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NUMERICAL INVESTIGATIONS FOR PERFORMANCE IMPROVEMENT IN SHELL AND TUBE HEAT EXCHANGERS USING NANO FLUIDS

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ABSTRACT
Heat exchangers play a important role in the field of energy conservation, conversion, and recovery**.** Shell and tube heat exchangers are most widely used in many engineering applications for the transfer of heat energy. They are widely adopted in many industries due to their ability to transfer large amounts of heat in relatively low cost, serviceable designs without mixing the hot and old fluids. They can provide large amounts of effective tube surfaces while minimizing the requirements of floor space, liquid volume and weight. For compacting the size of the heat exchangers, the heat transfer coefficient has to be increased. With the rapid development of modern nanotechnology, nanoparticles are used for dispersing in base liquids, which are called as Nano fluids. Nano fluids can be applied to improve the performance of heat exchanger. In this thesis, thermal performance of a shell and tube heat exchanger operated with Nano fluids has been analytically investigated at different volume concentrations and compared with water as the base fluid. Turbulent flow conditions are considered in the analysis. Thermal and CFD analysis is done on the heat exchanger by applying the physical properties of the nanofluid with different volume fractions calculated from the theoretical calculations. 3D model of the heat exchanger is done in CATIA and analysis is done in Ansys fluent. Aluminum and Copper are considered as the materials for tubes in the heat exchanger.

Keywords: Shell and Tube heat exchanger, Nano fluids, eat transfer coefficient, Thermal analysis.

I. INTRODUCTION
Heat exchangers are devices in which heat is transfer from one fluid to another. The most commonly used type of heat exchanger is a shell-and-tube heat exchanger due to the property of non-mixing the both fluids. Shell-and-tube heat exchangers are used extensively in engineering applications like power generations, refrigeration and air-conditioning, petrochemical industries etc. These heat exchangers can be designed for any capacity. The main purpose in the heat exchanger design is given task for heat transfer measurement to govern the overall cost of the heat exchanger.

The steadily increasing use of shell-and-tube heat exchangers and greater demands on accuracy of performance prediction for a growing variety of process conditions resulted in the explosion of research activities. These included not only shell side flow but also, equally important, calculations of true mean temperature difference and strength calculations of construction elements, in particular tube sheets.

By far the most common type of heat exchangers to be encountered in the thermal applications is shell-and-tube heat exchangers. These are available in a variety of configurations with numerous construction features and with differing materials for specific applications. This chapter explains the basics of exchanger thermal design, covering such topics as, shell-and-tube heat exchanger components, classification of shell-and-tube heat exchangers according to constructions.

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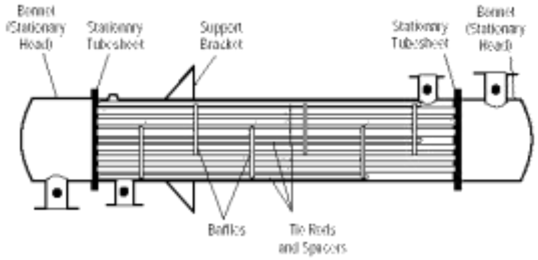

Fig1.1 shell-and-tube heat exchanger

Tube size, which type of materials and array are primary criteria of designing of tube and shell type of mat exchanger. Small tube gives less cost with good thermal conductivity and Use of multiple tubes because of that is increasing the heat transfer area. Reason of increasing heat transfer area is increase the velocity of fluid and lower effective ΔT. It will create less shell area and size. Heat exchangers are designed on two basic methods i.e. LMTD and NTU methods.

Heat flows between the hot and cold streams due to the temperature difference across the tube acting as a driving force. The difference will vary with axial location. Average temperature or effective temperature difference for either parallel or counter flow may be written as:

$$\Delta T_{LM} = LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad \text{..... (1)}$$

In the thermal analysis of shell-and-tube heat exchangers by the LMTD method, an equation (1) has been used. This equation is simple and can be used when all the terminal temperatures are known. The difficulty arises if the temperatures of the fluids leaving the exchanger are not known. In such cases, it is preferably to utilize an altogether different method known as the effectiveness-NTU method. Effectiveness of shell-and-tube heat exchanger is defined as:

$$\varepsilon = \frac{C_S(T_{Si} - T_{So})}{C_{min}(T_{Si} - T_{Ti})} = \frac{C_T(T_{To} - T_{Ti})}{C_{min}(T_{Si} - T_{Ti})} \quad \text{..... (2)}$$

Effectiveness for shell-and-tube heat exchanger can also be expressed as:

$$\varepsilon = \varepsilon\left(\frac{UA}{C_{min}}, \frac{C_{min}}{C_{max}}\right) \quad \text{...... (3)}$$

Where $\frac{C_{min}}{C_{max}} = \frac{C_S}{C_T} \, or \, \frac{C_T}{C_S}$ (depending upon their relative magnitudes).

Flow across banks of tubes is, from both constructional and physical considerations, one of the most effective means of heat transfer. However, it is recognized quite early that ideal tube bank correlations, if applied to shell-and-tube heat exchangers, needed substantial corrections.

Efforts are being made for improving the heat transfer of heat exchangers, compacting the size of the heat exchangers, reduce the total heat transfer time and their efficiency. These efforts commonly include passive and active methods such as creating turbulence, extending the exchange surface or the use a fluid with higher thermos physical properties. For the higher thermal conductivity of solid particles, the uses of solid particles in conventional fluids are also applied to enhance the heat transfer performance of these fluids. But the problems are fouling, sedimentation and increased pressure drop. The novel invention of nanofluid has provided the possibilities to overcome these problems.

Recent advances in nano technology have allowed development of a new category of liquids termed nanofluids, which was first used by Choi to describe liquid suspensions containing nanometer-size particles, including

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chemically stable metals, metal oxides, several allotropes of carbon with thermal conductivities, orders of magnitudes higher than the base liquids, and with sizes significantly smaller than 100 nm. A remarkable characteristic of nanofluids is that by the addition of small amount of nanoparticle, they show atypical enhancement in thermal conductivity over 10 times more than the theoretically predicted

II. LITERATURE REVIEW

Heat exchangers are generally used to transfer thermal energy between two or more media and extensively applied to power engineering, chemical industries, petroleum refineries, food industries and so on (Raja at el. 2012). However, shell and tube heat exchangers can be applied in the systems where large and small volume of heat transfer are needed and also can be used in high pressure systems. Therefore, it is widely used in industrial processes and power plants (Hajjat at el. 2010).

Thirumarimurugan, at el. (2008) 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. Experimental results such as exchanger effectiveness, overall heat transfer coefficients were calculated. 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.

Usman (2011) had investigated an un-baffled shell-and-tube heat exchanger design with respect to heat transfer coefficient and pressure drop by numerically modeling. The flow and temperature fields are resolved using a commercial CFD package and it is performed for a single shell and tube bundle and is compared with the experimental results. The heat transfer is found to be poor because the most of the shell side fluid by-passes the tube bundle without interaction. Thus the design can be modified to achieve the better heat transfer in two ways. Either, the shell diameter is reduced or tube spacing can be increased. Thus the design can further be improved by creating cross-flow regions in such a way that flow doesn't remain parallel to the tubes.

Jian at el. (2011) developed a method for design and rating of shell-and-tube heat exchanger with helical baffles based on the public literatures and the widely used Bell–Delaware method for shell-and-tube heat exchanger with segmental baffles. Comparison result shows that all shell and tube heat exchanger with helical baffles have better performance than the original heat exchanger with segmental baffles.

It has been found that CFD employed for the fluid flow mal-distribution, fouling, pressure drop and thermal analysis in the design and optimization phase. Different turbulence models such as standard, realizable and RNG, $k - \varepsilon$, RSM, and SST $k - \varepsilon$ with velocity-pressure coupling schemes such as SIMPLE, SIMPLEC, PISO and etc. have been adopted to carry out the simulations (Muhammad at el. 2011). The simulations results ranging from 2% to 10% with the experimental studies. In some exceptional cases, it varies to 36%.

The addition of nanoparticles in the fluid changes the flow structure, so that besides increasing the thermal conductivity, chaotic motion, dispersion and fluctuation of the nanoparticles especially near the tube wall of a heat exchanger leads to an increase in the rate of energy exchange and increases heat transfer between the fluid and the tube wall. Furthermore, at high flow rates, the effects on dispersion and chaotic motion of nanoparticles enhance mixing fluctuations and changes in temperature profile to a flatter profile similar to turbulent flow and cause an increase in the coefficient of heat transfer. And in low Peclet number, a lower rate of heat transfer can be observed at low temperature flow and agglomeration of nanoparticles may exist in the flow nanofluid. Experiments on convection heat transfer of nanofluids were conducted by several research groups (Buongiorno 2006; Chein and Huang 2005; Etemad et al. 2006;Kim et al. 2004a; Said and Agarwal 2005; Xuan and Li 2003).

From the existing literature, it is clear that most of the studies showed improvement of heat transfer performance of heat exchangers using nanofluids, but overall performance does not merely depend on heat transfer coefficient. There is a limited number of studies on the application of nanofluids to enhance convective heat transfer coefficient of shell and tube heat exchangers. To the best of the author's knowledge, the effect of changes in volume concentration of nanofluids has not been studied so far. Therefore, in this research a study on volume concentration and the heat transfer characteristics and have been compared with those of pure water.

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III. PROPERTIES OF NANOFLUID MIXTURE

For the analysis of the performance of the shell and tube heat exchanger two nano fluids of metal powders are considered. Based on their volume concentration in the base fluid the properties of the nano fluids are calculated from the following equations.

Density of the nano fluid

$$\rho_{nf} = \varphi.\rho_s + [(1-\varphi).\rho_w]$$

Specific heat of the nano fluid

$$C_{p-nf} = \frac{\varphi.\rho_s.C_{ps} + (1-\varphi)(\rho_w.C_{pw})}{\varphi.\rho_s + (1-\varphi).\rho_w}$$

Viscosity of the nano fluid

$$\mu_{nf} = \mu_w(1 + 2.5\,\varphi)$$

Thermal conductivit of nano fluid

$$K_{nf} = \frac{Ks + 2Kw + 2(Ks - Kw)(1+\beta)^3 \times \varphi}{Ks + 2Kw - (Ks - Kw)(1+\beta)^3 \times \phi} \times k_w$$

Table 1: Titanium carbide properties

Volume Fraction %	Thermal Conductivity(W/m-K)	Specific Heat(J/Kg-K)	Density(Kg/m^3)	Viscosity(Kg/m-s)
0.02	0.644	988	1076.836	1.05315×10^{-3}
0.04	0.7006	1003.4207	1155.472	1.1033×10^{-3}
0.07	0.7838	1013.0708	1273.426	1.178525×10^{-3}
0.15	1.04597	1098.8511	1587.97	1.379125×10^{-3}

Table 2: Titanium Nitridee properties

Volume Fraction.	Thermal Conductivity(W/m-K)	Specific Heat(J/Kg-K)	Density(Kg/m^3)	Viscosity(Kg/m-s)
0.02	0.6447	3835.55316	1083.036	1.05315×10^{-3}
0.04	0.69182	3539.4391	1167.872	1.1033×10^{-3}
0.07	0.7671	3168.005	1325.072	1.178525×10^{-3}
0.15	1.00057	2460.2749	1744.272	1.379125×10^{-3}

IV. NUMERICAL ANALYSIS

Conventional methods used for the design and development of Heat Exchangers are expensive. Numerical analysis is useful for studying fluid flow, heat transfer; chemical reactions etc by solving mathematical equations without conducting the experimental studies.. CFD provides cost effective alternative, speedy solution and eliminate the need of prototype. 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.

For the numerical analysis of shell and tube heat exhanger, the model is initallly crated in CAITIA from the collected data. Then the model is imported into ANASYS Fluent software for thermal and CFD analysis. Turbulent boundary conditions are considered for the analysis. Varios volume concentrations of the nano fluids are tested.

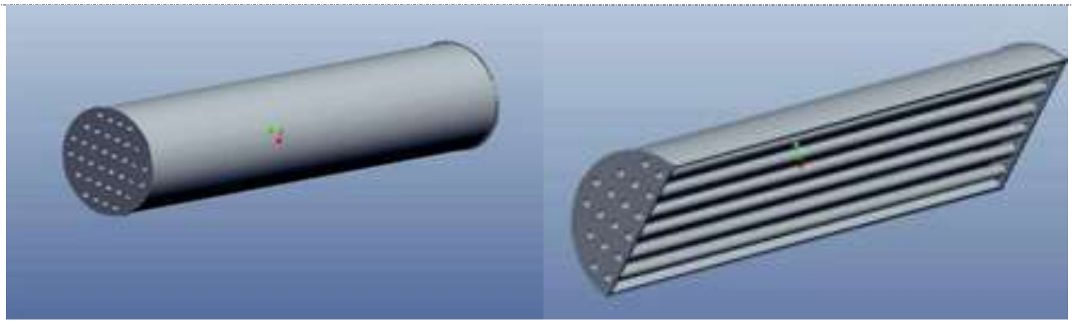
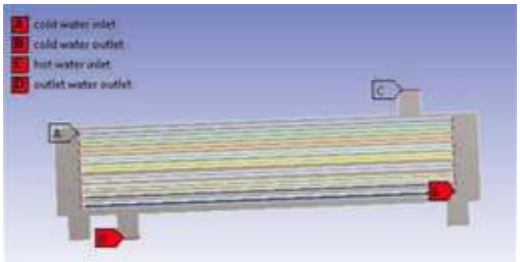


Fig 2 (a) 3d model of Heat exchanger (b) cut section

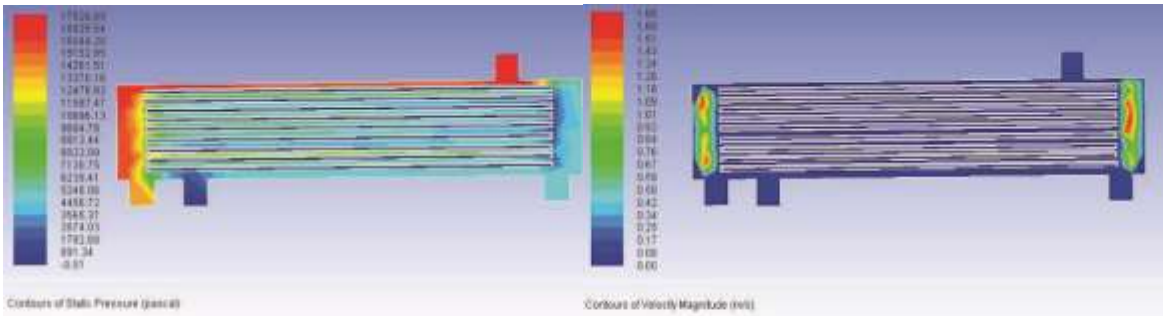


Inlet temperatures(T)	303°k, 353°k
Inlet pressure(P)	101325 Pa
Inlet velocity(V)	1.4412 m/s

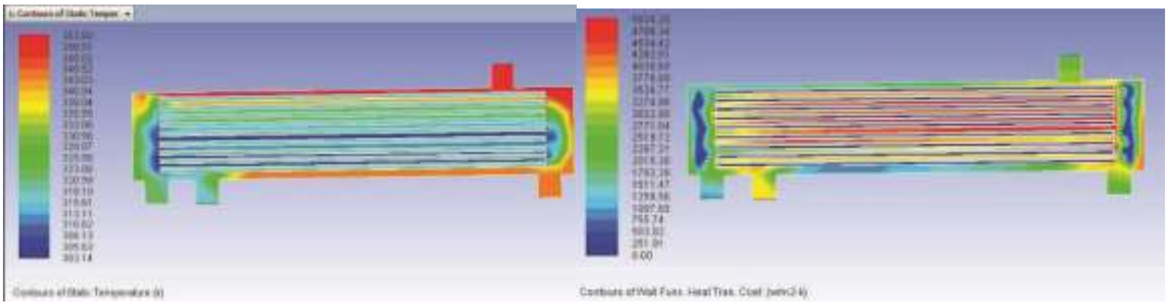
Fig 3 Applied boundary conditions for heat exchanger model

V. RESULTS AND DISCUSSION

To evaluate the effect of Nano fluid concentration on the performance of the heat exchanger, numerical simulation has be done n\by using Fluent. Aluminium and Copper are considered as the materials for the tubes of the shell and tube heat exchanger. Initially, flow analysis is done on all volume fractions of the Nano fluid to evaluate the pressure contours, velocity distribution, temperature distribution and heat transfer coefficients.



(a) *(b)*



(c) *(d)*

Fig 4: CFD analysis of STHE using 0.02 concentration of Titanium Carbide Contours of (a) Pressure (b) Velocity magnitude (c) Temperature distribution (d) Convective heat transfer coefficient.

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At volume fraction 0.04, 0.07 and 0.15, pressure contours, velocity magnitude, temperature and heat transfer coefficient for both nano fluids are numerically calculated for both material. When using Titanium Nitride as Nano fluid, the pressure is increasing by 55%, the velocity is increasing by about 63%, the heat transfer coefficient is decreasing by about 90%, the mass flow rate is increasing by about 98% and the heat transfer rate is increasing by about 96% when compared with that of Titanium Carbide Nano fluid.

By varying volume fractions, the heat flux (i.e.) heat transfer rate is increased by 1.11% for volume fraction 0.04 when compared with that of volume fraction 0.02, increasing by 2.6% for volume fraction 0.07 when compared with that of volume fraction 0.02, increasing by 6.36% for volume fraction 0.04 when compared with that of volume fraction 0.02 for Aluminum and Titanium Carbide Nano fluid.

Table2: Titanium carbide

Volume Fraction	Pressure Pa	Velocity m/s	Temperature °C	Film Coefficient W/m² °K	Mass flowrate Kg/s	Heat transfer rate W
0.02	17826	1.68	353	5038	0.0834	28406
0.04	19120	1.688	353	5536	0.0871	30750
0.07	21060	1.681	353	6255	0.0925	34000
0.15	26230	1.682	353	8600	0.1062	45220

The heat flux is increasing by 0.73% for volume fraction 0.04 when compared with that of volume fraction 0.02, increasing by 1.8% for volume fraction 0.07 when compared with that of volume fraction 0.02, increasing by 4.56% for volume fraction 0.04 when compared with that of volume fraction 0.02 for Aluminum and Titanium Nitride Nano fluid.

Table 3 Titanium nitride

Volume Fraction	Pressure Pa	Velocity m/s	Temperature °C	Film Coefficient W/m² °K	Mass flowrate Kg/s	Heat transfer rate W
0.02	39625	4.615	354	488	4.552	720780
0.04	42738	4.614	354	523	4.85	688480
0.07	48480	4.613	354	580	5.51	699650
0.15	63790	4.614	354	758	7.52	775736

The heat flux is increasing by 0.97% for volume fraction 0.04 when compared with that of volume fraction 0.02, increasing by 2.23% for volume fraction 0.07 when compared with that of volume fraction 0.02, increasing by 5.51% for volume fraction 0.04 when compared with that of volume fraction 0.02 for Copper and Titanium Carbide Nano fluid.

The heat flux is increasing by 0.41% for volume fraction 0.04 when compared with that of volume fraction 0.02, increasing by 1.023% for volume fraction 0.07 when compared with that of volume fraction 0.02, increasing by 2.68% for volume fraction 0.04 when compared with that of volume fraction 0.02 for Copper and Titanium Nitride Nano fluid.

By comparing the results between the Nano fluids Titanium Carbide has more heat transfer rate than Titanium Nitride.

VI. CONCLUSION AND FUTURE SCOPE

The present study is aimed at the usage of new nano fluid (water + Metal nitride/ carbides) at various volume concentrations and their effect on performance of shell and tube heat exchangers. The properties of the nano fluids are theoretically calculated. CFD and Thermal analysis are performed on the shell and tube heat exchanger using the mixture of water and different volume fractions of Nano fluids Titanium Carbide and Titanium nitride whose properties are theoretically calculated. At different nano particle concentrations the heat

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transfer enhancement of both nano fluids are not the same. By observing the CFD analysis results, the following conclusions can be made.

1. From the CFD analysis, the pressure, heat transfer coefficient, mass flow rate and heat transfer rate are increasing by increasing the volume fractions of the Nano fluids in water.
2. From the thermal analysis results, more value of heat flux is observed in copper tubes in STHE for high volume concentrations for any type of nano fluids.

The enhancement of the heat transfer capability of nano fluids makes their use in heatex changers a remarkable option, which makes a improved system performance and resulting an energy efficient. On the other side, nano fluids stability and its production cost are major factors that hinder the commercialization of nano fluids. Further theoretical and experimental investigations on the thermal conductivity and viscosity are needed to prove the potential of nano fluids and to realize the heat transfer characteristics of nano fluids as well as to identify new and exclusive uses in the heat exchangers

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