International Journal of Engineering & Technology, 7 (4.39) (2018) 272-277

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Performance Studies of a Triple Concentric Helical Tube Heat Exchanger using Al_2O_3 Nano-Fluid

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Abstract

A triple tube concentric type heat exchanger was selected for the analysis of heat exchanger characteristics. The heat exchanger was provided with a helical coil over the middle flow pipe. The heat exchanger characteristics were studied under turbulent flow conditions for the N-H-C and C-H-Nconfigurations of flow separately. Al_2O_3 nano-particles of approximated size of 50 nm were used to constitute the Al_2O_3 nano- fluid which was employed to enhance the effectiveness of the heat exchanger with both parallel and counter flow patterns. In the N-H-C configuration flow of nano-fluid at normal temperature took place in the inner pipe while the cold fluid flows in the annulus region and hot fluid was made to flow through the helical coil over the inner pipe.in C-H-Nconfiguration normal ,cold and hot fluid flowed in the- annulus region, inner and the helical coil respectively.the analysis revealed that the N-H-C flow arrangement was more effective in the transfer of heat to that for the C-H-Nflow arrangement. Also it was observed that with insertion of the helical coil and the use of nano-fluid enhance the effectiveness of heat exchanger.

Keywords: *concentric; helical tube; nano-fluid, Al_2O_3, heat exchanger.*

1. Introduction

Today's world of growing electronics, industrial and residential applications such as cooling of the systems, air conditioning, space heating, waste heat recovery, food and chemical industries etc requires a device for better heat transfer. The rate of heat transfer of a heat exchanger generally depends on the construction, flow arrangements and physical properties of the fluid. To improve the heat transfer rate of the heat exchangers mainly two methods i.e. the passive and the active method are considered. In the active method, an external power source such as vibrating force/pulsating flow/magnetic field was used while in the passive method the rate of heat transfer amplified by creating surface roughness by providing a tape/wire along flow path and also by modifying heat transfer surface by addition of fins. Many heat transfer designs are proposed to improve the heat transfer rate like double tube, shell and tube, triple tube, helical tube etc [1-4]. Quadir et al. [4] in their experimental investigation of triple concentric heat exchanger examined the N–H–C and C–H–N arrangements of flow and found that the temperature of cold water increased rapidly in the heat exchanger without insulation in N–H–C arrangement. Recently, many researchers found that by using nano-fluid (nano-particles in suspension in a base fluid) the heat transfer can be enhanced . Use of nano-fluid was proposed by Choi [5] in 1995 proposed use of nano fluids enhances the thermal conductivity of the circulating fluids in the heat exchanger. Darzi et al. [6] conducted investigations to study the effects of Al_2O_3 nano-fluid with different volume concentration and Reynolds improves by adding nano-particles in the ranges considered for number. They found that heat exchanger performance experimentation without any additional pressure drop penalty. Reddy et al. [7] studied the coefficient of heat transfer and friction factor of nano-fluid (TiO_2 and water) flowing through a double pipe heat exchanger with or without helical coil inserted within the pipe. They performed experiments at different Reynolds number in the range of 4000 to 15000 and with volume concentration. They found that coefficient of heat transfer and friction factor get increased by 10.73% and 8.73% for 0.02% volume concentration of nano-fluid in comparison to that of the base fluid circulation respectively. While in the tube inserted with helical coil of P/d=2.5, the heat transfer coefficient and friction factor increased by 13.85% and 10.69% respectively for 0.02% nano-fluid in comparison to that of base fluid. Duangthongsuk and Wongwises [8] studied the thermal characteristics of TiO_2-water nano-fluid in a horizontal double tube counter flow heat exchanger. Convective heat transfer coefficient increases with increasing mass flow rate of the hot fluid, and increases with a reducing nano-fluid temperature. They also found that pressure drop and friction factor of the nano-fluid marginally differs from the base fluid in the given conditions. Tiwari et al. [9] investigated the heat transfer performance and pressure drop of CeO_2/water nano-fluid in a plate heat exchanger at different concentration of nano-particles and coolant flow rate and found that the heat transfer rate enhances with increase concentration of nano-particles and coolant flow rate. AbbasianArani and Amani [10] experimentally studied the thermal properties and pressure drop over a wide range of Reynolds number for nano-fluid at different volume fraction of nano particles. They reported that nano-fluids have higher Nusselt number in comparison to that of distilled water. Zeinali Heris et.al [11] investigated the impact of Al_2O_3/water nano-fluid with different concentrations on laminar convective heat transfer with constant uniform heat flux boundary conditions. Addition of nano-particles has shown significant increase in heat transfer as compared to base fluid as water.

In the present work experiments were carried out in a TCH pipe heat exchanger by using both normal water and Al_2O_3 nano-fluid of different concentration. The variation of temperature of different circulating fluid with different flow arrangements were observed and analyzed for comparison.

2. Experimental Investigation

2.1. Experimental Setup and Procedure

The triple concentric heat exchanger is consists of an inner pipe made up of brass, middle helical pipe made up of copper and outer pipe is made of mild steel. The inner diameters of the inner pipe, helical pipe and outer pipe are 28.75 mm, 12.87 mm and 98.4 mm respectively with each of thickness 1.5 mm. The arrangement for conduct of experiment as shown in the Fig. 1 is composed of test section, normal water and nano-fluid, cold water and hot water loop provided with a temperature measuring system. Hot water loop is made up of a storage tank in which an electric heater of 3000W is immersed to obtain desired temperature of hot water, the flow is controlled by a pump and gate valve. The cold water loop consits of a storage tank, a pump and gate valve. Ice cubes are used to reduce the tap water temperature to nearly 13^0C. In the third loop normal water and nano-fluid is circulated alternately maintained at normal temperature in the storage tank to evaluate the impact of nano-particles on heat transfer. The gate valve is operated to control the flow rate of the fluid.
The water temperatures at different sections of the tubes are measured by the T copper-constantan thermocouple probes. Water temperatures of the inner tubes are measured by installing the thermocouple probes in the tubes.

1- Cold water tank
2- Hot water tank
3- Nano fluid water tank
10- Test rig
4- Pump for cold water tank
5- Pump for hot water tank
6-Pump for normal water tank
11- Data acquisition system
7-Gatevalve(coldwater flow)
8- Gate valve (hot water flow)
9- Gate valve (normal water flow)

Fig. 1: Experimental setup of triple concentric helical pipe heat exchanger

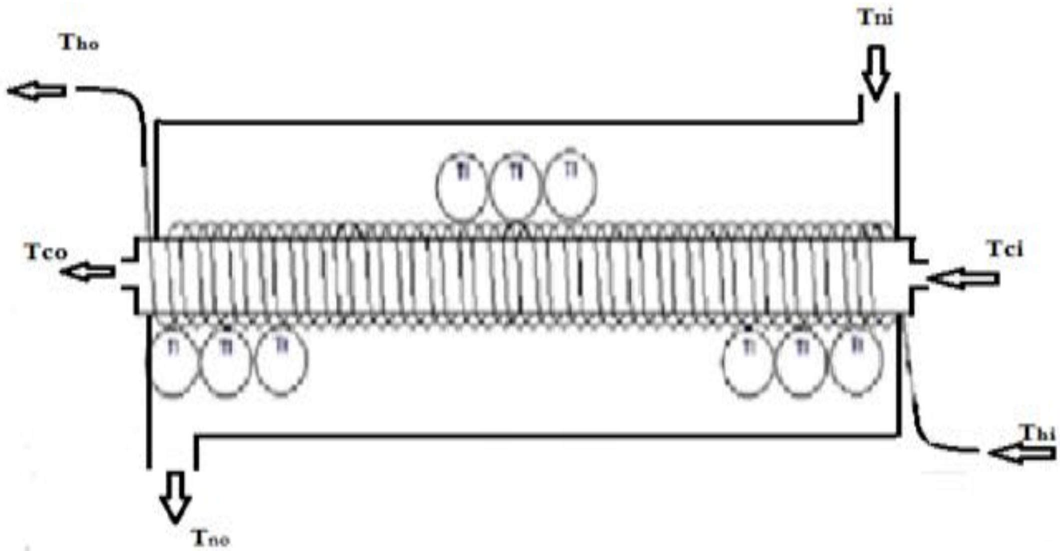

Fig.1 (b): Schematic diagram for TCH pipe heat exchanger with C-H-Nparallel flow

2.2 Preparation of Nano-Fluid

Single or two step methods are adapted for the preparation of nano-fluids. In the single step method, the NPs are directly added by method of physical vapour deposition (PVD) to the synthesized fluid. In two step method dry NPs are formed in a suitable liquid host by the use of magnetic stirrer followed by an ultrasonic vibrater. The increase in the volume fraction of NPs in the nano-fluid is certain to increase the thermal conductivity as well as friction factor of the fluid that leads to a pressure drop [12]. We prepare the nano-fluids of 0.3% volume concentrations by addition of required quantity of nano particles to the base fluid water. Stabilization of nano-fluid and an uniform distribution of NPs in the nano-fluid are achieved by means of ultrasonic pulses provided by the use of an Ultrasonicator (Hielscher, UP200H; 200 W, 24 kHz) for a duration of 4 h. 5 litres of nano-fluids is prepared at a time, in a batch. To ensure a better dispersion of NPs in the base fluid, 0.5 ml of oleic acid C-TAB (Cetyl Trimethyl Ammonium Bromide) amounting to 1/10th weight of Al_2O_3 nano-particles were added to the base fluid. The prepared sample of 0.3 % volume concentration nano-fluid is shown in Fig. 2.

Fig. 2: Prepared sample of Al2O3 nano-fluid

Then experiments are carried out with different flow arrangements. For each and every arrangement the mass flow rate is maintained at 0.12 kg/s for hot water and 0.54 kg/s for cold and nano-fluid.
Properties of prepared nano-fluids are projected using equations presented in the literature [7]. Solid-liquid homogeneous correlations to approximate density, specific heat, thermal conductivity and absolute viscosity of nano-fluid are given below:

$$\rho_{nf}=\left(1-\frac{\phi}{100}\right)\rho_{bf}+\frac{\phi}{100}\rho_p \ldots\ldots(1)$$

Where ρ_{nf}, ρ_{bf} and ρ_p are densities of nano-fluid, base fluid and of nano particles in kg/m^{3}respectively
ϕ= volume concentration of nano particles in percentage.

$$C_{nf}=\left(1-\frac{\phi}{100}\right)C_{bf}+\frac{\phi}{100}C_p \ldots\ldots(2)$$

Where C_{nf}, C_{bf} and C_p are specific heats of nano-fluid, base fluid and nano particles in J/kg K. respectively

$$\mu_{nf}=\left(1+\frac{5}{2}x\frac{\phi}{100}\right)\mu_{bf} \ldots\ldots(3)$$

Where μ_{nf} ,μ_{bf} and μ_p are dynamic viscosities of nano-fluid, base fluid and nano particles in kg/m^2 s respectively

$$k_{nf}=k_{bf}\left[\frac{k_p+2k_{bf}+2\frac{\phi}{100}\left(k_p-k_{bf}\right)}{k_p+2k_{bf}-\frac{\phi}{100}\left(k_p-k_{bf}\right)}\right] \ldots\ldots(4)$$

Where k_{nf} k_{bf} and k_p are thermal conductivities of nano-fluid, base fluid and nano particles in W/m K. respectively .

2.3. Effectiveness of Heat Exchanger

The effectiveness of heat exchanger was calculated for all the flow arrangements. The effectiveness of heat exchanger depends upon the mass flow rate of fluid, temperature difference between the flowing fluids and heat transfer surface. The effectiveness is compared for different flow arrangements.The heat exchanger effectiveness can be calculated by using the equation 1. [13].

$$\varepsilon=\frac{\dot{Q}}{\dot{Q}_{max}} \qquad (5)$$

$\dot{Q}$ is the actual heat transfer rate and $\dot{Q}_{max}$ is the maximum possible heat transfer rate of heat exchanger as per expressions [11].

$$\dot{Q}=C_h\left(T_{h,i}-T_{h,o}\right)\ldots\ldots\ldots(6)$$

$$\dot{Q}_{max}=C_{min}\left(T_{h,i}-T_{h,o}\right)\ldots\ldots\ldots(7)$$

$$C_{min}=\begin{cases}C_h & \text{if} \quad C_h\le C_n+C_c\\ C_n+C_c & \text{if} \quad C_h\ge C_n+C_c\end{cases}\ldots \qquad (8)$$

3. Results and Discussion

To analyze the variations throughout the length of heat exchanger for different flow arrangement experiments are conducted. As per the arrangements of N–H–C and C–H–N arrangements experiment are carried out with normal water at first phase for both parallel flow and counter flow fluids. Then in the next phase the experiments are repeated with different volume concentration of nano-fluid for comparison.

3.1. Temperature Variation in Heat Exchanger under C-H-N Configuration and Parallel Flow Arrangement

The temperature variations of fluids for C-H-N arrangement under parallel flow condition for normal fluid and nano-fluid is presented in Fig. 3 (a), (b) and (c) respectively**.** It was found Fig. 3 (a) that there was a drop in hot water temperature 60°C from to 34°C with regard from the entry to exit. On the other hand the temperatures of normal water and cold water increased from 29°C to 36°C and from 13°C to 20°C respectively, from their entry to exit.

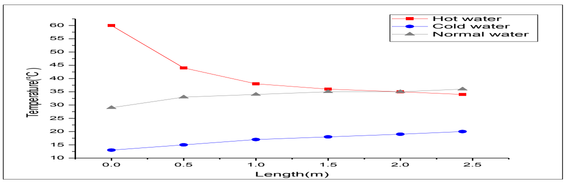

Fig. 3 (a): Temperature variation with length of heat exchanger in parallel flow C-H-Narrangement using normal water

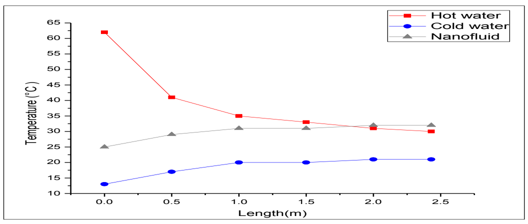

Fig. 3 (b): Temperature variation with length of heat exchanger in parallel flow C-H-Narrangement using nano-fluid of 0.1% volume concentration

3.2. Temperature Variation in Heat Exchanger under C-H-Nconfiguration and Counter Flow Arrangement

The experiments were carried out for counter flow conditions with both N-H-C and C-H-Nflow configurations.There was a drop of hot water temperature from 58°C to 28°C with regards from the entry to exit .On the other hand the normal water and cold water temperatures increased to 38°C from 29° and 26°C from 15°C respectively, from their entry to exit. It was observed that with counter flow arrangement the temperature of hot water drops to present atmospheric temperature. When experiments are carried out for 0.1% volume concentration of Al_2O_3 nano-fluid it is observed that there was a drop of hot water temperature to 29^{o}C from 64^{o}C. The temperature of cold water and nano-fluid increased to 23^{o}C and 35^{o}C from their entry temperature 10^{o}C and 29^{o}C respectively as illustrated in Fig. 4(b). Considerable rise in cold water temperature was observed. For same arrangements and mass flow rate when experiments are carried out for 0.3% volume concentration of nano-fluid it was observed that hot water temperature decreased from 64^{o}C to 26^{o}C with regard from the entry to exit. The cross over point for hot water appears before half of the length of heat exchanger with 3 ^{o}C lower temperature was achieved by the hot water at the out let. The temperature of cold water and nano-fluid increased from14^{o}C to 28^{o}C and from 29^{o}C to 38^{o}C respectively, from their entry to exit . as showed in Fig. 4(c).

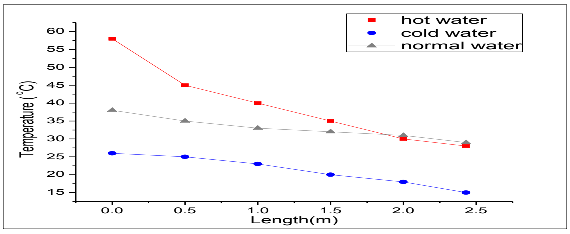

Fig. 4 (a): Temperature variation with length of heat exchanger in counter flow C-H-Narrangement using normal water

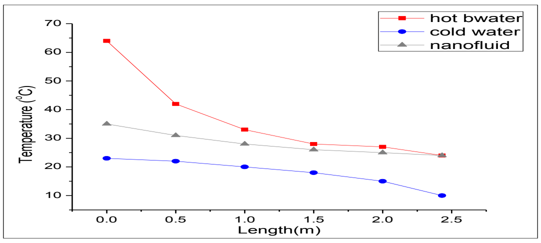

Fig. 4 (b): Temperature variation with length of heat exchanger in counter flow C-H-Narrangement using nano-fluid of 0.1% volume concentration

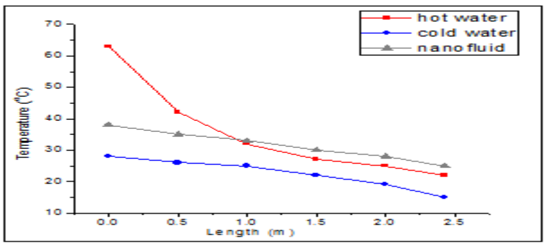

Fig. 4 (c): Temperature variation with length of heat exchanger in counter flow C-H-N arrangement using nano-fluid of 0.3% volume concentration

3.3. Temperature Distribution in Heat Exchanger under N-H-C Parallel Flow Configuration

The temperature variation of different fluids for N-H-C arrangement under parallel flow condition is presented in Fig. 5(a), (b) and (c). It is observed from Fig. 5(a) that there was a drop in hot water temperature from 60°C to 26°C with regard from the entry to exit .the temperature of normal water and the cold water increased from 29°C to 35°C and from13°C to 25°C respectively, from their entry to exit for N-H-C arrangement. In case of nano-fluid of 0.1% volume concentration the hot water temperature reduced to 23^{o}C from 62^{o}C, on the other hand the cold water temperature increased from11°C to 21°C and nano-fluid temperature increased from 26°C to 32°Cfrom their entry to exit as shown in Fig. 5(b). In case of 0.3% volume concentration of nano-fluid it is observed from Fig. 5(c) there was a drop in hot water temperature from 64°C to 26°C with regard from the entry to exit, the temperature of cold water increased from11°C(at entrance) to 23°C(at exit) and nano-fluid temperature increased from 25°C(at entrance) to 31°C(at exit) .The increase in temperature of cold water is comparatively higher than that of the normal water. This is because of the higher amount of heat is transferred to cold water due to better temperature difference between the cold water and hot water as well as it also gains heat from atmosphere. The heat transfer rate of cold water is further assisted by larger heat transfer area available between the helical coil and annulus. In this case the temperature variation curve for hot water intersects the temperature variation curve of normal water at a point known as cross over point. Temperature of hot water decreases below the temperature of normal water. This is due to the fact that availability of larger temperature difference throughout the length of heat exchanger and great heat transfer area between the cold water and hot water.

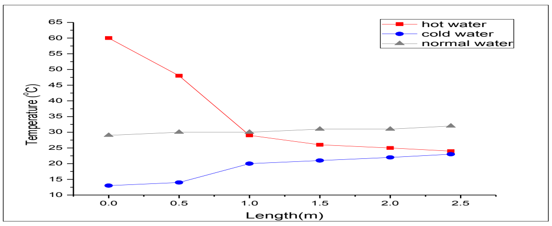

Fig. 5 (a): Temperature variation with length of heat exchanger in parallel flow N-H-C arrangement using normal water

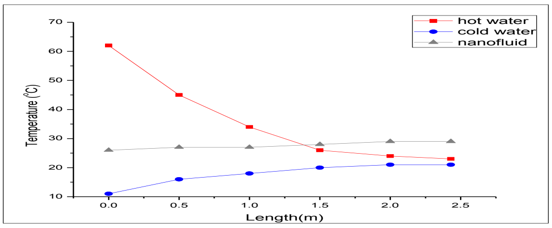

Fig. 5 (b): Temperature variation with length of heat exchanger in parallel flow N-H-C arrangement using nano-fluid of 0.1% volume concentration

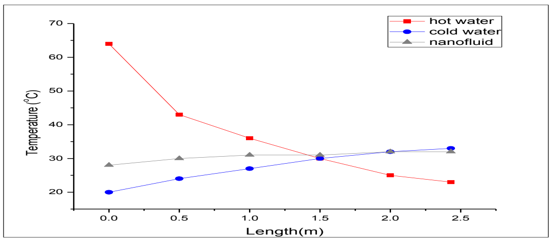

Fig. 5 (c): Temperature variation with length of heat exchanger in parallel flow N-H-C arrangement using nano-fluid of 0.3% volume concentration

3.4. Temperature Distribution in Heat Exchanger under N-H-C Counter Flow Configuration

When the heat exchanger was operated in counter flow under N-H-C arrangement, the temperature variation of three fluids along the length of the heat exchangers is shown in Figure 6(a) to (c). With normal water it is observed Fig. 6(a) that there was a drop of hot water temperature from 59°C to 23°C , with regards from entry to exit. cold water temperature increased from 18°C to 33°C and the normal water temperatures impoved from 28°Cto 35°C, from their entry to exit.due to the heat exchange between the fluids. When nano-fluid of 0.1% volume concentration is used as seen from Fig 6(b) it is observed the hot fluid temperature reduced to 22°C from its entering temperature 65°C, and nano-fluid temperature increased to 35°C and 32°C from their entering temperature 18°C and 27°C respectively. When 0.3% volume concentration nano-fluid is used it is observed from Fig 6(c) it was observed that the hot water temperature dropped down to 20°C from 58°C from it's entry to exit the cold water and nano-fluid temperature increased to 32°C and 33°C respectively, from their entry to exit.

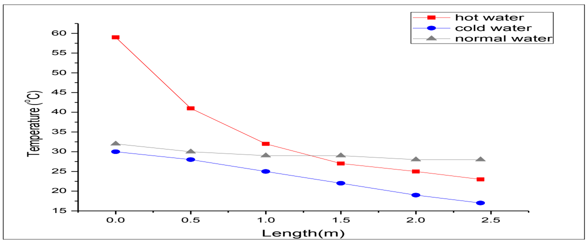

Fig. 6 (a): Temperature variation with length of heat exchanger in counter flow N-H-C arrangement using normal water

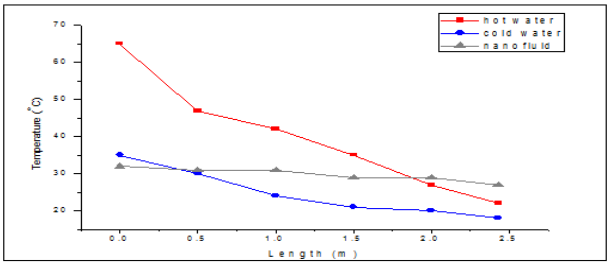

Fig. 6 (b): Temperature variation with length of heat exchanger in counter flow N-H-C arrangement using nano-fluid of 0.1% volume concentration

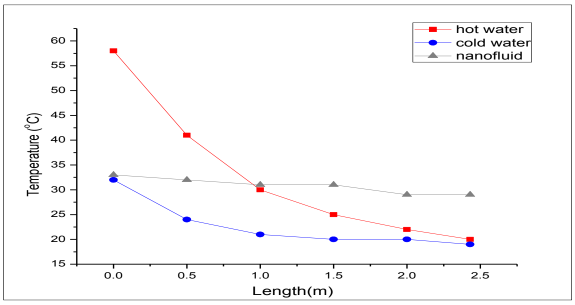

Fig. 6 (c): Temperature variation with length of heat exchanger in counter flow N-H-C arrangement using nano-fluid of 0.3% volume concentration

The temperature of cold water is increased too much higher degree in comparison to that of the normal water. As described earlier, the rate of heat transfer increases due to larger surface area available between the cold water and hot water. The counter flow configuration proved to be more effective on account of uniform temperature difference between hot and cold fluid as well as hot and normal fluid throughout the heat exchanger compared to parallel flow configuration. Because of this fact the heat transfer rate of the three fluids is more in counter flow condition. There is cross over point between the temperature variation curves of hot water and normal water observed nearly at the middle of the total length. The temperature variation curves of hot water and cold water intersect each other just after the mid length of heat exchanger. As compared to the parallel flow condition the heat transfer rate is more in counter flow condition of heat exchanger.

3.5 Effectiveness of Heat Exchanger

The effectiveness of heat exchanger was calculated for all the flow arrangements. It depends upon the mass flow rate of fluid, temperature difference between the flowing fluids and heat transfer surface. The effectiveness compared for both C-H-Nand N-H-C arrangements and depicted in Fig. 7. It is observed that the effectiveness of the heat exchanger was found to be 0.76, 0.764, 0.93 for normal water, 0.1% of Al_2O_3 nano-fluid and 0.3% of Al_2O_3 nano-fluid respectively in N-C-H arrangement with parallel flow while with counter flow the effectiveness increased to 0.85, 0.91and 0.97 respectively.

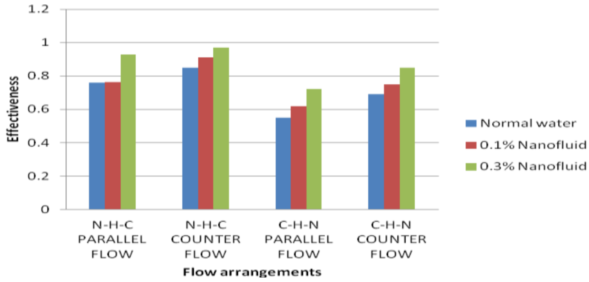

Fig. 7: Effectiveness of the heat exchanger at different flow arrangements

In case of C-H-Narrangement the effectiveness was found to be 0.55, 0.62, 0.72 for normal water, 0.1% of Al_2O_3 nano-fluid and 0.3% of Al_2O_3 nano-fluid respectively, while with counter flow the effectiveness increased to 0.69, 0.75and 0.85 respectively. It can be seen that the effectiveness of the heat exchanger increases with increase in volume concentration of nano-fluid. The highest effectiveness is observed for N-C-H arrangement with counter flow.

4. Conclusions

The experimental investigation is performed to study the behavior of the three fluids in the heat exchanger under different flow arrangements. The following observations are drawn from the experiment:

I. The N-H-C flow arrangement was found to be more effective than C-H-Nflow arrangement, where the hot water temperature reaches a temperature below cold water temperature.
II. Rate of heat transfer and effectiveness of the heat exchanger enhances with increase in volume concentration of Al_2O_3 nano-particles in the nano-fluid.
III. Highest effectiveness was observed for N-C-H arrangement in counter flow with 0.3% volume concentration of Al_2O_3 nano-fluid.

In general, the use of AL_2O_3 nano-fluid together with an insertion of a helical coil proved advantageous for the enhancement of the heat transfer rate and effectiveness of the heat exchangers.

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