CFD Analysis of Heat Transfer in Shell and Tube Heat Exchanger with and without Alumina Nano-Particles in the Shell Fluid

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Abstract— In our present study an attempt is made to analyze heat transfer in shell and tube heat exchanger with the help of Ansys fluent 14.5.Two cases have been analyzed. Case-1 Heat transfer in shell and tube heat exchanger with working fluid as water at tube side as well as shell side (i.e. water without alumina, Al2O3 nanoparticles). Case-2 Heat transfer in shell and tube heat exchanger with tube side fluid as water and shell side fluid as water with addition of alumina nano-particles of size 38 nm at volume fractions of 4%. From result obtained it is observed that heat transfer is more in shell and tube heat exchanger when nano-particles are added to the water compared with the without nano-particles in the water.

Key words: CFD, Ansys Fluent 14.5, Shell and Tube Heat Exchanger, Nano-Particles

I. Introduction

A heat exchanger is a device which is used to transfer heat from one fluid to another fluid without any direct contact between the fluids. The purpose of heat exchanger is just that--to exchange heat [1]. In heat exchanger there must be a fluid that requires a change in energy (heating or cooling) and a fluid that can provide that energy change. Heat exchangers have significant applications in process industry, mechanical equipments industry and home appliances [2]. There are many types of heat exchangers are present, among them the most important and widely used one is 'Shell and tube heat exchanger'. Shell and tube type heat exchanger is an indirect contact type heat exchanger as it consists of a series connected with tubes, through which one of the fluids runs. The shell can be a container for the shell fluid. Working of heat exchanger is based on the principle of counter flow heat exchanger. Hot water enters the tubes from one end-cap, passes through the tubes and leaves through the other end-cap. Cold water enters the shell-side of the heat exchanger through the inlet port on the shell. For this particular project a single pass shell is considered, and water is used as both the hot and cold fluid. Cooling water or cold water flows through the shell, and hot water flows through the tube. Heat transfer occurs in both directions; the hot water is cooled, and the cooling water is heated [3]. Heat transfer efficiency can also be improved by increasing the thermal conductivity of the working fluid [4].High thermal conductivity of solids can be used to increase the thermal conductivity of the fluid by adding small solid particles to that fluid. Nano-fluid is a mixture of nano sized particles of size up to 100 nm and a base fluid. In this the working fluid is nano-fluid. Nano-fluid is made by the suspending nano-particles in the fluid like water, ethylene glycol and oil, hydrocarbons, fluorocarbons etc [5]. Table-1 gives the properties of alumina nano-particles at temperature 298 K. Table-2 gives the properties of water based alumina nano-fluid at different volume fractions at temperature, T_0 = 298 K [6]. In this study we are considering two cases. Case one: shell fluid without alumina nano-particles, and case two is: shell fluid with alumina nano-particles at volume fractions of 4%. The size of the alumina nano-particles is 38 nm.

II. Computational Study

The shell and tube heat exchanger is modeled using ansys fluent. Fig.1 is the model view of shell and tube heat exchanger. The tube consists of six channels. Pyramid shaped end caps were attached to the two end channels and this pyramid shaped end caps acts as inlet and outlet for the tube-side fluid as shown in the fig.1. The geometry of the tube/channel cross section is as shown in fig.2.The dimensions such as height, width, and length of the tube used in shell and tube heat exchanger are given in table-3. Table-4 gives the velocity magnitude of working fluid.

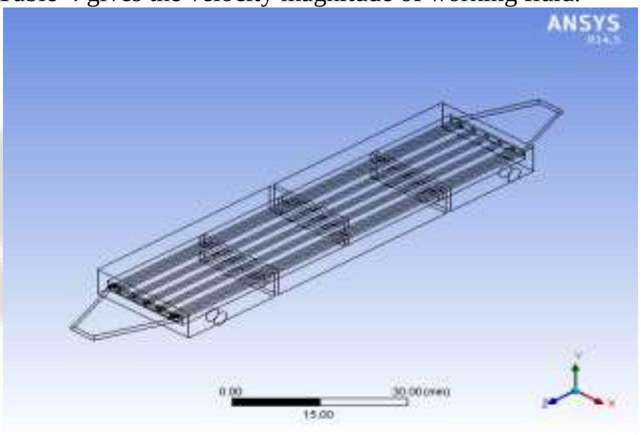

Fig. 1: Model view of shell and tube heat exchanger.

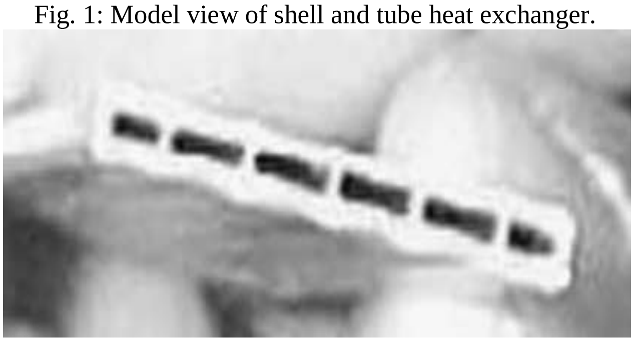

Fig. 2: Geometry description

	Density (ρ) (kg/m3	Specific heat Cp (J/kg K	Thermal conductivity k (W/mK
Alumina (Al_2O_3)	3880	773	36

Table 1: Properties of alumina nano-particles at 298 K

Nanoparticle volume fraction ϕ	Density ρ (kg/m^3)	Specific heat Cp (J/kg K)	Dynamic viscosity μ (Pa·s)
0%	998.2	4182	$998e^{-6}$
1%	1027	4053	$1083e^{-6}$

4%	1113	3707	$1486e^{-6}$

Table 2: Properties of water based alumina nano-fluid at different volume fractions at T_0 = 298 K

Channels/tube	**Dimensions**		
	Height	**Width**	**Length**
1st channel	1.0 mm	1.45+0.5 mm	661 mm
2nd channel	1.0mm	2.65 mm	661 mm
3rd channel	1.0 mm	2.65 mm	661 mm
4th channel	1.0 mm	2.65 mm	661 mm
5th channel	1.0 mm	2.65 mm	661 mm
6th channel	1.0 mm	1.45+0.5 mm	661 mm

Table 3: Dimensions of channel/tube

Part	**Velocity of water in m/s**
Tube	1.75
Shell	3.25

Table 4: Velocity magnitude of working fluid

Ansys Fluent 14.5 is used to mesh the shell and tube heat exchanger. Ansys Fluent 14.5 commercial package was used to perform the CFD simulations. Fig.3 shows the meshed geometry of the shell and tube heat exchanger which is used for this particular study. In meshing method we can specify the type of mesh we want to create, for example quad, tri, quad or tri etc. Table-5 gives the mesh information of shell and tube heat exchanger.

No. Of Elements	1123629
No. of nodes	197964

Table 5: Mesh information of shell and tube heat exchanger

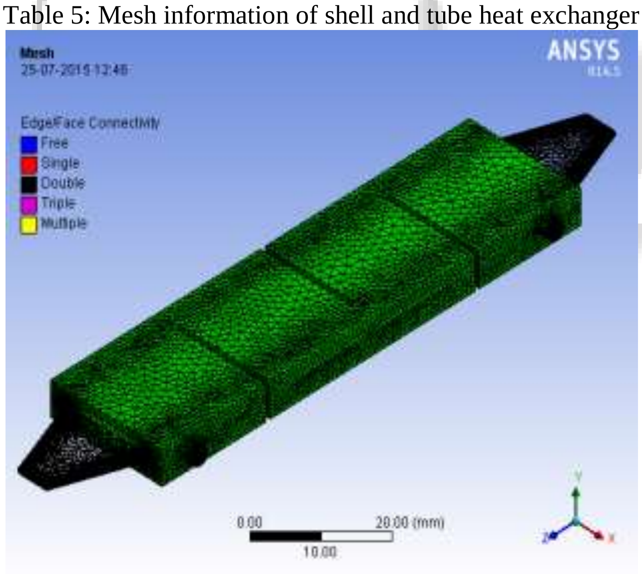

Fig. 3: Meshed geometry for shell &tube heat exchanger

III. COMPUTATIONAL MODELING

A. *Governing Equations*

1) *The standard k-ε model*

The standard *k-ε* model is a two-equation model that computes the Reynolds stresses by solving two additional transport equations, which are for the turbulence kinetic energy, *k* , and the dissipation rate of turbulence, ε.

$$\frac{\partial(\sigma k)}{\partial t} + \mathrm{div}(\rho k U) = \mathrm{div}[\frac{\mu_t}{\sigma_k}\mathrm{grad}\, k] + 2\mu_t E_{ij}.E_{ij} - \rho\varepsilon$$

Where E_{ij} is the mean rate of deformation tensor

$$\frac{\partial(\sigma k)}{\partial t} + \mathrm{div}(\rho\varepsilon U) = \mathrm{div}[\frac{\mu_t}{\sigma_\varepsilon}\mathrm{grad}\,\varepsilon] + C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}.E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

$$\mu_t = C_\mu \rho \frac{k^2}{\varepsilon}$$

B. *Boundary Conditions*

For computational purpose domain is defined with boundary conditions. General solution setup is taken as pressure based solver with absolute velocity in steady condition. Table-6 gives brief inputs given to solver stage

General setup	Pressure based solver is chosen with considering absolute velocity formulation and steady time.
Models	Models are considered having energy transfer between fluids and flow is viscous standard k-e with standard wall Fn
materials	Fluid- water Solid- Aluminum
Boundary conditions	Cold fluid- 298K Hot fluid-320 K
Solution controls	Relaxation factors Pressure:0.3 Density:1 Body forces:1 Momentum:0.7
Solution initialization	Setting gauge pressure, x and y velocities to zero, z velocity to -1.25601 m/s and keeping turbulent kinetic energy and turbulent dissipation rate at unity
Run calculation	Number of iteration=3000 profile update interval=1

Table 6: Solver Inputs

IV. RESULTS AND DISCUSSION

The heat transfer analysis of shell and tube heat exchanger is done for two cases one is without nano-particles and another is with nano-particles in shell fluid (water) for same initial and boundary conditions.

A. *Temperature Streamline*

Fig.4 shows the temperature streamline in shell and tube heat exchanger. Hot water flows through the tubes and cold water flows through the shell. Heat transfer takes place from the hot fluid to the cold fluid by means of conduction. There is no direct contact between the hot fluid and cold fluid. Temperature streamline represents the temperature of working fluid at different parts of the shell and tube heat exchanger. In the fig.4 green color represents the cold water and, red and yellow color represents the hot water in the tube. The maximum temperature is 320 K and the minimum temperature is 298 K. The hot water enters the tube at 320 K and the cold water enters the shell at 298 K.

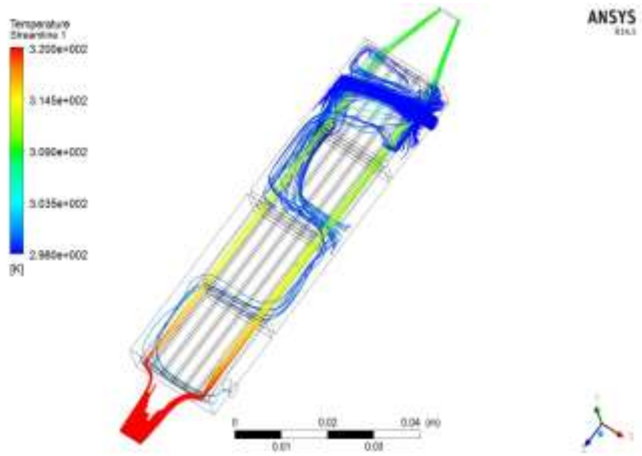

Fig. 4: Temperature Streamline

B. Temperature Contours

1) Temperature contours of tube in case of without Nano-Particles in Shell Fluid

Contours are the colorful graphics which indicates the temperature profile of the system. Fig.5 shows the static temperature contour of tube in case of without nano-particles in the water. Since the hot fluid flows through the tube, the inlet temperature of tube is 320 K and the outlet temperature is 309 K. Table-7 gives the tube side temperature in case of without nano-particles in the shell fluid.

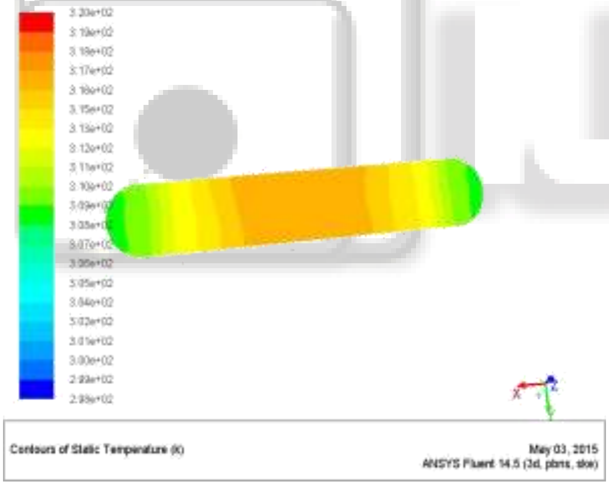

Fig. 5: Temperature contour of tube in case of without nano-particles.

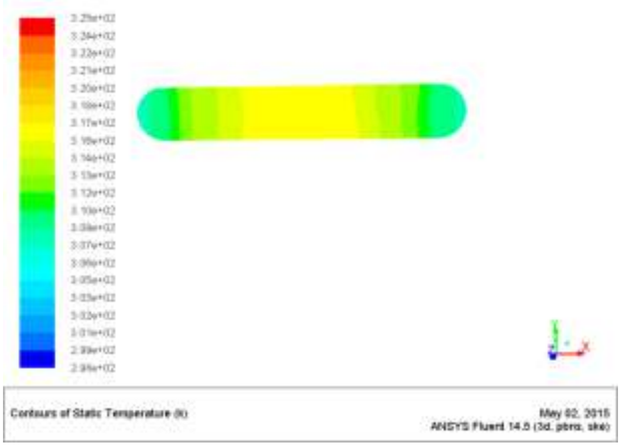

Fig. 6: Temperature contour of tube in case of with nano-particles

2) Temperature contours of tube in case of with nano-particles in shell fluid

Fig.6 shows the static temperature contours of tube in which working fluid is considered as with nano-particles. From fig.6 we can say that, the maximum temperature or the inlet temperature of tube is 320 K and minimum temperature or outlet temperature is 306 K. Table-8 gives the tube side temperature in case of 4% nano-particles in the shell fluid. From fig.5 & fig.6 we can say that, the inlet temperature of hot fluid is constant (i.e. 320 K) for both cases. But outlet temperature is 3 K less in case of water with nano-particles compared to the water without nano-particles in the shell fluid. Hence we can say that, "use of nano-particles in the cold fluid increases the rate of heat transfer from hot fluid to the cold fluid". Effective heat transfer rise in tube fluid in case of with nano-particles in water is given by table-9.

Tube		
Inlet temp (K)	**Outlet temp. (K)**	**Temp. diff. K**
320	309	11

Table 7: Tube side temperatures in case of without nano-particles in shell fluid

Tube		
Inlet temp (K)	**Outlet temp. (K)**	**Temp. diff. K**
320	306	14

Table 8: Tube side temperatures in case of with nano-particles in shell fluid

	Tube Inlet temp. (K)	**Tube outlet temp. (K)**	**Temperature difference (K)**
Without nano	320	309	$T_{without} = 11$
With nano	320	306	$T_{with} = 14$
Effective heat transfer rise in case of with nano-particles in water = $T_{effective} = 14 – 11 = 3$			

Table 9: Effective heat transfer rise in tube fluid

3) Temperature contours of shell in case of without nano-particles in the water

The tube fluid loses its heat to the shell fluid. Since hot fluid flows through the tube and cold fluid flows through the shell. During the flow of fluid, heat flows from hot fluid (tube fluid) to cold fluid (shell fluid). From fig.7 we can say that, the minimum temperature or the inlet temperature of shell is 298 K and maximum temperature or outlet temperature is 302 K.

Table-10 gives the shell side temperature in case of without nano-particles in the shell fluid. The cold fluid (or shell fluid) observes the heat from the hot fluid (tube fluid), due to this the temperature of the shell fluid increases. In this particular study, temperature of the shell fluid increases from 298 K to 302 K i.e. 4 K rise in temperature of shell fluid.

4) Temperature contours of shell in case of with nano-particles in the water

From fig.8 we can say that, the minimum temp. or the inlet temperature of shell is 298 K and maximum temperature or outlet temperature is 304 K, i.e. 6 K rise in temperature of shell fluid. Table-11 gives the shell side temperature in case of with nano-particles in the water.

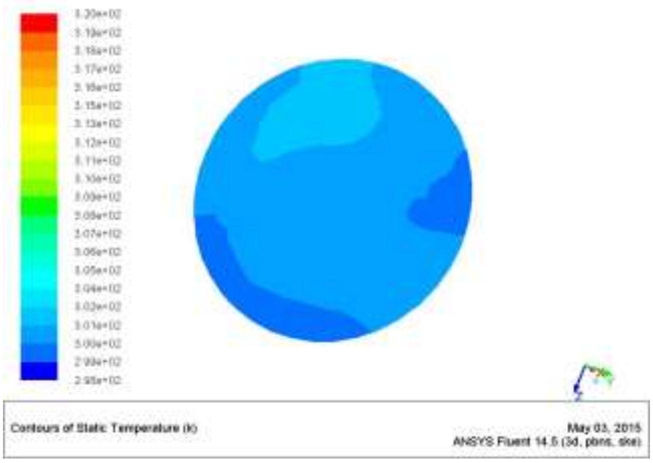

Fig. 7: Temperature contours of shell in case of without nano-particles.

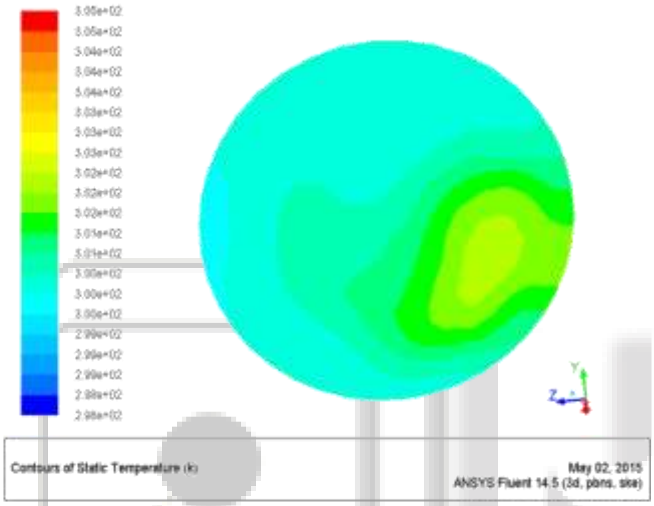

Fig. 8: Temperature contours of shell outlet in case of with nano-particles.

Shell		
Inlet temp. (K)	**Outlet temp. (K)**	**Temp. diff. (K)**
298	302	4

Table 10: Shell side temperatures in case of without nano

Shell		
Inlet temp. (K)	**Outlet temp. (K)**	**Temp. difference in (K)**
298	304	6

Table-11 Shell side temperatures in case of with nano

	Shell inlet temp. (K)	**Shell outlet temp. (K)**	**Temp. diff. (K)**
Without nano	298	302	$T_{without} = 4$
With nano	298	304	$T_{with} = 6$
Effective heat transfer rise in case of with nano-particles in water = $T_{effective} = 6 - 4 = 2$			

Table-12 Effective heat transfer rise in shell fluid

From fig.7 and fig.8 we can say that, the inlet temperature of cold fluid is 298 K whereas outlet temperature is 2 K more in case of with nano-particles compared to the without nano-particles in the water. Effective temperature difference in shell fluid in case of with nano-particles in water is given by table-12.

C. *Temperature Chart*

Comparisons between temperatures of tube fluid (hot fluid) for both cases i.e. with and without nano-particles have been shown in fig.9. The amount of heat transferred in case of with nano-particles is more compared to the amount of heat transferred in case of without nano-particles, that is why the fluid at the tube outlet in case of with nano-particles is at lower temperature compared to the fluid at tube outlet in case of without nano-particles.

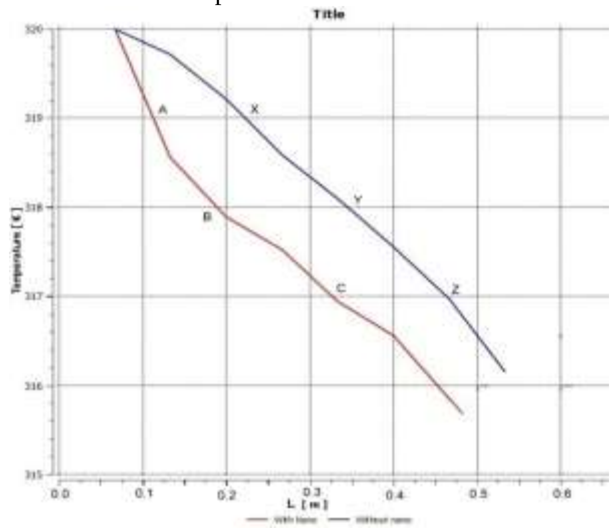

Fig. 9: Comparison Temperature Chart

Points on curve	**At 319 K**	**Points on curve**	**At 318 K**	**Points on curve**	**At 317 K**
	Length of tube (m)		**Length of tube (m)**		**Length of tube (m)**
A	0.125	B	0.188	C	0.325
X	0.220	Y	0.343	Z	0.467

Table 13: Length of tube at different values of temperatures

A, B, C are the points on the curve in case of with nano-particles, and X, Y, Z are the points on the curve in case of without nano-particles.

For 319 K, the length of tube is 0.125 m (at point A) in case of with nano-particles; whereas 0.220 m (at point X) is for without nano-particles in water. In other words, for same temperature effect the length of tube is less in case of with nano-particles compared to without nano-particles. Table-13 gives the values of tube length at different temperatures.

From table-13 we can say that use of nano-particles in the water reduces the size of the heat exchanger resulting to the compactness of the device. From our present study we can conclude that “heat transfer rate increases significantly by addition of nano-particles in cold water (shell fluid)”.

V. CONCLUSIONS

A. *Conclusion*

The comparison study was carried out for shell and tube heat exchanger with and without nano-particles in the working fluid with the help of CFD software. The analysis was completed and it is observed from the study that, the effect of nano-particles on heat transfer in shell and tube heat exchanger is significant. Based on the results obtained from the analysis, the following conclusions have been drawn.

- By the CFD analysis method it is found that heat transfer rate increases by addition of nano-particles in working medium/fluid (water).
- Due to the increased heat transfer, the efficiency of the heat exchanger increases.
- Use of nano-particles reduces the size of the heat exchanger resulting to the compactness of the device.
- The operating time and cost are minimized.

B. Future Work

In this study we are using Alumina (Al_2O_3) nano-particles; further we can use different nano-particles such as copper oxide (Cuo), Titanium dioxide (TiO_2) with different volume concentrations. In this project we are using nano-particles of size 38 nm, we can try for different size of nano-particles.

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