© 2017 IJSRSET | Volume 3 | Issue 3| Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Analysis of Shell and Tube Heat Exchanger With and Without Fins for Waste Heat Recovery Applications Using CFD

Deelip Kumar*, Ashish Muchrikar
Corporate Institute of Science & Technology, Bhopal Madhya Pradesh, India

ABSTRACT

Waste heat is defined as a process by fuel combustion or chemical reaction, and then dumped into the environment. The strategy how to recover this heat depends upon part on the temperature of waste heat gases and economics involved. At present scenario the rapid industrial growth is the main reasons for crisis of energy, also for pollution. Diesel engine is widely used device in all industrial application. Nearly about 2/3rd energy is now wasted through the exhaust gas, which is indirectly caused of global warming and overall requirement of energy. The energy available in the exit stream of many energy conversion devices such as I.C. Engine gas turbine etc. goes as waste and if not utilize properly. The present work has been carried out for predicting performance of shell & finned tube heat exchanger in light of waste heat recovery applications. The performance of heat exchanger has been evaluated by using CFD package ANSYS 15.0. An attempt been made for predict the performance in term of heat flux available with and without fins with different heat transfer fluids & results obtained have been compared. The performance parameters pertaining to heat exchanger such as heat flux from Tube internal side fluid & tube external side fluids, heat transfer coefficient from both the fluids.

Keywords : Waste heat, Heat Exchanger, CFD, Heat Transfer Coefficient, ANSYS.

I. INTRODUCTION

1.1 Historical Review

Many industries and facilities have implemented different methods of waste heat recovery. One popular choice is using a shell and tube heat exchanger. According to the Energy Efficiency Guide for Industry in Asia, these exchangers are best suited for recovery methods dealing with warming liquids with heat recovered from:

- ✓ Condensates from process steam, distillation processes or refrigeration, or air-conditioning systems
- ✓ Coolants from engines, lubricants, bearings, air compressors, furnace doors, pipes or grates
- ✓ Flue gas streams and exhaust streams from furnaces, dryers and exhaust stacks

The waste heat usually flows shell side, while the liquid is positioned tube side. This is because the higher-pressure liquid or vapor should be in the tube, because the shell is the weaker container. Utility fluids and products being heated can also be kept cleaner on the tube side of a heat exchanger. Waste heat typically produces condensation. Allowing condensates to form on the inside of the tube will typically cause flow irregularities and could lead to problems with the exchanger.

1.2 Theory And Application

Two fluids, of different starting temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, leading to the use of many tubes. In this way, waste heat can be put to use. This is an efficient way to conserve energy.

Heat exchangers with only one phase (liquid or gas) on each side can be called one-phase or single-phase heat exchangers. Two-phase heat exchangers can be used to heat a liquid to boil it into a gas (vapor), sometimes called boilers, or cool a vapor to condense it into a liquid (called condensers), with the phase change usually occurring on the shell side. Boilers in steam engine locomotives are typically large, usually cylindrically-shaped shell-and-tube heat exchangers. In large power plants with steam-driven turbines, shell-and-tube surface condensers are used to condense the exhaust steam exiting the turbine into condensate water which is recycled back to be turned into steam in the steam generator.

1.3 Waste Heat Recovery through Heat Exchangers

1.3.1 Sources of Waste Heat Waste heat can be classified into three categories according to the temperature such as

- ✓ High Temperature range- refers to temperature above 650 ^{0}C
- ✓ Medium temperature range- 230 ^{0}C – 650 ^{0}C
- ✓ Low temperature range : below 230 ^{0}C High and medium temperature range waste heat is released by furnaces while low temperature range waste heat is released by devices like condenser, solar flat plate collector, etc.

1.3.2 Potential Applications of Waste Heat

- ✓ Exhaust gas in the high temperature range can be used to preheat the combustion air for Boilers using air preheated , Furnaces using recuperators Ovens using recuperators Gas turbine using recuperators
- ✓ Medium temperature exhaust gases can be used to preheat boiling feed water using economizer.
- ✓ Exhaust gases in the low temperature range and warm cooling water from condenser can be used to heat water or other feed stock (solid) in industrial processes.
- ✓ High and medium temperature exhaust can be used to generate steam from waste heat boiler to produce process steam, heat and electricity.
- ✓ Waste heat can be utilized to run absorption refrigeration systems for air conditioning etc.

1.4 Essential considerations in making optional choice of waste heat recovery device:

- ✓ Temperature of waste heat. (Temperature is a measure of quality of waste heat)
- ✓ Flow rate of the fluid
- ✓ Chemical composition of waste fluid
- ✓ Properties of waste fluid (Cp, μ, ρ, κ)
- ✓ Allowable pressure drop
- ✓ Minimum temperature to which waste heat can be cooled
- ✓ Corrosive elements in the exhaust fluid
- ✓ Temperature to which the designed fluid is to be heated

II. LITERATURE REVIEW

M. Thirumarimurugan, T.Kannadasan and E.Ramasamy [2003] have investigated heat transfer study on a solvent and solution by using Shell and Tube Heat Exchanger. In which Steam is taken as the hot fluid and Water and acetic acid-Water miscible solution taken as cold fluid. A series of runs were made between steam and water, steam and Acetic acid solution .The flow rate of the cold fluid is maintained from 120 to 720 lph and the volume fraction of Acetic acid is varied from 10-50%. Experimental results such as exchanger effectiveness, overall heat transfer coefficients were calculated. . MATLAB program was used to simulate a mathematical model for the outlet temperatures of both the Shell and Tube side fluids. The effect of different cold side flow rates and different compositions of cold fluid on the shell outlet temperature, tube outlet temperature and overall heat transfer coefficients were studied. Result shows that the overall effectiveness of heat exchanger was found to increase with decrease in composition of water. From the comparisons it can be said that the mathematical model developed and simulated using MATLAB and compared with the experimental values for the system is very close.
Huadong Li and Volker Kott Ke (2015) conducted experiments on the Effect of leakage on pressure drop and local heat transfer in shell and tube heat exchangers for staggered has slight contribution to the local heat transfer at the surfaces of the external tubes of the tube bundle, but reduces greatly the per-compartment average heat transfer.
Qiao He and Wennan Zhang 2016) presented a theoretical analysis and an experimental test on a shell and tube latent heat storage exchanger. The prediction by the mathematical model on the performance of the heat storage exchanger is reasonable and in agreement with experimental measurements. The experimental outcome confirms that helically corrugated tubes are particularly effective in enhancing convective heat

transfer for generalized Reynolds number ranging from about 800 to the limit of the transitional flow regime.

Hosseini et al (2016), they experimentally obtained the heat transfer coefficient and pressure drop on the shell side of a shell and tube heat exchanger for three different types of copper tubes (smooth, corrugated and with micro-fins). Corrugated and micro fin tubes have shown degradation of performance at a Reynolds number below a certain value (NRe < 400). At a higher Reynolds number the performance of the heat exchanger greatly improved for micro finned tubes.Tan and Fok (2006) developed an educational computer aided design tool for shell and tube heat exchanger that integrates thermo hydraulics analysis with mechanical design.

III. ANALYSIS DESIGN PARAMETER

The geometry of shell and tube heat exchanger and fins &baffles have been modeled on CATIA V5R20 software and ANSYS design modeler.

Table 1. Geometric modeling details

Shell outer diameter (Do)	168.30 mm
Shell thickness (ts)	18.30 mm
Fin thickness (tf)	1 mm
Fin height (hf)	8 mm
Tube outer diameter (do)	19.1 mm
Tube thickness (tT)	3.302 mm
Length of the shell (Ls)	600 mm
No. of tubes inside the shell (n)	7
Transverse pitch(ST)	38.971 mm
Longitudinal pitch(SL)	22.5 mm
Total no .of baffles inside the shell (Nb)	6
No. of C type baffles inside the shell(Ncb)	3
No. of D type baffles inside the shell(Ndb)	3
Baffles thickness(Cut Segmental) (tb)	4 mm
Baffles arc(Cut Segmental) (**ba**)	75 mm
Baffles horizontal length (Bhl)	145.616 mm
Distance between baffles D to C (Bdc)	81.5 mm
Distance between baffles D to D (Bdd)	167.5 mm
Distance between 1 finned tube to another finned tube (SD)	45 mm

Figure 1. Analysis Setup

IV. ANALYSIS AND TEST DATA

To perform analysis is done on the following test data available are shown in Table 1. Based on the analysis in the investigation measurements through Computational Fluid Dynamics (CFD) software employed, the uncertainties in the measurement .

Table 2. Properties of working fluid

Fluid	properties	values
Shell side (Exhaust Gas) at inlet temperature 400 k	Density	0.871 Kg/m3
	Specific Heat	1014 j/kg-k
	Thermal conductivity	0.0336 w/m-k
	Viscosity	0.000023 kg/m-s
Tube side (transformer oil) at Inlet temperature 308 k	Density	890 Kg/m^3
	Specific Heat	2060 j/kg-k
	Thermal conductivity	0.12 w/m-k
	Viscosity	0.01664 kg/m-s

V. RESULT AND DISCUSSION

After the exporting the model into analysis has done in two steps. In first step fluent analysis of without fin for the Shell and tube heat exchanger at three different fluid velocities is taken into consideration. All the analysis has been done. In same as with fin for the Shell and tube heat exchanger.

Fluent analysis of without fin for the heat exchanger

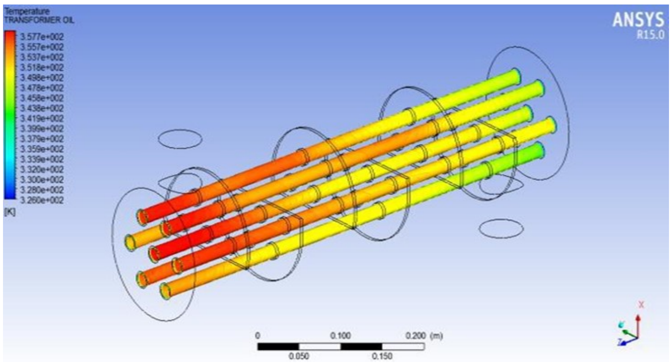

Figure.2.a. Temperature distribution for the Transformer oil without fin at tube inlet velocity is 0.04m/s

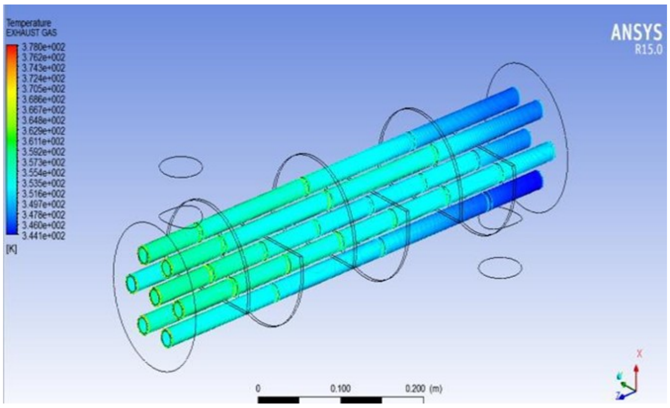

Figure 2. b: Temperature distribution for the Exhaust gas without fin at tube inlet velocity is 0.04m/s

On the other hand, temperature of exhaust gas is decreasing rapidly there are two reasons for this first is exhaust is continuously expanding and other is because tubes are absorbing heat from gas. Show in the figure 2.c and 2.d

Fluent analysis of with fin for the heat exchanger

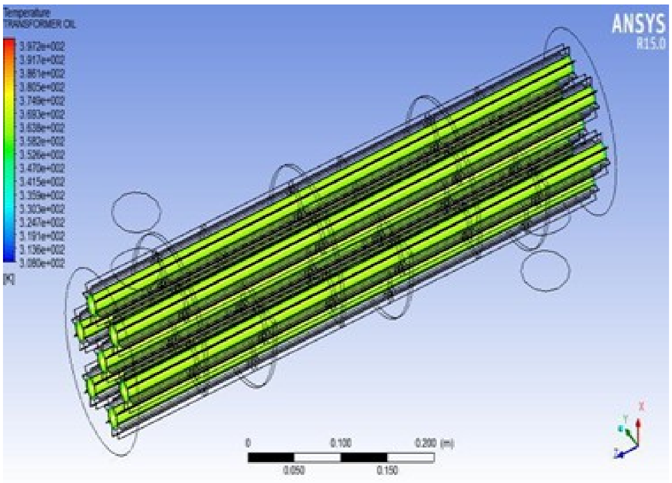

Figure 2.c. Temperature distribution for the Transformer oil with fin at tube inlet velocity is 0.04m/s

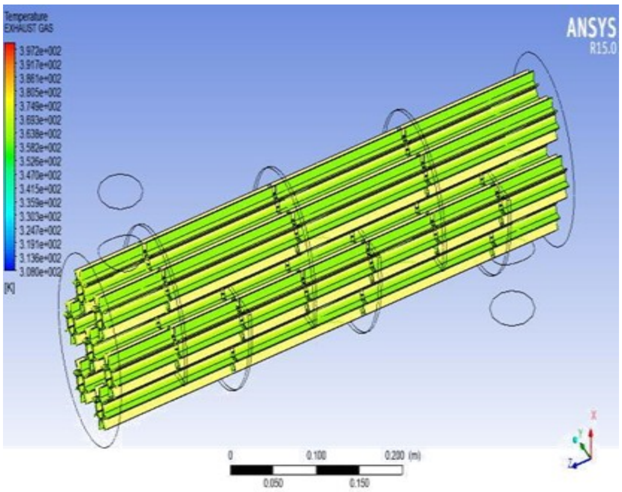

Figure 2.d. Temperature distribution for the Exhaust gas with fin at tube inlet velocity is 0.04m

VI. FINAL ANNULMENT

6.1 Without Fin

As tube side inlet velocity increases from 0.04m/s by keeping shell side velocity constant the temperature at the outlet of tubes is decreasing and pressure is almost same. As velocity is increased total time for contacting surface to tubes will be decreasing and gas will goes on simply expanding. Similarly velocity 0.06, 0.09 is simulated and desired results are found and then statements are concluded.

6.2 With fin

As tube side inlet velocity increases from 0.04m/s by keeping shell side velocity constant the temperature at the outlet of tubes is decreasing because of additional surfaces of fins there is more turbulence this is because less decrement in temperature and pressure is varying for each simulation (0.04, 0.06, 0.09). As velocity is increased total time for contacting surface to tubes will be decreasing in this case fins are impeding gas flow so less heat is wasted compare to without fin design. Similarly velocity 0.06, 0.09 is simulated and desired results are found and then statements are concluded

6.3 CFD analysis of shell and tube heat exchanger output without fins

Table 3 Heat exchanger without fin at tube inlet velocity 0.04 m/s, 0.06 m/s, 0.09 m/s comparison of Average temperature (K), pressure (pa), velocity (m/sec)

Velocity m/s	0.04	0.06	0.09
	Oil	Oil	Oil
Shell Inlet K	400	400	400
Shell outlet K	362.226	361.698	361.707
Tube inlet K	308	308	308
Tube Outlet K	315.5917	313.475	311.871
Shell inlet (Pa)	8.27938	8.27938	8.27938
Shell Outlet (Pa)	0	0	0
Tube inlet (Pa)	50.798	70.7029	116.2084
Tube Outlet (Pa)	0	0	0
Shell Inlet (m/Sec)	2	2	2
Shell outlet (m/Sec)	2.10456	2.10652	2.13378
Tube inlet (m/Sec)	0.04	0.06	0.09
Tube Outlet (m/Sec)	0.04969	0.07454	0.111813

Table 4 Heat exchanger Without fin at tube inlet velocity 0.04 m/s, 0.06 m/sec, 0.09 m/sec comparison of Average of heat flux and Average of heat transfer coefficient.

Velocity m/s	0.04	0.06	0.09
	Oil	Oil	Oil
Average of Internal side heat transfer coefficient (hi) [W m^-2 K^-1]	118.84	118.84	118.84
Average of External side heat Transfer coefficient (he) [Wm^-2 K^1]	91.27	91.2792	91.209
Average of Internal side heat flux (qi) [W m^-2]	3584.98	3874.64	4105.56
Average of External side heat flux(qe) [W m^-2]	651.170	651.170	678.717

6.4 CFD analysis of shell and tube heat exchanger output with fins

Table 5 Heat exchanger With fin at tube inlet velocity 0.04 m/s, 0.06 m/s, 0.09 m/s comparison of average temperature, pressure, velocity

Velocity m/s	0.04	0.06	0.09
	Oil	Oil	Oil
Shell Inlet K	400	400	400
Shell outlet K	360.2 25	360.8 34	361.7 79
Tube inlet K	308	308	308
Tube Outlet K	316.7 45	314.3 19	312.7 20
Shell inlet (Pa)	12.0 301	15.4 93	8.06 938
Shell Outlet (Pa)	0	0	0
Tube inlet (Pa)	50.7 039	76.7 214	116.2084
Tube Outlet (Pa)	0	0	0
Shell Inlet (m/Sec)	2	2	2
Shell outlet (m/Sec)	2.070 55	2.046 75	2.054 66
Tube inlet (m/Sec)	0.04	0.06	0.09
Tube Outlet (m/Sec)	0.050 55	0.075	0.113

Table 6. Heat exchanger With fin at tube inlet velocity 0.04 m/s, 0.06 m/sec, 0.09 m/sec comparison of average heat flux and average heat transfer coefficient

Velocity m/s	0.04	0.06	0.09
	Oil	Oil	Oil
Average of Internal side heat transfer coefficient (hi) [W m^-2 K^-1]	128.104	128.104	128.104

Average of External side heat Transfer coefficient (he) [Wm^-2 K^1]	127.6022	127.6837	127.683
Average of Internal side heat flux (qi) [W m^-2]	4151.1471	4500.49	5038.81
Average of External side heat flux(qe) [W m^-2]	-99.9305	-207.195	-186.98

Shell side temperature at outlet is almost same in all three case of velocity but at the outlet of tubes the temperature is decreasing but comparing without fins design temperature at outlet is always higher, mass average pressure increasing from inlet to outlet with same rate with and without fins. Mass flow averaged velocity is increasing with same rate in all three cases by 26.375% for 0.04 m/s, 26.3783% for 0.06 m/s, 26.3731% for 0.09 m/s. Internal and external heat transfer coefficient is almost constant irrespective velocities at inlet of the tubes. Increasing velocity causing increase in internal heat flux comparing this with design of heat exchanger without fins it has increased by 15.79% at 0.04 m/s, 16.15 % at 0.06 m/s, 22.7% at 0.09 m/s. Conversely, External heat flux is decreasing as inlet velocity increasing and comparing this values with design of heat exchanger without fins, the value is 6.5162 times more than value of same for design heat exchanger without fins at velocity 0.04 m/s, for 0.06 m/s it is 3.22 times more, for 0.09 m/s it is 3.6298 times more.

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