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Review on Shell and Tube Heat Exchanger Using Nano Fluids

B. Senthil Kumar[1], C. Deepak Kumar[2], A. Dhana Vishnu[3], N. Guru Prasath[4]
[1]*Professor, Department of Mechanical Engineering, Sri Ramakrishna Engineering College, Coimbatore, India*
[2,3,4]*Student, Department of Mechanical Engineering, Sri Ramakrishna Engineering College, Coimbatore, India*

***Abstract*: Nanofluids are the new-generation heat transfer fluids largely used in heat exchanger for thermal energy transport application. Investigate the heat transfer characteristics of nanofluids in a shell and tube heat exchanger. In generally the test matrix is worked out in the turbulent regime with Reynolds number will vary, particle volume concentration of (0%, 0.05%, 0.1% and 0.2%). The morphology and structure of fabricated nanoparticles where characterized using X-ray diffraction analysis (XRD) and scanning electron microscope (SEM). The influence of mass flow rate, inlet temperature and volume concentration of LMTD, effectiveness, convective heat transfer coefficient and pressure drop are studied. When compared nanofluids with pure water it has more effectiveness. The use of nanofluids increased the friction factor by 21% in comparison with pure water. Because of change in heat transfer and friction factor, heat transfer performance coefficient increased by upto 42.2%, indicated enhanced heat transfer compared to undesirable pressure drop in the test. According to the research, the nanofluid can be a good alternative in similar applications such as heat exchangers. Although the nanofluids were cost effective, it has more cop of heat exchanger.**

***Keywords*: Nano fluids, Shell Heat Exchanger, Tube Heat Exchanger**

1. Introduction

Shell and tube heat exchanger is one of the common types of exchangers widely used in the industries. This exchanger having a vessel with different sizes contains a number of tubes inside. Heat transfers between these specified tubes together and with the shell side through tube walls. The rate of heat transferred depends on several factors such as given temperature and pressure, shell diameter, a number of tubes, tube dimensions, baffle spacing and cutting spacing.

With the rapid development of modern nanotechnology, particles of nanometer size (normally less than 100nm) are used instead of micrometer size for dispercing in base fluid are called nanofluids. Many researchers have investigated the heat transfer performance and flow characteristics of various nanofluids with different nanoparticles and basefluid.

2. Nomenclature

A-Area,m^2
A_p-collector plate area,m^2
c-capacitance
C_p-specific heat capacity,J/kgK
D-diameter,m
h-convective heat transfer coefficient,W/m^2 K
k-thermal conductivity,W/mK
L-length,m
LMTD-logarithmic mean temperature Difference,
m-mass flow rate,kg/s
NTU-number of transfer units
Pr-Prandtl's number
r-cylindrical coordinates
Re-Reynolds number
U-overall heat transfer coefficient,W/m^2 K
Subscript
c-cold fluid
ci-cold fluid inlet
co-cold fluid outlet
h-hot fluid
hi-hot fluid inlet
ho-hot fluid outlet
I-inside surface of the wall
Nf-nanofluid,
o-outside surface of the wall
p-nanoparticle
w-wall

Since solid particles have thermal conductivity higher than that of common fluids,when they are dispersed in the fluids result in higher heat transfer characterisitics. There are many type of particles such as metallic, non-metallic and polymeric.since thermal conductivity is one of the important parameters for heat transfer enhancement, some studies have been done on thermal conductivity of nano fluids. All experimental results have indicated the enhancement of thermal conductivity by addition of nanoparticles.

Table 1
Specifications of the shell and tube heat exchanger

Specification	Shell	Tube
Material	Stainless steel	Copper
Outer diameter (mm)	200	6
Inner diameter (mm)	150	4
Length (mm)	700	700
Number of tubes	–	25

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3. Experiments

A. Nano fluids

The base fluids such as water, ethylene glycol, engine oil, and ethylene/water mixtures are commonly used fluids for the preparation of hybrid nanofluids. The size of the hybrid nanoparticles is very important and it should be less than 100 nm for achieving the stable hybrid nanofluids. It synthesized ND-Ni and NDFe3O4 hybrid nanoparticles using the in-situ and chemical co-precipitation method and then prepared water based nanofluids. They also analyzed the particle size distribution of ND-Ni and ND-Fe3O4 using Zetasizer nanoZS. The results indicate the particle size of ND-Ni is 22 nm and the particle size of ND-Fe3O4 is 21.2 nm, respectively. The in-situ and chemical co-precipitation method is a very effective method to obtain the small size hybrid nanoparticles.

B. Preparation of nanofluids

The preparation of nanofluids from nanoparticles can be broadly categorized under the following two methods.

1) Two-step method

The Two-step method is most commonly used method for preparing nanofluids which is the source for heat exchanger. Nanoparticles, nanotubes, nanofibers and other nanomaterials utilized in this method are produced as dry powders first by the means of chemical and physical methods. After that the powder is be dispersed into a base fluid in the second step, with the help of external mixing or like magnetic agitators, ultrasonic agitators, high-shear mixers, homogenizing or ball milling. Two-step method is the large quantities because the nanopowder manufacturing techniques have already started providing up to required industrial production levels. The high surface area and surface related active, the nanoparticles have a tendency to accumulate together. It is one of the important methods to improve the stability of nanoparticles in base fluids is to use surfactants which reduce surface tension of the base fluids.

2) One-step method

Because of difficulties on stabiility during the mixing of process in preparing the nano fluid two step method, the One-step method was developed. In order to accumulate of nanoparticles, Eastman et al. Suggested. In this step his method, it involves simultaneous synthesis and dispersion of the nanoparticle the base fluid. By this method, the drying, storage and transportation to process are removed, so the accumulate of nanoparticles is kept minimum. Thus the stability of fluids is increased. The one-step of the method can be used to prepare fluids with the uniformly dispersed nanoparticles in a stable manner. It has square, polygonal or circular morphological shapes. It is the preferred to avoid the unwanted particle of aggregation quite well.

4. Test facility and discussion

The test section chosen for the present study is a single pass shell and tube heat exchanger with the shell side constructed using stainless steel material and the tubes with copper. The schematic layout of the test facility is shown in Fig. 3, which shows two circuits namely, tube side the shell side. The nanofluid heated by solar radiation from the solar flat plate collector flows into the tube side circuit. The other circuit carries the cold fluid from a temperature controlled tank to the heat exchanger along the shell side. The nanofluid and the chilled water form a counter flow heat exchanger configuration. The specifications of the shell and tube heat exchanger are shown in Table 1. The flow rate, which is measured using a mass flow meter with 0.1% accuracy regulated by a valve so as to set the desired flow rate, is then passed to the shell and tube counter flow heat exchanger along the tube side. The K type thermocouples with 0.1% accuracy are positioned in the fluid path to measure the bulk fluid temperatures between the inlet and outlet of test section. Two piezo-resistive static pressure sensors with 0.1% accuracy are inserted in the fluid path at the inlet and outlet of the heat exchanger to measure the net pressure drop. The entire test section is insulated in the periphery to avoid any heat infiltration into the heat exchanger. The temperature at the inlet and outlet of the two fluids are logged using a data acquisition system.

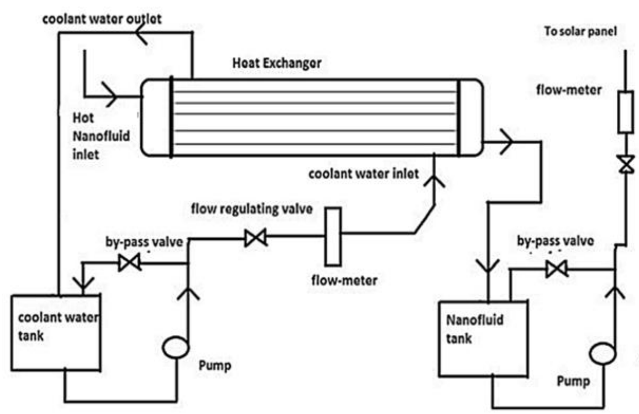

Fig. 1. Schematic diagram of the experimental layout

A. Theoretical Formulation

The specific heat of the nano fluid is calculated by xuan and roetze equation.

$$\frac{\mu_{n\mathcal{F}}}{\mu_{\omega}}=(1.005+0.497\varphi-0.1149\varphi^2) \quad (1)$$

$$\frac{K_{n\mathcal{F}}}{K_W}=(0.9692\varphi+0.9508) \quad (2)$$

$$\rho_{n\mathcal{F}}=\phi_{\rho_P}+(1-\phi)\rho_{\omega} \quad (3)$$

$$\mu_{n\mathcal{F}}=(1+2.5\phi)\mu_{\omega} \quad (4)$$

$$(\rho^{C_p})_{n\mathcal{F}}=\phi(\rho^{C_p})_p+(1-\phi)(\rho^{C_p})_{\omega} \quad (5)$$

Where $\rho_{n\mathcal{F}}$ is the density of the nano fluid, ρ_p is the density of the nano particle, ρ_{ω} is the density of water, μ represent viscosity, k stands for thermal conductivity, C_p represent the specific heat, subscripts ω and p are the properties of water and nano particles. Here ϕ is the volume concentration of the nano fluid. The uncertainity analysis is then and maximum error in the observed reading and calculated parameters are found to be less than ±5%.

The heat transfer rate from the heating fluid is calculated using the following equation

$$Q = mC_p(T_{hi} - T_{ho}) \quad (6)$$

The capacitance of hot fluid and cold fluid is then determined

$$C_h = mc_h \quad (7)$$

$$C_c = mc_c \quad (8)$$

The logarithmic mean temperature (LMTD) is then determined by the following equation:

$$LMTD = \frac{(T_{hi}-T_{\infty})-(T_{ho}-T_{ci})}{\ln\{\frac{(T_{hi}-T_{\infty})}{T_{ho}-T_{ci}}\}} \quad (9)$$

The overall heat transfer co-efficient is then obtained by

$$Q = UA_P(LMTD) \quad (10)$$

Where

$A_p = N(\pi DL)$

The effectiveness of the heat exchanger is determined by

$$\varepsilon = 2\{1 + c + \sqrt{1+c^2}\,\frac{1+\exp[-NTU\sqrt{1+C^2}]}{1-\exp[-NTU\sqrt{1+C^2}]}\} \quad (11)$$

Where

$NTU = \frac{UA}{C_{min}}$, $c = \frac{C_{min}}{C_{max}}$

5. Discussion

To improve the performance of STHXs, some researchers have studied the effect of applying nanofluids in them. Albadr et al. reported an experimental study on the forced convective heat transfer and flow characteristics of water–Al2O3 nanofluids flowing in a STHX under turbulent conditions. The results showed that the heat transfer coefficient of nanofluid is slightly higher than that of the base liquid at same mass flow rate and same inlet temperature. The heat transfer coefficient of the nanofluid increased with an increase in the mass flow rate and the concentration, however increasing the concentration caused increase in the viscosity leading to increase in friction factor. The value of the overall heat transfer coefficient of the nanofluid was 57% greater than that of pure water.

Bahrehmand and Abbassi investigated heat transfer of Al2O3 nanofluid flow inside shell and helical tube heat exchangers. The results indicated that the presence of 0.2% and 0.3% volume concentration increases the heat transfer rate by approximately 14% and 18%, respectively. The results also showed that the coil-side, shell-side and overall heat transfer coefficients enhance with the concentration increment. It was indicated that for the same mass flow rate, the heat transfer rate of nanofluid enhances noticeably compared to water and it increases marginally with the further increase in the concentration. In addition, it was found that the effectiveness enhances by decreasing the mass flow rate and increasing the concentration, tube diameter and coil diameter.

Some contributions have examined the effect of nanoparticle shape on the characteristics of STHXs.

Elias et al. studied the effect of different particle shapes (cylindrical, bricks, blades, and platelets) on the overall heat transfer coefficient, heat transfer rate and entropy generation of a STHX with different baffle angles and segmental baffle. Cylindrical shape nanoparticles showed best heat transfer coefficient among the other shapes for different baffle angles along with segmental baffle. An enhancement of overall heat transfer coefficient for cylindrical shape particles with 20° baffle angle was found 12%, 19.9%, 28.23% and 17.85% higher than 30°, 40°, 50° baffle angles and segmental baffle, respectively for 1 vol% concentration of Boehmite alumina. Heat transfer rate was also found higher for cylindrical shape at 20° baffle angle than other baffle angles as well as segmental baffle. However, entropy generation decreased with the concentration increment for all baffle angles and segmental baffle.

Due to the favorable characteristics of CNTs, some studies have focused on utilizing nanofluids containing CNTs in STHXs. Lotfi et al. studied heat transfer enhancement of a MWCNT–water nanofluid in a horizontal STHX. CNTs were synthesized by the use of catalytic chemical vapor deposition method over Co Mo–MgO nanocatalyst. Obtained MWCNTs were purified using a three stage method. COOH functional groups were inserted for making the nanotubes hydrophilic and increasing the stability of the nanofluid. The results indicated that heat transfer in the heat exchanger enhances in the presence of MWCNTs in comparison with the base fluid. Overall heat transfer coefficient increased from 30 to 32 W/m2 K by adding the nanoparticles.

Hosseini et al. presented the performance of CNT–water nanofluid as a cooling fluid in a shell and tube intercooler of a LPG absorber tower. It was observed that for maximum CNT volume fraction which was 0.278%, the overall heat transfer coefficient and heat transfer rate increased about 14.5% and 10.3%, respectively, compared to water. This advantage can decrease the heat transfer area of the heat exchanger which will lead to decrease the manufacturing cost. The outlet temperature of the hot fluid decreased with increasing the volume fraction whereas the pressure drop due to the nanoparticles suspended in water was too low.

Although the above two studies show that employing CNTs increases heat transfer in STHXs, one particular challenge concerning the use of CNTs is their entanglement which leads to their quick sedimentation. To prevent this, CNTs can be used in hybrid form with magnetic nanoparticles. Functionalizing CNTs using magnetic nanoparticles can combine the characteristics of magnetic nanoparticles and CNTs, which can develop materials with new chemical and physical features and therefore, promising applications. Indeed, the magnetic

Table 1
Some of the studies conducted on application of shell and tube heat exchangers

Researcher(s)	Year	Nanoparticles	Finding(s)
Bahmani et al.	2018	Al_2O_3	Using counter flow heat exchangers was recommended at greater Reynolds number
Chun et al.	2008	Al_2O_3.	The surface properties of nanoparticles, particle loading and particle shape are important causes for enhancing heat transfer in the heat exchanger
Aghayari et al.	2015	Al_2O_3	Enhancement of convective heat transfer coefficient depends on the fluid thermal conductivity and thermal boundary layer thickness
Bahiraei et al.	2017	Ag	When concentration and Reynolds number increase, the overall heat transfer coefficient and heat transfer rate augment
Zamzamian et al.	2011	Al_2O_3	Nanoparticles enhance the forced convective heat transfer coefficient of the base fluid significantly
Hazbehian et al.	2016	TiO_2	Heat transfer coefficient is further increases for nanofluid in the tube with strip insert
Kumar et al.	2017	Fe_3O_4	Maximum heat transfer enhancement of 14.7% was achieved at 0.06% volume concentration and Re = 28,970 compared with water
Reddy and rao	2014	TiO_2	Using helical coil inserts is advantageous to increase heat transfer, while it also causes pressure drop
Durga Prasad et al.	2015	Al_2O_3	The friction factor for the inner tube for 0.03% concentration of nanofluid with helical tape inserts intensifies by 1.38-times compared to water
Rabie natraj Darzi et al.	2013	Al_2O_3	Adding the nanoparticles to the base fluid has better result at high Reynolds numbers
Duangt hongsuk and wongwise	2009	TiO_2	The nanofluid incurs no penalty of pumping power and can be appropriate for practical application
Sozen et al.	2016	Al_2O_3	Using the nanofluid can improve thermal performance and efficiency of heat exchangers
Shakiba and vahedi	2016	Fe_3O_4	By applying a non-uniform transverse magnetic field, the ferrofluid flow is controlled and the cooling process improves
Sozen et al.	2016	Fly ash	Performance of the heat exchanger improved through an increase in the amount of heat transferred into the cold fluid
Sarafraz and hormozi	2015	Ag	The nanofluid can change flow regime earlier from laminar to transient and transient to turbulent
Prasad et al.	2015	Al_2O_3	Average Nusselt number enhances with an increase of Reynolds number and nanoparticle concentration
Akhtari et al.	2013	Al_2O_3	Nanoparticles increase the heat transfer rate and overall heat transfer coefficient
Wu et al.	2013	Al_2O_3	For constant Reynolds numbers, no multiphase phenomenon was observed and the employed alumina nanofluids behave like homogeneous fluids
Bahiraei et al.	2017	Ag	At large concentrations and Reynolds numbers, particle migration have a significant effect on entropy generation rates
Saeedan et al.	2016	Cu, CuO and CNT	Increasing volume concentration has the most effect on heat transfer attributes for Cu compared with other nanoparticles
Huminic and huminic	2011	CuO and TiO_2	Outlet water temperature increases by increasing particle concentration, and CuO is better than TiO2
Sona wane et al.	2013	Al_2O_3	Heat transfer rates for nanofluids are higher than those for the water, and this increases with concentration increment

particles connect to the wall of CNTs by hydrophobic interactions. Therefore, the ferromagnetic property is added to the CNTs without altering the great yield of tube formation. This quick and simple process causes the spatial organization of the CNTs in the magnetic field direction. Utilizing this technique in the presence of magnetic fields prevents entanglement of CNTs in liquids.

6. Conclusion

The present study is deal with heat transfer characteristics of nanofluids in a shell and tube heat exchanger. The experimental investigation shows the strong influence of thermal conductivity on heat transfer process. The percentage increase in heat transfer coefficient of 0.01%, 0.03% and 0.04% are respectively 9.2%, 10.87% and 12.4%. It has been found out that the overall heat transfer coefficient and effectiveness of nanofluids based heat exchanger is higher than that compared to water. The noticeable increase in the heat transfer coefficient is due to the enhanced thermophysical properties of the nanofluids and delay in the boundary layer development in the entrance regions with the addition of nanoparticles. It should be mentioned that baffles in STHXs are one of the important design parameters that affect the performance significantly; one improvement can be the modification of baffle configurations. Baffle spacing and baffle cut are the most important geometric elements affecting both heat transfer rate and pressure loss. Nevertheless, little research has been conducted concerning the effect of baffle configuration on the characteristics of STHXs which work with nanofluids. This has to receive further attention in future studies.

The Table 1, is a summary which presents some of the research contributions performed on use of nanofluids in STHXs containing the quantified results as well as main findings.

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