Journal of Applied Fluid Mechanics, Vol. 10, Special Issue, pp. 7-13, 2017.
Selected papers from *International Conference on Newer Engineering Concepts and Technology*, ***ICONNECT2K17***, *2017*
Available online at www.jafmonline.net, ISSN 1735-3572, EISSN 1735-3645.
DOI: 10.36884/jafm.10.SI.28265

Heat Transfer Enhancement and Pressure Drop Analysis of a Cone Helical Coiled Tube Heat Exchanger using MWCNT/Water Nanofluid

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(Received February16, 2017; accepted July 30, 2017)

ABSTRACT

In this investigation, the heat transfer and pressure drop analysis of a cone helically coiled tube heat exchanger handling MWCNT(Multi Walled Carbon nanotube)/water nanofluid have been carried out experimentally. The MWCNT/water nanofluids of 0.1%, 0.3%,and 0.5% particle volume concentration have been synthesized with the addition of surfactant Sodium dodecylbenzene solfonates by using two step method and characterized. The test runs conducted laminar flow in the Dean number range of 481 < De < 2130 .The thermo physical properties have been determined by using the existing mathematical models. It is found that the tube side experimental Nusselt numbers are 22%, 41% and 52% higher than water for the 0.1%,0.3% and 0.5% nanofluids volume concentration respectively. These are due to higher thermal conductivity of MWCNT nanofluid than water and better mixing of fluid and nanotube.. This may also be due to very strong secondary flow formation in cone coiled tube. It is also found that the pressure drop of 0.1%, 0.3% and 0.5% were found to be 25%, 50% and 81% respectively higher than water. The increase in pressure drop is due to increase in nanofluid viscosity while adding nanotubes . The measurement of nanofluid thermal performance factor is found to be greater than unity. It is concluded that the MWCNT nanofluid can be applied as a coolant in cone helically coiled tube heat exchanger to enhance heat transfer with considerable pressure drop.

Keywords: MWCNT/water; Cone helically coiled tube; Nusselt number; Thermal conductivity; Secondary flow; Volume concentration.

NOMENCLATURE

A	surface area
c_p	specific heat capacity
di	diameter of coiled tube
De	dean number
h	convective heat transfer co-efficient
k	thermal conductivity
L	effective length of tube
$\dot{m}$	mass flow rate
Nu	Nusselt number
Q	heat transfer rate
Re	Reynolds number
Rc	curvature radius
T	temperature
v_i	tube side velocity
Uo	overall heat transfer Coefficient

Subscripts

cr	critical
f	base fluid
i	inside condition
nf	nanofluid
o	outside condition
r_f	liquid particle size
r_p	nano particle size
w	water

1. INTRODUCTION

Enhancement in heat transfer coefficient improves the performance of heat exchanger and also reduces the size of the heat exchangers are the crucial issue in meeting out the culling demand. In this method generally the heat transfer enhancement techniques are two groups like Active and Passive techniques. The Active technique needs external forces and passive group needs special surface geometric face or fluids additives and various tube insert. Coiled tube configuration is widely used in industrials like power plants, nuclear reactors, refrigeration and air-conditioning systems, heat recovery systems, chemical processing pharmaceutical industries and food industries. The coiled tube is of two types like helical coil and spiral coiled tube. Dean (1927) reported the flow pattern in helical coiled tube is complicated due to the formation of secondary flow induced by centrifugal force. Secondary flow provides better thermal contact between the surface of the tube and fluids due to the creation of vertex and resulting the mixing of the fluid which improves the temperature gradient. Prabhanjan (2002) studied the heat transfer coefficient in helical coil tube higher than that of an similar geometry of straight tubes. Naphon (2006) recapitulated the heat transfer and flow characteristics of single phase and two phase flow through the curved pipe as both helical coil and spiral coil heat exchanger. Purandare (2013) Presented the effect of geometric and operating condition on the performance of helical coiled tube heat exchanger. Naphon (2002) investigated the heat transfer rate increase with increase the Dean number at different mass flow rate in spiral coil heat exchanger. Salimpour (2009) experimentally investigated the overall heat transfer coefficient of shell and helical coil with water. It is reported that the Nusselt number correlation and reported the heat transfer rate differs while varying coil tube pitch. Purandare (2015) investigated the effect of Nusselt number on changing the tube angle in a cone shaped helically coiled tube. Srinivasan (1970) analyzed the heat transfer and friction coefficient and proposed the critical Reynolds number Re_{cr} in curved pipes. The present heat transfer fluids have limited thermal energy management capacity to face the higher cooling demand. More than a decades the research on applications of the nonomaterials is picking up momentum among the researchers. In particular, the existing cooling fluids are going to be replaced with the nanofluids in future to solve the hurdles faced by the existing conventional heat transfer fluids. Choi (1995) introduced a new traditional heat transfer fluids with 1 -100 nm sized suspended nanoparticles in the base fluids. Suggested that the thermal performance of nanofluids is better than that of water. Assael (2004) observed the thermal conductivity enhancement in nanofluids by using stabilized by SDBS (Sodium dodecylbenzene solfonates). Ding (2006) studied the effective thermal conductivity increases with increasing temperature and volume concentration of MWCNT dispersed with Gum Arabic as a surfactant. Kumaresan (2012) investigated the thermo physical properties of MWCNT water –ethylene glycol mixture based nanofluids with SDBS as surfactant. The maximum enhancement of thermal conductivity were 19.75% at 0.45 vol% MWCNT. Das (2003) measured the thermal conductivity of nanofluids containing Al_2O_3 nano particles and investigated the effect of base fluid on the thermal conductivity. Wen (2004) studied the convective heat transfer improved in the laminar flow condition with Al_2O_3 nanoparticle with water. It is suggested that the convective heat transfer enhances with Reynolds number as wall as particle volume concentration. Suresh (2011) presented the convective heat transfer and friction factor characteristics of plain and helically dimpled under turbulent flow by Cuo water based nanofluids. The heat transfer rate increase with increase Nusselt number at high volume concentration. Wang (2013) investigated the heat transfer and pressure drop of working fluids as water based CNT nanofluids in circular tube as horizontal position. It is concluded that the enhancement of average convective heat transfer increase with increase the volume concentration of nanoparticles at constant Reynolds number. Kumar (2014) studied the heat transfer and pressure drop in helically coiled tube heat transfer working fluid as Al_2O_3 nanofluids under a turbulent flow region. The increase in heat transfer coefficients and pressure drop are enhanced with increasing the particle concentration. Kahani (2013) investigated the effect of nanofluids concentrcation on heat transfer in a helically coiled tube heat exchanger under MWCNT/water nanofluid. The maximum achievable Nusselt number is obtained with small curvature ratio change and at increasing the pitch spacing of the helical coil tube. Amiri (2014) reported the pool boiling heat transfer coefficients of the non – covalent nanofluids is lower than that of the deionized water. Sheikhzadeh (2012) numerically identified the nanofluid significantly increases the strength, Nusselt number and entropy generation. Sheikhzadeh (2017) investigated the convective heat transfer of Al_2O_3/EG- Water based nanofluids with volume fraction 0.012% used in car radiator. They reported that using the nanofluid with 0.012% volume fraction result in: (a) the convective heat transfer coefficient increase 10% compared to base fluids at same flow rate, (b) 8.9% increase Nusselt number with increase the nanofluid flow rate. Vahidifar (2015) carried out an experimental study on heat transfer enhancement in double pipe tube heat exchanger with insert as a wire coil and rings. They found that using wire coil and rings to increase Nusselt number ratio increase for rings 2.3 -2.4 compared without inserts and overall heat transfer enhancement efficiency of 128% is found that in rings inserts.

Based on the literature survey, a few of the experimental investigation have been done and reported on the application of water as a working fluids in helically cone coiled tube heat exchanger under. Therefore the main objective of this investigation is to analyze the heat transfer and pressure drop of shell and helically cone coiled tube heat exchanger by using MWCNT/water nanofluids as target fluid.

2. Experimental Setup

The configuration speciation in this work handle conical helical coiled configuration. the conical coiled configurations is combined helical coiled and spirally coiled configuration. The conical coiled tube is shown in Fig. 1.

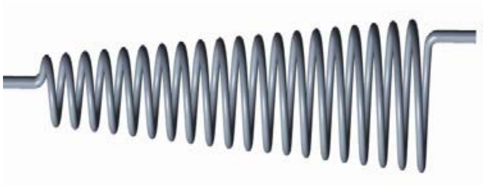

Fig. 1. Cone helical coiled.

Figure 2. illustrates the schematic diagram of the experimental setup. The experimental set-up consists shell side loop and cone helical coiled tube side loop. Shell side loop uses hot water. Cone helical coiled tube uses MWCNT / water nanofluid. The shell side flow and coiled tube side flow are in counter flow configuration. Shell side loop is connected with storage vessel size 15cm x 15cmx15cm, with 2KW capacity, magnetic pump and thermostat. Cone coiled tube loop side is connected with a mono bloc pump with 0.5hp power, valve to control the flow on tube side, test section ,cooling unit and storage vessel of six liter capacity. The cone coiled tube is made by winding a straight copper tube on wooden patterns. Fine sand is filled the tube to not have the distortion of the inner surface. Cone helical coiled tube is made up of copper and shell is made of stainless steel (SS). Thermostat is used to measure the temperature of hot water in shell storage vessel. Four K-type thermocouple of 0.1°C accuracy were used to measure the inlet and outlet temperature of the shell side and Cone coiled side. Four K –type thermocouple of 0.1°C were fitted on the outer surface of coiled to measure the tube wall temperatures. The thermocouples were fitted and glued with epoxy to avoid leakage. The calming section is provided in cone helical tube to avoid the entrance effort. U-tube mercury manometer is fitted across and uncertainty of U-tube manometer are 1 m and 0.003. The shell is insulated with asbestoses tape. A valve is fitted in the flow pipe to control the flow, radiator is used to cool the hot nanofluids.

The Dimensions of test section are Cone helical coiled angle (θ) – 8 degree, internal cone helical coiled tube diameter (di) – 8 mm, external diameter of cone helical coiled tube(do) – 10 mm, shell diameter – 114 mm, the effective length (L) of the coil – 5000 mm, coil pitch(b) – 20 mm, length of calming section – 110 mm, Cone helical coil diameter (D) – 64 mm.

At the outset water is circulated to check the experimental set up and its fittings and their corresponding leakages a and assure their function.

The Cone angle is maintained constant throughout the test. Hot water and cold water are allowed to shell and tube side respectively under counter flow condition. The pump is operated when the shell side attains the required temperature. The shell side fluid temperature is controlled by thermostat. The corresponding temperatures are noted at the shell and cone helical coil tube side. The nanofluid at 0.1% 0.3% and 0.5% volume concentration are circulated through tube side. Hot water is circulated to the shell side. Flow rate on the shell side is kept constant (0.15 kg/sec) and flow rate on tube side is varied. The temperatures are measured after getting steady state condition. The flow rates are recorded manually by collecting the fluid with the precise measuring Jar and stop watch. The tests were conduced in the range of $481 < De < 2130$ under flow condition. The range of nanofluid flow rate is in the range of 0.01 – 0.04 kg/sec. The pressure drop is recorded by using 'U' tube manometer. All the quantities that are measured to estimate the tube side Nusselt number are subjected to uncertainties due to the errors in the measurements.

3. Nanofluid Preparation

The MWCNT nanoparticles were purchased from Nanostructure & Amorphous Materials, Inc. Houston, TEXAS and USA. The purchased MWCNT nanoparticles were characterized by XRD (Rigaku Cu- $k_{\acute{\alpha}1}$ X ray Differatometer). The average CNT dimensions were found to be between 50-80.nm (the error is within the limit of ±5nm) using XRD pattern of nanoparticles Fig. 3. In this investigation MWCNT water based nanofluid is prepared by using two method. Because two step method is better for nanostructure and this method gives higher stability and less agglomeration Ghadimi (2011). The MWCNT water based nanofluids have been synthesized at 0.1%, 0.3%, 0.5%, volume concentration and morphological characterized of nanofluid obtained using with transmission electron microscopy (TEM) are shown Fig. 4. TEM Image clearly show that the MWCNT core is hollow with multiple layers almost parallel to the MWCNT axis.

From the Fig. 4. the nanostructures are stable without any agglomeratation and uniformly dispersed. It is observed that there was no significant settlement of nanotubes even after 30 days of static condition of nanofluid. Kumaresan (2012) presented the Sodium dodecylbenzene solfonates (SDBS) as a surfactant to add to maintain the long standing stability of nanotubes in base fluid. Garg (2009) investigated the effect of ultrasonication with TEM analysis on heat transfer performance of the MWCNT based aqueous nanofluids. Reported that maximum heat transfer enhancement is obtained by the 40 minutes ultrasonication. The required `amount of MWCNT was taken and dispersed in distilled water with the Ultrasonic bath (Citizen, India) generating Ultrasonic pulses 110 W at 40 ± 5 kHz and it was switched on for 3 hour to get the uniform dispersion and stable

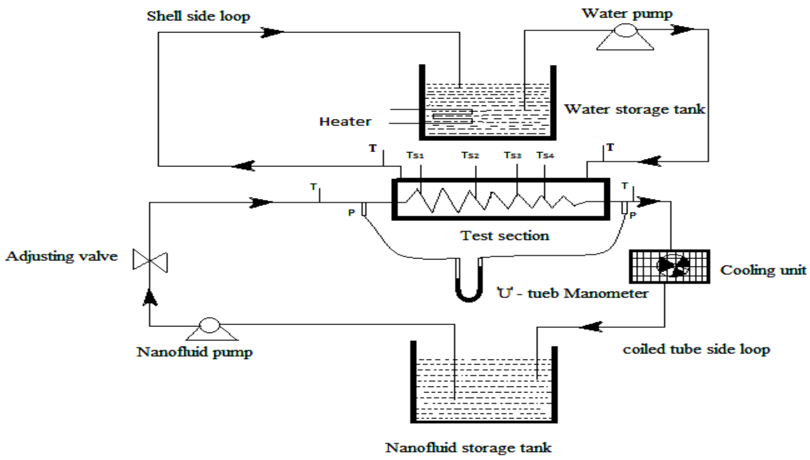

Fig. 2. Schematic diagram of experimental setup.

suspension of nanoparticles. The 0.1 vol % of Sodium dodecylbenzene solfonates Surfactant was taken added to have more stability.

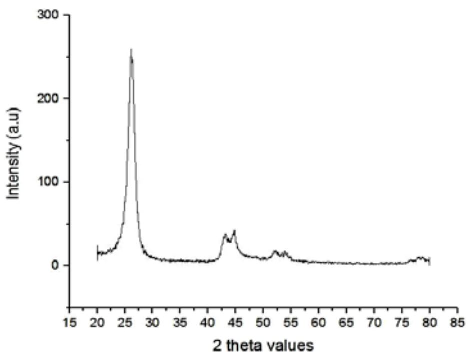

Fig. 3. XRD pattern of MWCNT nanoparticle.

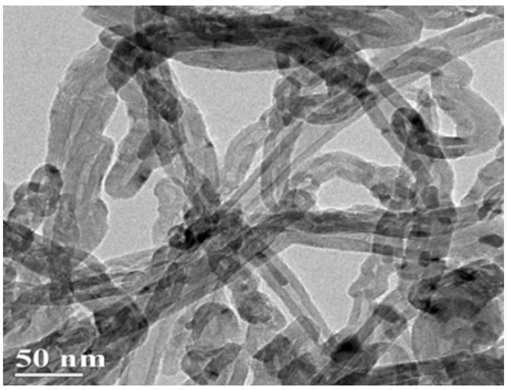

Fig. 4. TEM image of MWCNT/water nanofluid.

4. THERMO PHYSICAL PROPERTIES

Pak and Cho (1998), H. E. Patel (2008). and Ebrahimnia-Bajestan (2011). proposed the Eqs. (1) - (4) for calculating the thermo physical properties such as density, effective thermal conductivity, specific heat, and viscosity.

Density in kg/m^3

$$\rho_{nf} = \phi\rho_s + (1-\phi)\rho_w \,. \tag{1}$$

Specific Heat J/kg K

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p) + \phi(\rho c_p)_s \tag{2}$$

Effective thermal conductivity W/mK

$$k_{nf} = k_f \left[1 + \frac{k_p \phi r_f}{k_f (1-\phi) r_p} \right] \tag{3}$$

Dynamic viscosity , kg/m^{2}s

$$\left[\mu_{nf} = \mu_f \,(1 + 22.7814\varphi - 9748.4\varphi^2 + 1000000\varphi^3 \right] \tag{4}$$

5. MATHEMATICAL FORMULATION

The flow condition is obtained by using the Dean number Eq. (5). The average heat transfer of the tube side and shell side are calculated from Eqs. (6) and (9)

$$De = Re_i(d_i/2R_c)^{0.5} \tag{5}$$

$$Q_w = m_w c_{p,w} (T_{in} - T_{out})_w \tag{6}$$

$$Q_{nf} = m_{nf} c_{p,nf} (T_{in} - T_{out})_{nf} \tag{7}$$

$$Q = U_o A_o (\Delta T) \tag{8}$$

$$Q = h_i A_i (T_{wall} - T_{bulk}) \tag{9}$$

$$Nu_i = \frac{h_i d_i}{k_{eff}} \tag{10}$$

$$\Delta P = (\Delta\rho)\, gh \tag{11}$$

7. RESULTS

7.1 Heat Transfer of MWCNT Nanofluids

Figure 5. describes the increase of overall heat transfer coefficient with increasing tube side Dean number and particle volume concentration. Th enhancement of The maximum overall heat transfer coefficient is 45% at 0.5% volume concentration at tube side Dean number of 2133. It is due to more heat transfer and lowering the temperature drop between the bulk fluid in coil and the fluid in shell side.

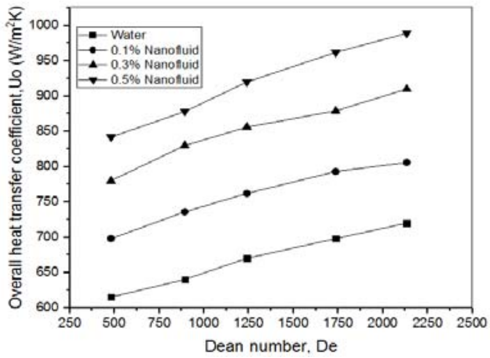

Fig. 5. Variation of overall heat transfer coefficient with tube side Dean number.

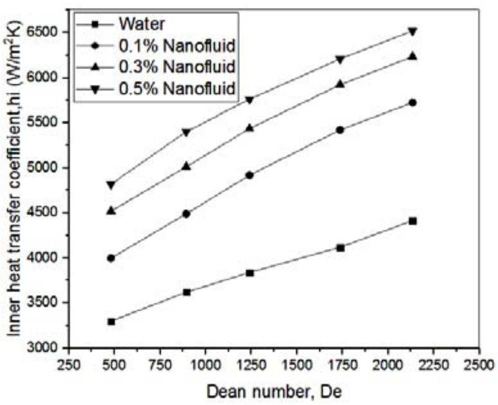

Fig. 6. Variation of inner heat transfer coefficient with tube side Dean number.

Figure 6. depicts the effect of change of particle volume concentration on inner heat transfer coefficient. It is studied that the tube side heat transfer coefficient increases with respect to the Dean number. The enhancement of tube side inner heat transfer coefficient were found to be 25%, 48% and 58% higher than the water at 0.1%, 0.3% and 0.5% MWCNT/water nanofluids respectively. It is found that heat transfer coefficient is improved even at 0.1% particle volume concentration. This is because of the reduction in temperature difference between the wall and the bulk nanofluids. The reduction of wall temperature occurs when the dispersed and suspended MWCNT impinges the bend surface as conical shape. Fig. 7 indicates the enhancement of experimental Nusselt number by varying tube side Dean number and particle volume concentration. The enhancements of tube side experimental Nusselt numbers were found to be 22%, 41% and 52% at 0.1%, 0.3% and 0.5% MWCNT/water nanofluids, respectively when compare to water. The enhancement may due to through mixing of fluid particles and CNTs, and Brownian motion of CNTs. It means that the formation of secondary is not affected when MWCNT is allowed in the cone coiled tube.

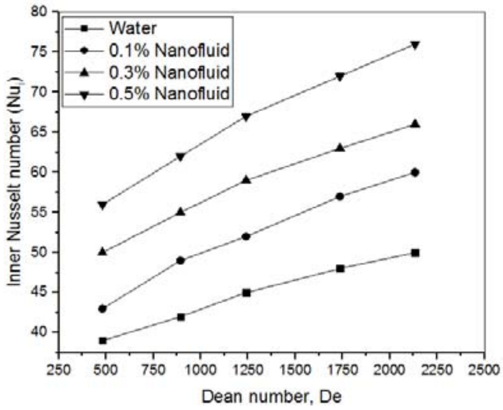

Fig. 7. Variation of inner Nusselt number with tube side Dean number.

7.2 Effect of Pressure Drop

Figure8 shows that the pressure drop increases with increasing particle volume concentration and Dean number. The pressure drop of 0.1%, 0.3% and 0.5% are 25%,50% and 81% higher than water respectively. This is due to increase in viscosity when increasing particle volume concentration. It is found that pressure drop at 0.5% nanofluid and at maximum Dean number is the highest.

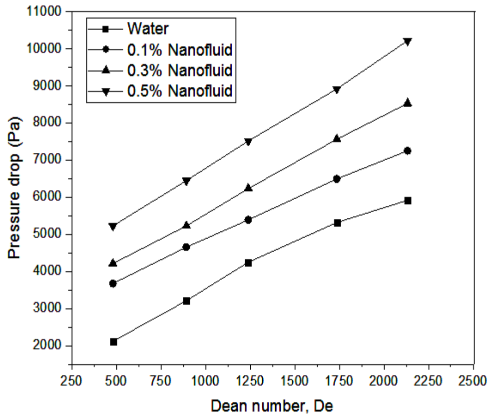

Fig. 8. Variation of pressure drop with tube side Dean number.

8. CONCLUSION

In this experimental investigation, laminar(481 < De < 2130) heat transfer and experimental pressure drop of cone helically coiled tube with MWCNT/

water nanofluid at 0.1%, 0.3% and 0.5% particle volume concentration were tested. It is studied that the heat transfer coefficient increase with increasing the particle concentration. The maximum enhancement of overall heat transfer coefficient, inner heat transfer coefficient and inner Nusselt number were found to be 45%,52% and 56% respectively higher than water at 0.5% volume concentration. These enhancement are due to higher thermal conductivity of nanofluid, through mixing of nanofluids, and easy movement of nanoparticle. Further, it is observed that the presence of CNts does not lead to the formation of very strong secondary flow in coiled tube. It is also noted that the pressure drop increases while increasing particle volume concentration. The pressure drop is 81%. higher than water at 0.5% volume concentration. This pressure drop increase is due to increase of viscosity when the particle volume concentration is increased. Therefore, the MWCNT / water nanofluids are the suitable cooling fluids in Cone helically coiled tube heat exchanger with considerable pressure drop .

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