using gear pump [8].

3.GEOMETRICAL MODELLING

The geometry of finned tube heat exchanger has been modeled on Gambit. The heat exchanger specification used for present work has been shown in the Table 1 given below.

1	Shell outer diameter	323 mm
2	Shell thickness	6mm
3	Fin thickness	2 mm
4	Fin height	6mm
5	Tube outer diameter	12.5 mm
6	Tube thickness	1.65mm
7	Length of the shell	500 mm
8	No of tube inside the shell	36
9	Transverse pitch	37.5 mm
10	Longitudinal pitch	37.5 mm

The shell material, fin and tube materials is mild steel, and copper respectively. Longitudinal type of fin tube has been used and inline square arrangement has been adopted. The girded view has shown in fig 3.1.1 & fig3.1.2 respectively.

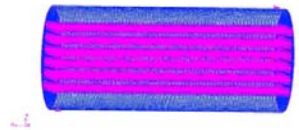

Fig 3.1.1:- Grided view of Heat exchanger

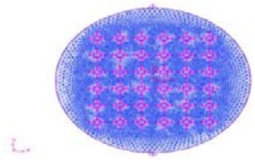

Fig 3.1.2:- C.S view of gridded heat exchanger

4. PROPERTIES OF WORKING FLUID

The model which has been developed on gambit is taken for further analysis. Here water and castor oil has taken as heat transfer fluid .Castor oil having better thermal properties than water is used as heat transfer fluid. As boiling point of water is 100 degC where as for castor oil it is 313 deg C . [6].For shell side fluid exhaust gas from 15 HP diesel engine has been considered [5].

5. DATA COLLECTION AND ANALYSIS:-

The shell side fluid is exhaust gas which is coming from a 15 HP diesel engine exhaust and having temperature of 120^0C [8].The tube side fluid temperature is taken as 25^oC and 35^0C respectively. Keeping shell side fluid velocity constant and only varying the tube side velocity at various condition, analysis has been done. Here Nusselt no is the most important dimensionless parameter and is dependent on another factor called friction factor. The expression for Nusselt No is given by

$$\frac{\left(\frac{f}{2}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{2}\right)^{\left(\frac{1}{2}\right)}\left(Pr^{(2/3)}-1\right)}$$

Where f= friction factor and is given by

f =

Re and Pr are the Reynolds and Prandtl no at the corresponding temperature [10].

6. RESULT AND DISCUSSION:-

After the exporting the model into the fluent the analysis has done in two step. In first step water is taken into consideration. All the analysis has been done at five different fluid velocities. Similarly for castor oil same thing is done.

6.1. ANALYSIS WITH WATER:-

Taking the inlet condition velocity inlet and out let condition is pressure outlet the temperature rise along the tube surfaces and pressure drop along the tube has been observed by some of the temperature contour and plot are given in the following figure.

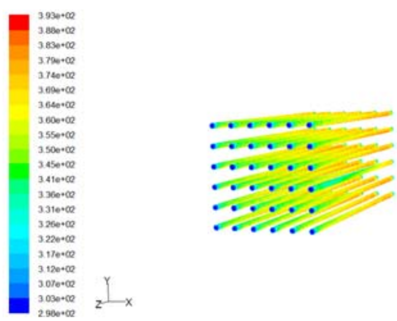

Fig 6.1.1:- Temperature contour of tube @
V= 0.85 m/s

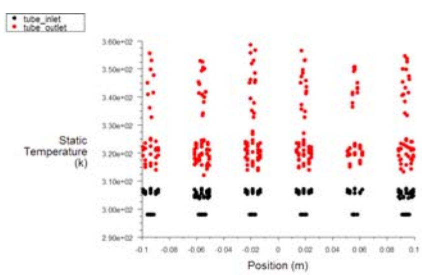

Fig.6.1.2:- Temperature Plot for tube

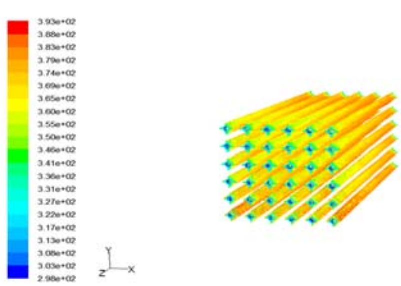

Fig.6.1.3:- Temperature contour for Fins

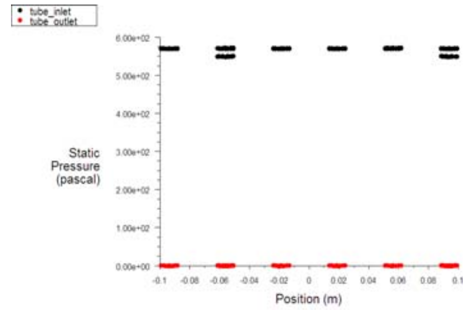

Fig.6.1.4:- Pressure drop along the tube

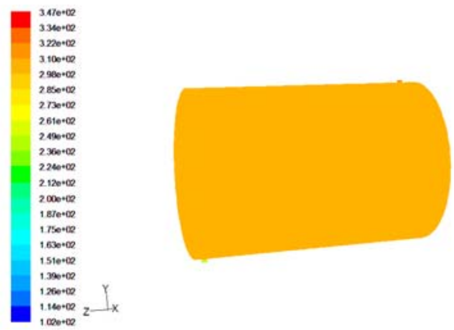

Fig. 6.1.5:- Temperature contour for shell wall and inlet and out let.

All these results are obtained from the analysis using water as heat transfer fluid at 0.85 m/s velocity. Similarly five times analysis has taken. From all above figure it is clearly observed that temperature increases along the fins tube and in case of shell the temperature is decreasing. All result has been shown in various the graph and plots.

6.2. ANALYSIS WITH CASTOR OIL:-

Temperature rise along the tube surfaces and pressure drop along the tube has been observed by some of the temperature contour and plot is given in the following figure. Here inlet temperature for tube inlet is more than the water inlet.

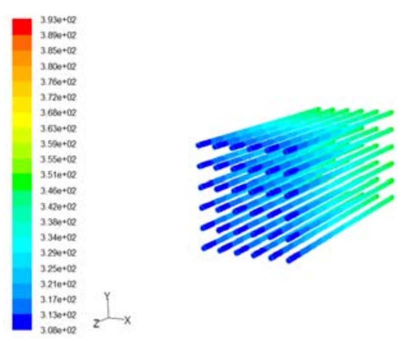

Fig.6.2.1:- Temperature contour for tube @ V= 0.85m/s.

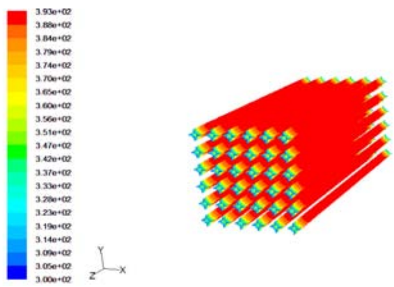

Fig. 6.2.2:- Temperature contour for Fins tube.

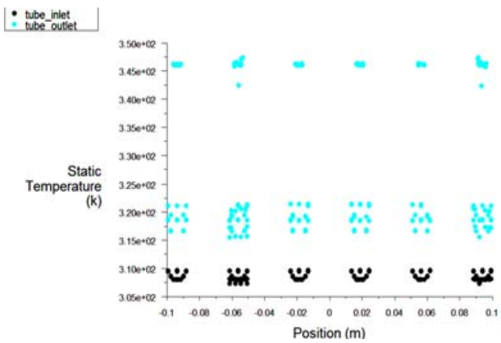

Fig.6.2.3:- Temperature plot for tube.

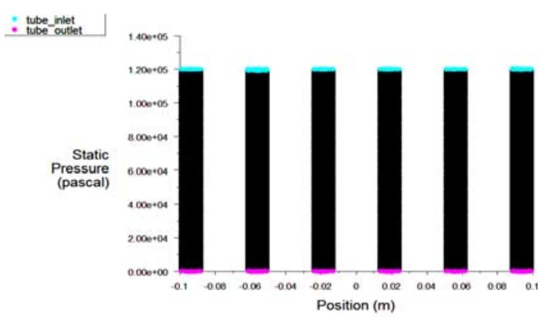

Fig6.2.4:- Pressure drop along the tube surfaces.

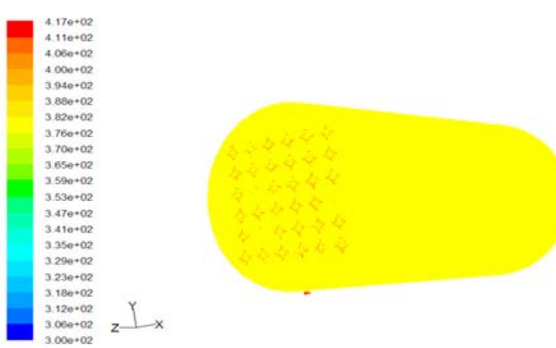

Fig. 6.2.5:- Temperature contour for shell wall and inlet and out let.

]From above analysis it is evident that heat transfer is more in case of castor oil than water when used. All results are compared with the help of various plot in following figures.

6.3. Comparison between the obtained result:-

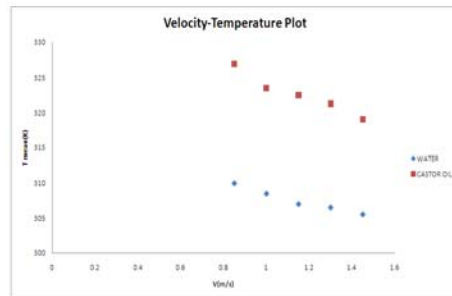

Fig.6.3.1:- Velocity Vs Temperature plot for both fluids.

From above figure it is clear that with the increasing of velocity the temperature is also increased for both fluids .but in case of castor oil the rate is more.

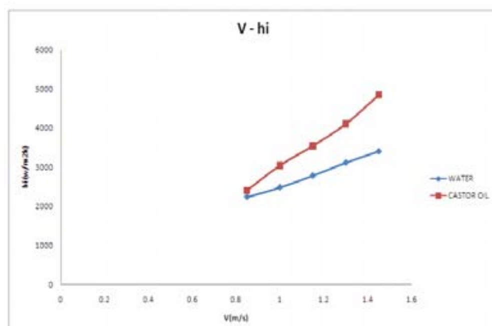

Fig.6.3.2:- Velocity Vs Inner heat transfer coefficient.

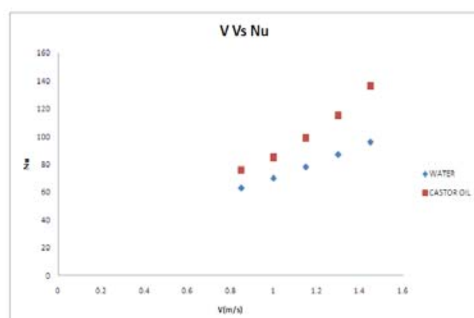

Fig6.3.3:- Velocity Vs Nusselt No

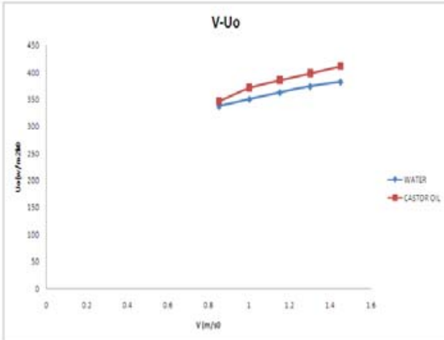

Fig.6.3.4:- Velocity Vs Overall heat transfer coefficient.

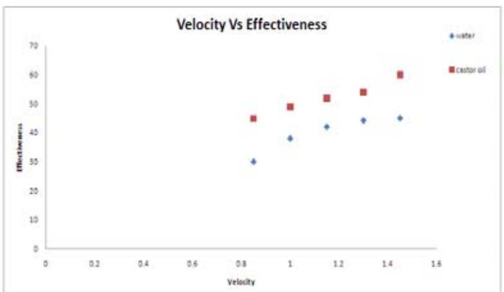

Fig .6.3.5:- Velocity Vs Effectiveness

So from the above contour and plot it is visible that after increasing the velocity of both fluids temperature of shell side fluid decreases and tube side fluids increases after exchanging the heat with each others. Since shell side fluid become mixed along the path of the flow therefore shell side fluid's exit temperature become nearly uniform. Pressure drop is observed quite high which denotes the necessities the large pumping power. The pressure drop across the exhaust side is very low which means that there is no back pressure and hence there is no effect on working in the engine shell side fluid is a gas. And we know that viscosity of gas increases with increasing in temperature. Therefore shell side Reynold number (Re) decreases with increasing in mean temperature.

6.4. Comparisons between the computational and experimental work

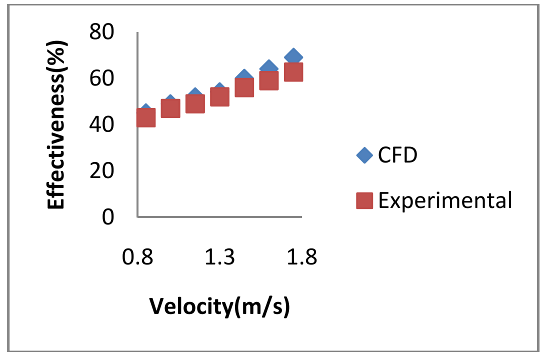

Fig 6.4.1 :-Experimental and CFD comparision of effectiveness (ε)

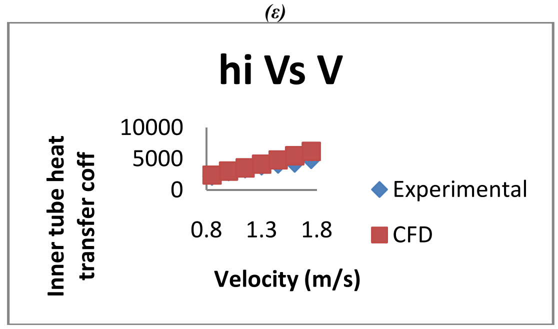

Fig 6.4.2:-Experimental and CFD comparision of Inner Tube Heat transfer cofficient (h_i)

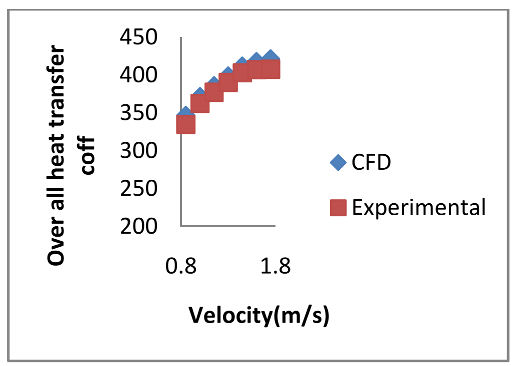

Fig 6.4.3:- Experimental and CFD comparison of Overall heat transfer coefficient (Uo)

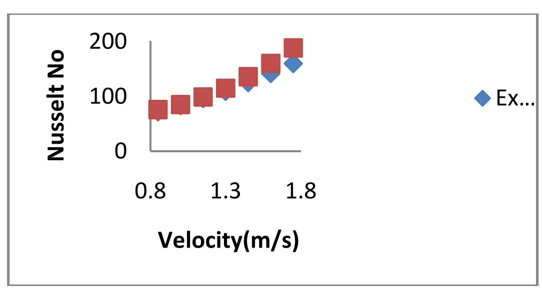

Fig 6.4.4 :-Nusselt No.(Nu) comparision between Experimental and computational.

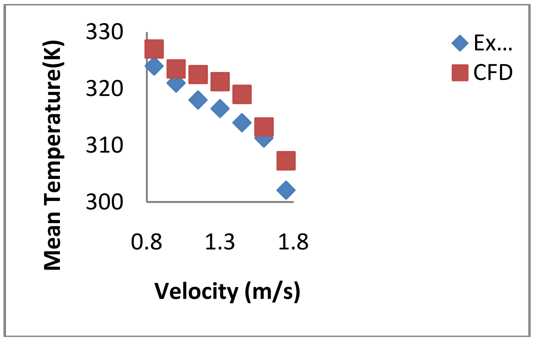

Fig 6.4.5:- Mean Temperature (k) comparision between CFD and experimental work

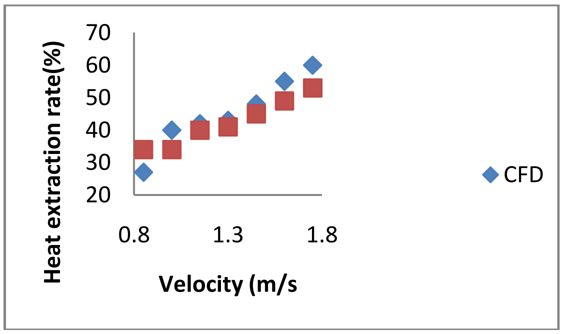

Fig 6.4.7 :- Heat extraction rate comparison (E)

In case of tube temperature there is decrease in temperature drop which is might be due to decreased residence time of the fluid . and increasing in heat transfer coefficient is due to the turbulent flow and the flow rate does not greatly changes the wall effect. As increasing the velocity all the other dimensionless no like Nusselt no(Nu), Prandtl No(Pr), is increasing . This effect greatly changes the effectiveness. In case of Overall heat heat transfer coefficient (Uo) same condition can be applied. Friction factor (f) is mainly depends on tube inner surface roughness. Though it's variation is not that much but due to velocity and viscosity of the fluid effect it's reduces in a small amount. Hence from above discussion it can be clearly said that castor oil gives better effectiveness than the water though it is costlier than the water. From fig 5.4.1 to 5.4.7 all are the graphical representation of experimental and computational comparisons. It is obvious from above discussion that the a considerable percentages of error has been achieved between both analysis which is a good agreement of the used correlation for Nusselt number. This percentages of error is 5.3%.

7. CONCLUSIONS:-

An investigation was carried out to study the shell and finned tube heat exchanger computationally. The analysis has done and pressure drop and temperature rise along the tube surfaces has been investigated. Based on the obtained result it can be concluded as follows

1. Temperature variation with same velocity of castor oil and water is greatly noticeable. This is due to better thermal properties of castor oil than the water.
2. All dimensionless parameters are changes for their own properties such as specific heat, viscosity, density, and thermal conductivity properties.
3. Better effectiveness can be achieved by using castor oil as heat transfer fluid whereas water gives the traditional effectiveness. The effectiveness of the finned tube heat exchanger is quite comparable with other conventional heat exchanger
4. The results from the computational analysis appear to be in good agreement with the available experimental results.
5. Energy extraction rate is also quite significant

.That means a sufficient amount of heat can be recovered by the using of finned tube heat exchanger.

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