CFD Analysis of Shell and Tube Heat Exchanger with Flower Baffle Using Carbon Nano Tubes as Nanofluid and Water as a Base Fluid

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Abstract - *Nanofluids have demonstrated their capacity to work on the thermal conductivity of base liquids and heat transfer in heat exchangers and other devices. The heat exchanger consists of a hollow shell, a single tube, and a flower baffle plate. The baffle plates are placed inside the shell side of the heat exchanger. The angle of the plate affects the pressure drop, fouling of the heat exchanger as well as the heat transfer rate. The nanofluid of carbon nano tubes (CNTs) is introduced as cold fluid to increase the heat transfer rate as CNTs has higher thermal conductivity. Double distilled water is used to prepare the nanofluid and sodium dodecyl sulphate is used as a surfactant to increase the stability of the nanofluid. The objective of this research is to enhance the rate of heat transfer of the shell and tube heat exchanger (STHX) by using nanofluids CNTs. The model of heat exchanger is modelled by using SOLIDWORK 2020 and ANSYSFLUENT 2020 to run the simulations. The temperature at the outlet of the tube side and shell side and pressure drop of the heat exchanger are calculated and plotted graphically. The results shows that the nanofluid has higher heat transfer rate than the combination of nanofluid and flower baffle plates.*

Key Words: **Shell and tube heat exchanger, Nanofluids, Carbon nanotubes, Flower baffle plates, Convective heat transfer coefficient.**

1. INTRODUCTION

Heat exchanger is a mechanical device that reuses the heat energy present in the working fluid. The shell and tube are a versatile heat exchanger due to its flexibility in design and is commonly used in many industries for cooling of turbine and compressor, oil industries, for refrigeration and air conditioning, etc. The shell and tube heat exchanger has a bundle of tubes encased within a shell. The baffle plates are one of the important barriers located within the shell to create turbulence which will increase the rate of heat transfer and also provide support to the lengths of the tube. Baffle plates used in the shell and tube heat exchanger may be longitudinal flow baffles, impingement baffles (used for the protection of bundle when enter with high velocity) and orifice baffles. Shinde (2017) [1] did an investigation on shell and tube heat exchanger with continuous helical baffle. Different helix angle was taken into consideration and investigated mathematically by modelling helical baffle on shell-and-tube heat exchanger for various mass flow and inlet temperature conditions. Results suggest that the higher helix angle (30°, 38°, and 50°) adds to lower heat transfer and lower pressure drop, and with lower value of helix angle (21°, 19°and 10°) higher will be the pressure drop and heat transfer. Mahenndran (2019) [2] studied the shell and tube heat exchanger with conventional single plates and new designed baffle plates were designed and compared using SOLID WORKS. The performance of both the baffles were also analysed. The results suggested that the overall performance of the conventional model is more efficient than the segmental baffle plate heat exchanger. Chen (2020) [3] investigated the impact of the baffle pattern on the heat transfer and mass flow rate of shell and tube heat exchangers. Different types of baffle plates were used including tri-flower baffle, pore plate, rod baffle, segmental and pore baffle, and segmental baffle. To analyze the hydrodynamics and heat transfer attributes of the five heat exchangers, a water-water heat transfer system was constructed. The outcomes show that the shell side heat transfer coefficient of the tri-flower baffle and pore plate baffle were predominant. Wang (2011) [4] experimentally investigated the flower baffle heat exchanger and the original segmental baffle heat exchanger. The outcomes recommend that, under similar conditions, the general exhibition of the flower baffle was 20–30% higher than that of the segmental baffle heat exchanger. You et al. (2012) [5] investigated the numerical modeling, experimental validation of heat exchanger and flow resistance on the shell side of a shell and tube heat exchanger with flower baffle. The work shows that the model was economic and effective in the thermal-hydraulic design and analysis of a whole device. Geete et al. (2021) [6] worked on a shell- spiral heat exchanger. The performance of constructed heat exchanger for various flow rates and temperatures (inlet) of hot and cold fluids shows that the highest achievable effectiveness is 0.988. Kunwer et al. (2020) [7] did a comparison on the selected STHX with segmental and helical baffles, which shows that pressure drop in helical baffle was low as compared to the segmental baffle. Different nanofluids were used to enhance the performance of the heat exchanger. The nanofluid consisted of nanoparticles and a base fluid. Liu et al.'s (2011) [8] experimental investigation results show that nanofluids with a low concentration of carbon nanotube (CNT), CuO and Cu had higher thermal conductivity than base liquids. Singh (2020) [9] experimentally validated that CNT has higher coefficient of thermal conductivity up to

3000-6000 W/m-K when contrasted with other solid particles. Consequently, it could be conceivable that a lower concentration of CNT would give better thermal conductivity. CNT nanofluid has higher heat transfer upgrade up to 13% when contrasted with nanofluids of alumina, ethylene glycol and water at 0.25vol%. They found that the heat transfer coefficient of Carbon nanofiber (CNF) nanofluid increased up to 3.39W/m^{2}K at 0.6wt%. Venkataraman et al. (2019) [10] studied that CNT nanofluid has unique properties that makes them suitable in heat transfer applications. Carbon nanotubes (CNTs) pulled in huge interest because of their novel blend of properties including high mechanical strength, high aspect ratio, large surface area, high electrical and thermal conductivity, which make them reasonable for a wide scope of uses. Almanassra et al. (2019) [11] conducted a study on stability and thermal conductivity of water/CNTs nanofluid using a different surfactant. The result obtains experimentally of the shell and tube heat exchanger exhibit increments in rate of heat transfer with the convergence of CNT up to 65%, with an increase in pressure drop of around 15% utilizing 0.5 wt.% of CNT. The pumping power computations demonstrated that the necessary ability to give a same measure of heat with the use of nanofluids is 33% of that needed for water. Moorthy & Srinivas (2016) [12] studied about the anticorrosive properties and improved heat transfer properties of carboxylated water-based nanofluids. The stability of nanofluid was greater with carboxylated water rather than normal water. Vivekanandan et al. (2020) [13] conducted an experimental and computational fluid dynamic analysis on helical coil heat exchanger with flower baffles. The analysis was done in between the counter and parallel flow heat exchanger by varying the flow rates of the hot and cold fluid. The results suggested that the heat transfer rate in counter flow is higher than that in parallel flow.

From the above-mentioned research, we see that STHX is versatile and can be modified according to the need without compromising the performance of the heat exchanger. The counter flow heat exchanger has a higher rate of heat transfer than the parallel flow heat exchanger. Further, the flower baffle plates give lower pressure drop than other baffle plate. Nanofluids formed with a lower concentration of carbon nanotubes give better heat transfer rate than other nanofluid and the pumping power required is lesser than water which decreases the energy required to pump the nanofluid in the heat exchanger.

In this work, the mass flow rate is varying for hot water to find the one which has a higher rate of heat transfer and higher convective heat transfer coefficient keeping the pressure drop as minimum as possible.

1.1 Design and CFD analysis

The analysis was divided into two parts, first, the designing of the STHX with flower baffle and second, the thermal analysis on the STHX.

For the design, the model of STHX and flower baffle is done on different platforms. The STHX are designed on ANSYS 2020, and the flower baffle is designed on SOLIDWORKS 2020. Then the flower baffle is imported on the ANSYS 2020 platform for further analysis.

The meshing was done by taking the model as a k- epsilon turbulent model as shown in Fig.1. Geometry has been meshed with an element size of 10 mm. Convergence criteria for the different parameters are different. For continuity equation, 1.0e-05 is used, for velocities in all directions 1.0e-05 is used, for energy equation 1.0e-08 is used and for k and e 1.0e-05 is used. To reach the convergence value fast, relaxation value assigned to pressure is 0.3 while k and ∈ is 0.7 and temperature is 0.9. The inlet of both the fluid is mass-flow inlet and outlet are taken as pressure outlet.

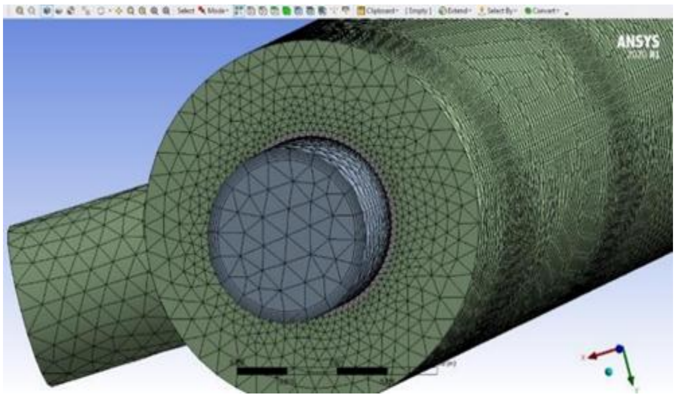

Fig -1: Meshed geometry and inflation of the heat exchanger

All the dimensions are taken in millimeters (mm). The outer and inner diameter of the tube is 43 and 40, respectively and the shell diameter is 84. The length of the heat exchanger is 1000. The heat exchanger is designed as a counter-flow heat exchanger and the inlet and outlet for the cold fluid is 40 in diameter and extruded for 50 mm from the shell surface. The baffle plates are mounted on the tube in a helical path. For the length of 1000mm, 52 flower baffles are mounted on the tube. The helix angle for the flower baffle is 0° and its thickness is 5mm.

The material of the heat exchanger is aluminum.

The inlet temperature was taken as 300 K for cold fluid and 353 K for hot water.

The hot fluid is water, and the cold fluid is nanofluid CNT (Carbon nanotubes) with water (double distilled) as a base fluid.

The analysis is performed and compared with and without the effect of the flower baffle for all cases. The different temperature values are obtained by taking the average of the values obtained at 10 equally distant positions on the model. Different parameter values are noted from the post- analysis.

1.2 Terminology used

Nano fluid density (ρ_{nf}):
$\rho_{nf} = 1001$ kg/m^3
Nano fluid specific heat ($C_{p\,nf}$):
$C_{p\,nf} = 4100$ J/kg-K
Nano fluid viscosity (μ_{nf}):
$\mu_{nf} = 0.025 \times 10^{-3}$ kg/m-s
Nano fluid thermal conductivity (K_{nf}):
$K_{nf} = 12.647$ W/m-K

2. Result and discussion

Performed analysis of the STHX using nano fluid and flower baffle is as follows:

2.1 Temperature variation

For the case of cold fluid, the average and maximum temperature obtained with nanofluid is higher than that obtained with the use of flower baffle as shown in Fig.2. This is due to the higher thermal conductivity of the nanoparticles of Carbon nanotubes present in a nanofluid.

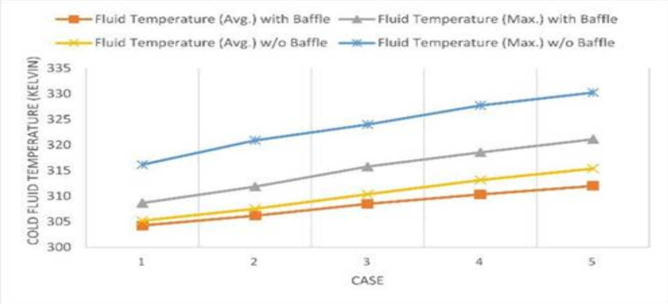

Fig -2: Maximum and average cold fluid temperature

In the case of hot fluid, the difference in temperature of hot fluid is more with the use of flower baffle because the flower baffles are the extension of the tube acting as fins and extracts more heat from the hot fluid as shown in Fig.3.

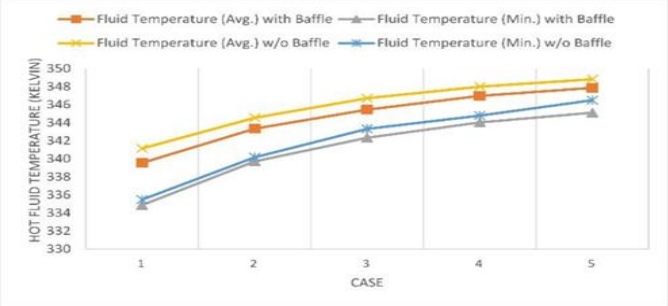

Fig -3: Maximum and average hot fluid temperature

2.2 Heat Flux

The nanofluid gives high value of heat flux for hot and cold fluid due to the higher thermal conductivity of Carbon nanotubes, which increases the difference in the wall and fluid temperature thereby increasing the overall heat flux, whereas in tube side of the STHX for the case of 1-1 lpm and 1-2 lpm the combination of flower baffle and nanofluid gives higher heat flux value. But for remaining cases nanofluids have higher heat flux value as shown in Fig.4.

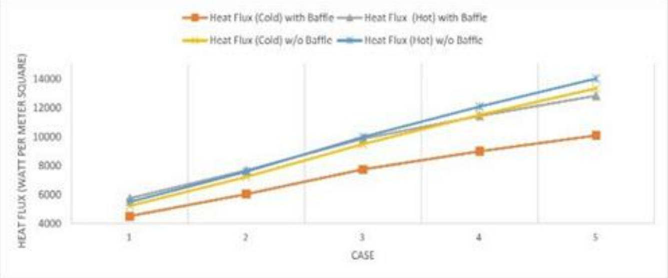

Fig -4: Heat flux for hot and cold fluid for all cases

2.3 Convective heat transfer coefficient

It has been observed that the maximum convective heat transfer coefficient in the case of flower baffle and nanofluid obtained is 2497.57 W/m²K in the cold side of the heat exchanger for the flow rate of 1 lpm on both the cold side and the hot side. In the case of hot fluid, 5 lpm has a higher convective heat transfer coefficient of 450.04 W/m²K. The case of 1-5 mass flow rate (l lpm on the cold side and 5 lpm on the hot side) shows a satisfying result with a convective heat transfer coefficient of 2330.05W/m²K on the cold side and 450.04W/m²K on the hot side of the heat exchanger.

In the analysis only with nanofluid, the maximum convective heat transfer coefficient is observed in the case of 1-4 mass flow rate i.e., 1 lpm on the cold side which is 2100.45 W/m²K and 4lpm on the hot side which is 480.65 W/m²K. But we can also see that the maximum convective heat transfer coefficient for the hot side is obtained for the flow rate 5 lpm giving a value of 595.25 W/m²K as shown in Fig.5.

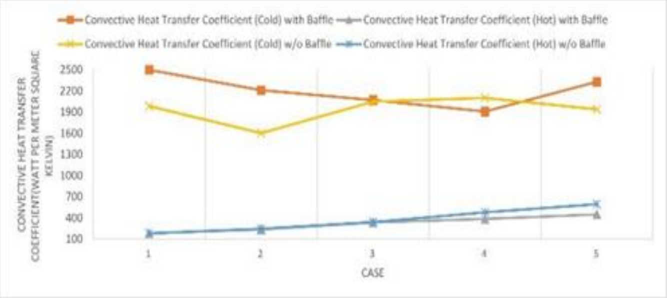

Fig -5: Convective heat transfer coefficient for all cases

2.4 Pressure drop

The pressure drop on the cold side is greater than that in the case of nanofluid. The cold side gives approximately constant pressure drop at a constant flow rate i.e., ranging from 4.750608Pa to 4.750597Pa in all 5 cases. While in without flower baffle case the value of pressure drop is constant i.e., 3.54Pa. So, from here we can conclude that the pressure drops in the case of shell and tube heat exchanger with flower baffle and nanofluid are larger than without flower baffle on the cold side. Pressure drop for all cases is shown in Fig.6.

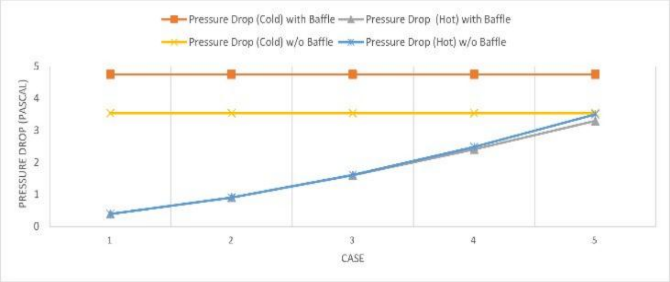

Fig -6: Pressure drops in shell and tube side

3. CONCLUSIONS

The nanofluid gives higher heat flux with the increase in the difference in mass flow rate of hot and cold fluid, whereas the combined effect of flower baffle and nanofluid gives a higher convective heat transfer coefficient for cold fluid.

It is evident that in the case of flower baffle with nanofluid, keeping the flow rate of 1 lpm and 5 lpm on cold and hot side, respectively, gives satisfying results with a pressure drop of 4.75Pa on the cold side, and with nanofluid 1 lpm and 4 lpm on cold and hot side respectively gives satisfying result with a pressure drop of 2.48Pa in tube side.

The combined effect of flower baffle and nanofluid CNT decreases the pressure drop on the cold side with a constant mass flow rate, whereas in the case of the hot side the pressure drops increase as the mass flow rate increases.

Above results indicate that with low-pressure drop-in tube side CNT nanofluid gives higher heat flux.

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