FLOW ANALYSIS OF CuO/WATER NANO-FLUID FLOW IN A SHELL AND TUBE HEAT EXCHANGER BY USING CFD

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Abstract

CFD analysis is performed for the estimation of convective heat transfer and friction factor of CuO/water nano-fluid flow in a Shell and Tube heat Reynolds number ranges from 3000 to 22000. The prototype of shell and tube heat exchanger was developed using ANSYS 16.0 workbench. The inner and annulus tube materials used in this study is stainless steel and cast iron respectively. The particle volume concentrations of 0.1% and 0.3% were used in this analysis. The mass flow rate of hot fluid kept constant and the mass flow rate of CuO/water nano-fluid varies from 0.2 to 0.4 kg/sec. The temperatures of nano-fluids flow in a heat exchanger are kept at 345 K. The results revealed that as volume fraction and Reynolds number increased Nusselt number increased, and friction factor decreased. Based on the numerical results, the Nusselt number enhancement for 0.3% nano-fluid is 18% with a friction penalty of 1.4-times compared to water results.

Keyword: *Nusselt number, Numerical analysis, heat exchanger, heat transfer, friction factor, enhancement.*

Introduction: The thermal conductivity of heating or cooling of fluids is very important property for the development of energy efficient heat transfer equipment. Meanwhile, all the processes involving heat transfer, the thermal conductivity of the fluid is one of the basic and most important parameter taken into account in designing and controlling the processes. Nanofluids are engineered colloids which are made of a base fluid and nanoparticles of (1-100) nm. It has been found by many researchers that the nanofluids provide higher thermal conductivity compared to base fluids. Its value increases with the increase in particle concentration, temperature, particle size, dispersion and stability. Nevertheless, it is expected that other factors like density, viscosity, and specific heat are also responsible for the convective heat transfer enhancement of nanofluids. Nanofluids are having high thermal conductivity and high heat transfer coefficient compared to single phase fluids.

Heat transfer and separation of fluid flow in annular channel occurred due to change in pressure gradient caused by an increase or decrease of cross-sectional area of annular channel. Fluid flow in annular channels can be found in several heat exchange devices, such as heat exchangers, nuclear reactors, evaporators, condensers, etc. Generally, many experimental and numerical studies are concerned with the phenomena of separation and reattachment flow.

A nanofluid is prepared by dispersing particles of metal or metal oxide with sizes ranges from 0-70 nm, in a base liquid such as water. The purpose of using nanofluids is to achieve higher values of heat transfer coefficient compared with that of the base liquid. This is achieved by the dispersion of solid particles, which have higher thermal conductivity than the base liquid. There are many engineering applications that can benefit from the use of nanofluids, for example absorption refrigeration, micro electromechanical systems, lubrication of automotive systems, coolant in machining, automobile radiator cooling, solar water heating, heat exchangers, several medical applications, nuclear reactors, and in several aerospace applications. Recent advances in material technology have made it possible to produce innovative heat transfer fluids by suspending nanometer-sized particles in base fluids, which could change the transport and thermal properties of the liquids. Nanofluids represent solid-liquid composite materials consisting of solid nanoparticles with sizes no larger than 100 nm suspended in liquid. This study presents the work undertaken by various investigators and the possible impact of nanofluids on the enhancement of heat transfer in the near future.

Large volume of studies devoted to characterization of individual thermo-physical properties of nanofluids, such as thermal conductivity, viscosity, and agglomeration of nanoparticles, has been summarized in a number of review articles.

Evaluation of cooling efficiency, i.e., ability to remove heat from the heat source, includes assessing flow regime-dependent contributions from thermal conductivity, viscosity, specific heat, and density of the fluid and also depends on the applied flow regime. The studies devoted to evaluation of the heat transfer performance of nanofluids are scarce and inconclusive compared to the studies on the thermo-physical properties of various nanofluids indicating a significant gap between fundamental research and practical applications of nanofluids for thermal management.

II. Computational Fluid Dynamics

CFD is useful for studying fluid flow, heat transfer; chemical reactions etc. by solving mathematical equations with the help of numerical analysis. CFD resolve the entire system in small cells and apply governing equations on these discrete elements to find numerical solutions regarding pressure distribution, temperature gradients. This software can also build a virtual prototype of the system or device before can be apply to real-world physics to the model, and the software will provide with images and data, which predict the performance of that design. More recently the methods have been applied to the design of internal combustion engine, combustion chambers of gas turbine and furnaces, also fluid flows and heat transfer in heat exchanger. The development in the CFD field provides a capability comparable to other Computer Aided Engineering (CAE) tools such as stress analysis codes.

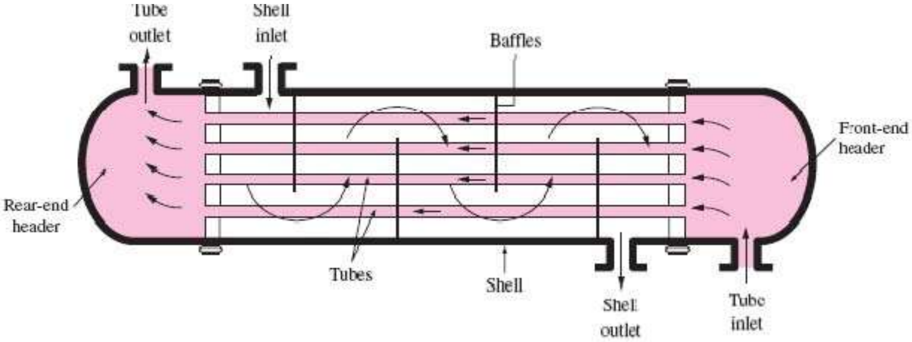


Fig 1.Schematic diagram of heat exchanger

The analysis is performed on a shell and tube heat exchanger with the specifications as mentioned below.

Table 1. Shell and Tube heat exchanger specifications

Specification	**Dimensions (mm)**
Length of heat exchanger	1500
No of tubes	09
Diameter of inner shell	136
Diameter of outer shell	142
Diameter of inner tube	17
Diameter of outer tube	23
No of baffles	05

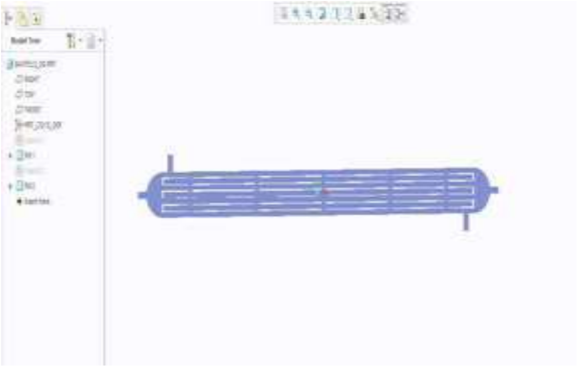


Fig 2. Geometrical model of heat exchanger

Grid Independence is the term used to designate the enhancement of results by using successively smaller cell sizes for the calculations. A calculation should reach the correct result so the mesh becomessmaller; hence the term is known as grid Independence. The ordinary CFD technique is, to start from coarse mesh and gradually improve it until the changes detected in the values are smaller than a pre-defined acceptable error. There are 2 problems with this. Firstly, it can be quite difficult with other CFD software to gain even in a single coarse mesh resulting for some problems. Secondly, refining a mesh by a factor two or above can lead to take more time. This is clearly offensive for software intended to be used as an engineering tool design operating to constricted production limits. In addition to that the other issues have added significantly to the perception of CFD as an extremely difficult, time consuming and hence costly methodology. Finally grid independence test has beenconducted at a flow rate of 8 LPM hot water, 10LPM cold water flow rates in ANSYS-FLUENT, by decreasing and increasing the size of the elements. The gained results are tabulated in Table 1, for outlet temperatures of cold water and hot water of 2-pass double pipe heat exchanger.

III. RESULTS AND DISCUSSION

Temperature contours the temperature contours of inside pipe of Shell and Tube heat exchanger are shown in Fig. 3. From the figure it was observed that temperature of inside fluid i.e. CuO nano fluid gradually increased from inlet to the outlet of pipe. Fig. 4 shows the temperature contours of annulus pipe of Shell and Tube heat exchanger. From the figure it was observed that temperature of annulus fluid i.e., pure water gradually decreased from inlet to the outlet of annulus pipe.

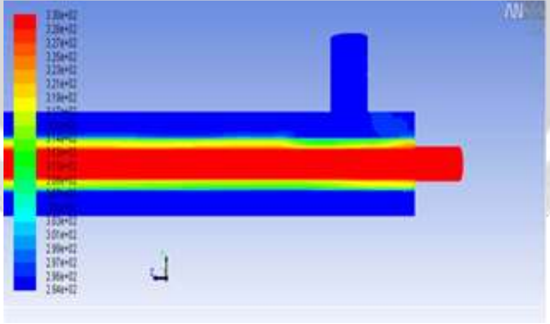


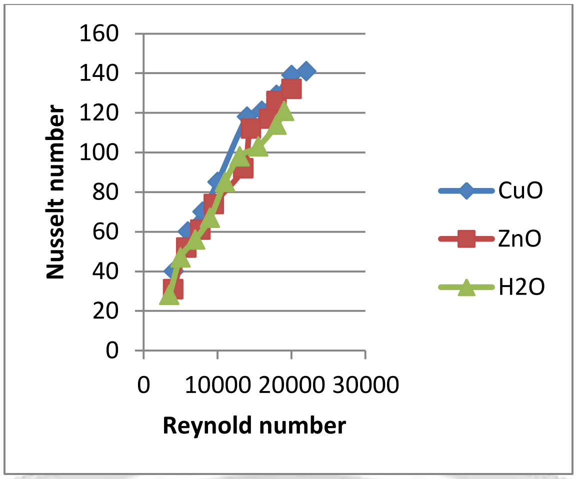
Fig 3. Temperature distribution

Validation of numerical results with the correlations

The obtained numerical results for water are compared with the available Nusseltnumber correlations in the estimated Reynolds number range. The Nusselt number correlations used for comparison purpose. The CFD resultsare plottedand compared with analytical. The numerical Nusselt number values are in very good agreement when compared with thecorrelated values.

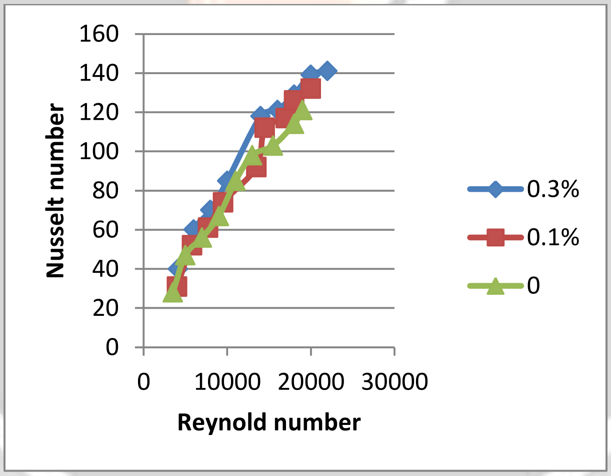
The correlations for estimation of Nusselt number for single phase fluid are given below:

Correlation for turbulent flow



Nusselt number of CuO/water nanofluid

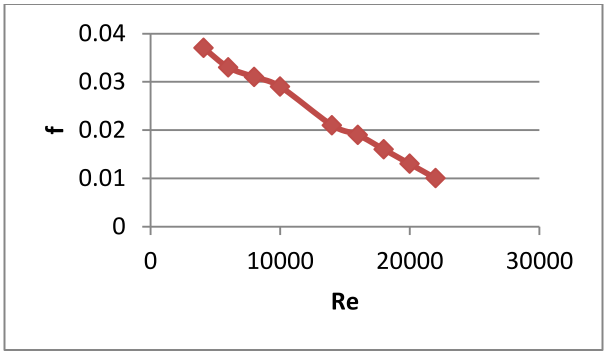
Comparison of Nusselt number with corresponding Reynolds number of pure water and CuO/water nanofluid. It can be seen that the Nusselt number increases gradually with the increase in Reynolds number. The enhancement of heat transfer coefficient at 0.1% volume concentration of CuO nanofluid is 16% for Reynolds number of 22000 when compared to water. Similarly, the enhancement of heat transfer coefficient at 0.3% volume concentration of CuO nanofluid is 18% compared to water. Graph shows that the Nusselt number increases gradually with increasing volume concentration as well as increase in flow rate of CuO nanofluid.



Validation of friction factor with the correlations

The obtained numerical results for water are compared with the available friction factor correlations in the estimated Reynolds number range. The friction factor correlations are used for comparison purpose. The CFD results areplotted and compared with analytical. The numerical friction factor values are in very good agreement when compared with the correlated values. The correlations for estimation of friction factor for single phase fluid are given below:

Equation for turbulent region
$f=0.3164\ Re-0.25$ (9)
$3000<Re<105$
Equation for turbulent region
$f=(0.790\ ln(Re\ -1\ 64\ -2\ 10$
$2300<Re<5\times106$



Effect of Nanoparticle volume concentration on friction factor

Comparison of friction factor values obtained analytically and Simulation results at corresponding Reynolds numbers. There is a decrease in friction factor gradually with increase in Reynolds number. The maximum friction factor enhancement of 1.1-times and 1.5-times at 0.1%and 0.3% volume concentration of CuO nanofluid at a Reynolds number of 2200 comparedto water.

Conclusion:

A steady state computational fluid dynamics (CFD) models were simulated by ANSYS FLUENT 16.0 and the effect of Reynolds number and Nusselt number on the flow behaviour of the nanofluid in the pipe were studied and the variations in the properties are presented. The heat transfer enhancement is observed to be better in the turbulent region compared to that of laminar region for all volume fractions considered in the analysis. There is a good agreement between the results gained from the simulation and analytical data. The maximum error was found that 10.56%. It is observed that according to simulation results there is a 18% enhancement in heat transfer coefficient at 0.3% volume concentration of CuO nanofluid when compared to water at Reynolds number range of 22000. It is observed that there is a maximum friction penalty of 1.2-times at 0.3% volume concentration of CuO nanofluid at Reynolds number of 22000 when compared to water. The friction factor is increased with the increase of volume concentration but it is observed that the friction factor enhancement is less compared to the enhancement to the heat transfer for volume fraction considered in the analysis.

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