Hair Pin Heat Exchanger Layered with Graphene in Tube Side Using Al_2O_3 as Nanofluid

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Abstract - *A well-designed heat exchanger improves the effectiveness of the heat exchanger. A hairpin heat exchanger resembles a hairpin when a shell-and-tube heat exchanger with a single-pass unit is folded in half, which can be used where space is a constraint. Design, CFD analysis and evaluation of various parameters of hairpin heat exchanger with graphene layer and its comparison with hairpin heat exchanger without graphene layer is the main aim of this paper. The heat exchanger is modified with the addition of a graphene layer on both the side (inner and outer side) of the tube of the heat exchanger. Graphene is an allotropic form of carbon having a single layer of atoms distributed in a 2-D honeycomb lattice. The coefficient of thermal conductivity of graphene is very high as compared to other materials. In addition to it, nanofluid Al_2O_3 is introduced as cold fluid. Nanofluids are colloidal suspensions made of nanoparticles in some base fluid. ANSYS FLUENT 2020 has been used to model the geometry and to perform numerical simulation. Turbulent flow conditions were used to analyse the heat exchanger. CFD analysis has been done on hairpin heat exchangers using graphene layer. The results indicate that the high thermal conductivity of graphene increases rate of heat transfer, and the numerical value of convective heat transfer coefficient is also high.*

Key Words: **Hair pin heat exchanger, Graphene, Nanofluid, Thermal analysis, Convective heat transfer coefficient.**

1. INTRODUCTION

The increase of convective heat transfer coefficient is one of the foremost vital technical aims for industrial appliances used in heat transfer applications. A hairpin heat exchanger resembles a hairpin when a shell-and-tube heat exchanger with a single-pass unit is folded in half. Unlike multi-pass heat exchangers (multiple passes on the tube side), hairpin heat exchangers have the peculiarity that the shell side stream circulates countercurrent to the tube side flow, in all passes. water, glycol, and engine oil are conventional fluids normally used for heat transfer. Various procedures are applied to help the heat transfer since low heat transfer coefficient of these ordinary fluids hinders the improvement in performance and the compactness of heat exchangers. Blending of solid particles in the base liquid is a method to increase rate of heat transfer. As metal have higher thermal conductivity than liquids, suspending solid particles into the base fluid is relied upon to upgrade the thermal conductivity of that liquid. The upgrade of thermal conductivity of normal liquids by the suspension of solid particles, similar to millimetre or micrometre sized particles, has been notable for quite some time.

Experiments were conducted to increase the heat transfer in laminar and turbulent flow of different compositions of glycol blended in with water in a double tube hair pin heat exchanger. Acquired outcomes showed that the heat transfer coefficient of the blend of ethylene glycol and water increment with Reynolds number and ethylene glycol concentration [1]. Various investigations show that nanofluids will improve rate of heat transfer because of their higher thermal conductivity than base fluids [2-5]. Many researchers focused to increase the convection characteristics by considering different parameters like addition of nanoparticles, pipe cross-sectional area, materials, the concentration of nanofluid, and flow conditions [6-11]. A study was conducted on the specific heat of ethylene glycol, Al_2O_3 and water (EG/W) nanofluid and its outcome on the cogeneration efficiency of a 45-kW diesel electrical generator (DEG) shows that the productivity of waste heat recovery within the device was augmented because of the higher convective heat transfer coefficient of the nanofluids [12]. The experiments were done to analyze the feasibility of Al_2O_3/water nanofluid in an air-cooled heat exchanger. Results show that Al2O3/water nanofluid has better heat transfer rate than water [13]. CFD examination on hair pin heat exchanger using Al2O3 and TiC nanofluids blended in with base fluid independently at 0.6 and 0.7 percent volume fraction affirm that TiC is the reasonable fluid at 0.6 percent volume part inside the hair pin heat exchanger for a superior rate of heat transfer [14].

Aluminum graphene nanoplatelet composites were fabricated by the stir casting method to increase the mechanical properties of aluminum. [15]. Heat transfer in condenser tank using Al_2O_3- DI water Nanofluids was analyzed in this experiment, and it was observed that nanofluid enhances the heat transfer and the convective heat transfer coefficient [16].

1.1 Objective of present study

Current article deals with CFD analysis of the double pipe heat exchanger with Graphene layer using Al_2O_3. The analysis is done on heat exchanger with graphene layer and without graphene layer. Hair pin heat exchanger offers a thermal efficient design with a smaller shell than customary shell and tube heat exchangers and it likewise withstands high terminal temperature gradients along these lines forestalling possible disappointment because of thermal induced stresses. To the best of our knowledge from literatures there has been no study with the use of graphene layer in the heat exchanger. So, in this article, an analysis of hairpin with Al_2O_3 has been done.

1.2 Design and CFD analysis

The geometry of the heat exchanger modeled on ANSYS Workbench 2020 with the dimensions as below.

Shell side diameter - 84 mm
Tube OD – 42 mm
Tube ID – 40 mm
Thickness of graphene layer – 0.5 mm
Inlet and outlet diameter of cold and hot fluid – 40 mm

The materials used are aluminum and graphene. The shell and tube are made up of aluminum and the inner and outer side of the tube is layered with graphene. Graphene layers are pasted on aluminum by the use of spin-coating or drop-cast. The tube side is filled with hot fluid and the shell side is filled with cold fluid.

1.3 Numerical solution procedure

Basic governing equations like momentum equation, energy equation, the continuity equation is used in the CFD analysis of hairpin heat exchanger. PRESTO scheme is used in the coupling of pressure and velocity under SIMPLEC algorithm. For numerical discretization of all the equations, the upwind scheme of second-order is in use because of more accuracy than the first-order upwind scheme. 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. Mass flow inlet is used for inlet of the cold and hot fluid and pressure outlet is used for the outlet of both fluids.

1.4 Boundary Conditions

The hot fluid's mass flow rate is 1 lpm, 2 lpm, 3 lpm, 4 lpm and 5 lpm but the mass flow rate is kept constant for the cold fluid, which is 1 lpm. The temperature of cold fluid inlet is 300 k while hot fluid inlet is 353 k.

1.5 Grid Formation

After model formation of the heat exchanger, meshing is to be done on the model. Meshing is the process of distributing surfaces into small areas. These small areas are analyzed separately to find the final solution. Mesh should be fine, and the quality of the meshing is checked by aspect ratio and skewness. Aspect ratio should be less than 600 and skewness should be less than 0.9.

Geometry has been meshed with an element size of 10 mm. Inflation is given on both inner and outer fluid separately to take into consideration of no-slip condition and laminar sub-layer in the boundary layer. Meshed geometry and the inflation are shown in Fig.1. The first layer thickness is calculated from the wall y+ calculator. The naming of both inlet and outlet of cold and hot fluid is done for the counter flow of fluid. Boundary conditions are applied on the setup page of Ansys 2020. Energy equations are kept on and flow is assumed to be turbulent. A turbulent model of k- epsilon is used. Materials properties are added for graphene and Al_2O_3 nanofluid. The hot fluid is water, and the cold fluid is nanofluid. The material of the shell and tube is aluminium, and the layer of the tube side is graphene. The mass flow rate of cold fluid is kept fixed i.e., 1 lpm, and mass flow of hot fluid is varied from 1 to 5 lpm. Iteration is done till the convergence is reached. All the data has been calculated from post-analysis. Heat flux, temperature of the wall and fluid, pressure drop, skin friction coefficient, surface Nusselt number, and effective Prandtl number are calculated. Convective heat transfer coefficient is calculated from the standard equation of heat transfer i.e., q = hdT. The fluid temperature, wall temperature and heat flux are taken at 10 different locations each at 0.1 m. Then average of all the data to calculate the convective heat transfer coefficient, is taken

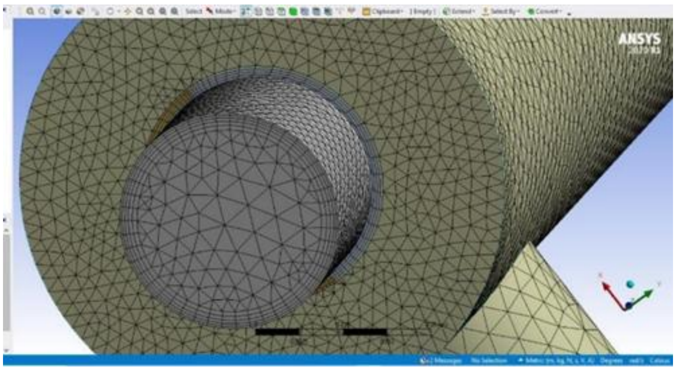

Fig -1: Inflation on tube side of the heat exchanger

Terminology Used:

At volume fraction = 0.6
Nano fluid density (ρ_{nf}):
ρ_{nf} = 2727.28 kg/m^3
Nano fluid specific heat ($C_{p\,nf}$):

$C_{p\ nf}$ = 1389.02 J/kg-K
Nano fluid viscosity (μ_{nf}):
μ_{nf} = 0.0025075 kg/m-s
Nano fluid thermal conductivity (K_{nf}):
K_{nf} = 5.13 W/m-K

2. Result and discussion

Performance analysis of heat exchanger with graphene layer and without graphene layer using Al_2O_3 is as follows:

2.1 Heat Flux

In the case of a heat exchanger with a graphene layer, heat flux increases for both the fluid as the flow rate increases, as seen from Fig.2. Heat exchanger with graphene layer, for cold fluid, heat flux increases from 5954 W/m^2 to 9905 W/m^2 but for hot fluid, heat flux increases from 6610 W/m^2 to 10861 W/m^2. In heat exchanger without graphene layer, heat flux increases for both cold and hot fluid as flow rate increases but variation is less. For cold fluid, heat flux varies from 7549 W/m^2 to 9092 W/m^2. Heat flux in the case of heat exchangers with graphene is higher in comparison to heat exchangers without graphene.

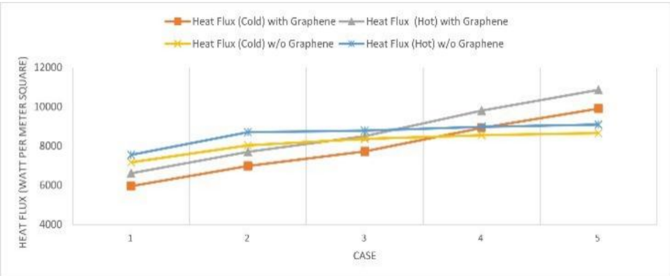

Fig -2: Heat flux of hot and cold fluid

2.2 Convective heat transfer coefficient

Convective heat transfer coefficient for cold fluid first increases from 1610 W/m^{2}K for the flow rate of 1-1 to 1717 W/m^{2}K for the flow rate of 1-3 and then decreases to 1614 W/m^{2}K for the flow rate of 1-5. (1-3, where 1 is the flow rate of cold fluid and 3 is the flow rate of hot fluid). In the case of hot fluid, the convective heat transfer coefficient increases as we increase the flow rate i.e., 1-1 lpm to 1-5 lpm. Its value increases from 490.64 W/m^{2}K to 822 W/m^{2}K.

For the cold fluid, there is a slight variation in convective heat transfer coefficient but for the hot fluid, convective heat transfer coefficient increases from 398 W/m^{2}K to 1117 W/m^{2}K, as the flow rate increases from 1-1 lpm to 1- 5 lpm (Where 1-5 lpm indicates 1 lpm for the cold fluid and 5 lpm for the hot fluid). The value of the convective heat transfer coefficient for the hot fluid goes up to 1117 W/m^{2}K due to the graphene layer. Due to high thermal properties of graphene, it transfers more heat from hot to the cold fluid.

Graphical representation of convective heat transfer coefficient can be seen from Fig.3. The abscissa shows the case, and the ordinate shows the convective heat transfer coefficient. This graph shows the comparison between the convective heat transfer coefficient of both hot and cold fluid. Cold fluid heat transfer coefficient is more and lies in the range of 1600 W/m^{2}K to 1700 W/m^{2}K but for the hot fluid with graphene layer, it goes up to 1117.2 W/m^{2}K.

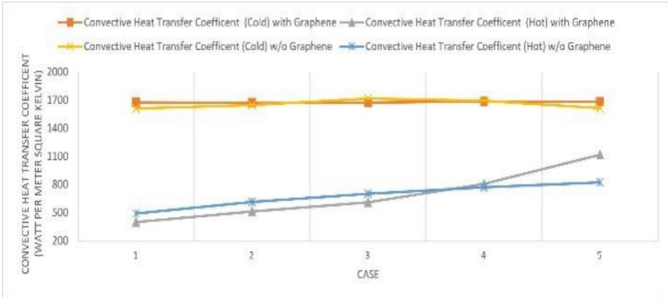

Fig -3: Convective heat transfer for cold and hot fluid

2.3 Pressure drop

In the case of a heat exchanger without graphene, pressure drop decreases as flow rate increases for cold fluid, but pressure drop increases for the hot fluid as flow rate increases. But with graphene, pressure drop in the case of cold fluid approximately remains constant, but the hot fluid pressure drops increase. Heat exchanger with graphene gives the least pressure drop in the range of 0.40 bar. Pressure drop is shown in Fig.4.

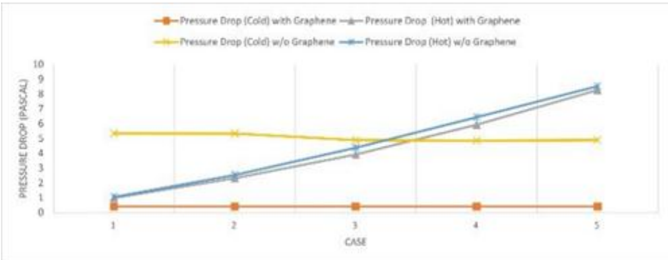

Fig -4: Pressure drop for hot and cold fluid

3. CONCLUSIONS

Convective heat transfer coefficient for hot fluid using graphene layer when it flows at 5 lpm gives the highest value of 1117 W/m^{2}K.

Convective heat transfer coefficient lies in the range of 1600 W/m^{2}K to 1700 W/m^{2}K for Al_2O_3 for both cases studied in this work.

The change in velocities at the inlet and outlet for both the fluid is negligible. There is a maximum increase of 1.2 percentage in velocities. This shows the losses in the pipe are considerable.

Present results are compared with the study performed by Pavushetti Abhilash, Udutha Raghupati [14]. Results indicate that heat flux and convective heat transfer coefficient gives higher value with the use of graphene.

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