EFFECT OF NANOFLUID ON HEAT TRANSFER CHARACTERISTICS OF DOUBLE PIPE HEAT EXCHANGER: PART-I: EFFECT OF ALUMINUM OXIDE NANOFLUID

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Abstract

A nanofluid is a mixture of nano sized particles of size up to 100 nm and a base fluid. Typical nanoparticles are made of metals, oxides or carbides, while base fluids may be water, ethylene glycol or oil. The effect of nanofluid to enhance the heat transfer rate in various heat exchangers is experimentally evaluated recently. The heat transfer enhancement using nanofluid mainly depends on type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid. In the present paper, an experimental investigation is carried out to determine the effect of various concentration of Al_2O_3 nano-dispersion mixed in water as base fluid on heat transfer characteristics of double pipe heat exchanger for parallel flow and counter flow arrangement. The volume concentrations of Al_2O_3 nanofluid prepared are 0.001 % to 0.01 %. The conclusion derived for the study is that overall heat transfer coefficient increases with increase in volume concentration of Al_2O_3 nano-dispersion compared to water up to volume concentration of 0.008 % and then decreases.

Keywords: *Nanofluid, Heat Transfer Characteristics, Double Pipe Heat Exchagner, Al_2O_3 Nano-dispersion*

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1. INTRODUCTION

Different types of heat exchangers are extensively used in various industries to transfer the heat between cold and hold stream. The key role of the heat exchanger is to transfer heat at maximum rate. The enhancement in heat transfer rate is possible to achieve by two steps viz. (1) to optimize the design of the heat exchanger and (2) to optimize the operational parameters. To optimize the operational parameters play a key role in enhancement of heat transfer rate after the design of heat exchanger.

The method of enhancement of heat transfer rate operationally is broadly divided as (1) active methods and (2) passive methods. Active method includes electro hydrodynamics, jets, sprays, ultrasound waves, synthetic jet heat transfer and high amplitude vibratory motion, while passive method include surface coating, nanoscale coating, nanofluid, hydrodynamic cavitations, turbulence promoters and mixing promoters [1]. Among them, three methods are considered as effective methods to enhance the heat transfer which are (1) utilizing nanofluids, (2) inserting fluid tabulators and (3) roughing the heat exchanger surface. A nanofluid is a mixture of nano sized particles and a base fluid. Typical nanoparticles are made of metals, oxides or carbides, while base fluids may be water, ethylene glycol or oil. The nanofluid exhibits different thermo physical properties than the base fluid. Generally thermal conductivity of nanofluids is higher than the base fluid which increases the heat transfer rate. The heat transfer enhancement using nanofluid mainly depends on type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid.

A comprehensive review of published papers in last ten years and available in open literature related to the application of nanofluid in heat transfer has been carried out. Out of total twenty nine research papers, ten research papers [2-11] are related to double pipe heat exchanger, six research papers [12-17] are in the field of shell and tube heat exchanger, twelve studies [18-29] are in other type of heat exchangers and one [30] in the field of phase change material. Nine researchers [2-6, 13, 16, 25, 26] have utilized Al2O3 based nanofluid, three [7, 8, 10] have employed TiO2 based nanofluid, while two – two studies are carried out using CuO2 [24, 30], MWCNT [14, 22] and Fe2O3 [9, 20] based nanofluids. The detailed review of published papers pertaining to application of nanofluid in heat exchanger is presented below.

W. A. Aly [2] has carried out computational fluid dynamics (CFD) analysis to study the heat transfer and pressure drop characteristics of water-based Al2O3 nanofluid flowing inside coiled tube-in-tube heat exchangers. He found that the heat transfer coefficient increases by increasing the coil diameter and nanoparticles volume concentration while, friction factor increases with the increase in curvature ratio. Their results validated the Gnielinski correlation and Mishra and Gupta correlation for predicting average heat transfer and friction factor in turbulent flow regime and they have found that nanofluids behave like a homogeneous fluid. Rabienataj Darzi A. A. and et. al. [3] have carried out an experimental study in order to find out the effects of Al_2O_3 nanofluid, having nanoparticles concentration up to 1% by volume and mean diameter of 20 nm, on heat transfer, pressure drop and thermal performance of a double tubes heat exchanger. They have established the empirical correlation for Nusselt number variation based on the Reynolds number and nanoparticles concentration. Akhtari, M. and et. al. [4] have performed an experimental and numerical study on the heat transfer of α-Al2O3/water nanofluid flowing through the double pipe and shell and tube heat exchangers, under laminar flow conditions. They have found that the heat transfer performance of both double pipe and shell and tube heat exchangers increases with increasing the hot and cold volume flow rates, as well as the particle concentrations and nanofluid inlet temperature as compared with pure water.

Aghayari, R. and et. al. [5] have investigated the heat transfer of a fluid containing nanoparticles of aluminum oxide with a diameter of about 20 nm, with the water volume fraction (0.1 – 0.3) percent in a horizontal double pipe counter flow heat exchanger under turbulent flow conditions. They have found that heat transfer of nanofluid in comparison with the heat transfer of fluid is slightly higher than 12 %. Chun, B. H. and et. al. [6] have investigated the convective heat transfer coefficient of nanofluids made of alumina nanoparticles and transformer oil which flow through a double pipe heat exchanger system in the laminar flow regime. They have proposed an experimental correlation for an alumina-transformer oil nanofluid system to understand the enhancement of heat transfer of nanofluid.

Duangthongsuk, W. and Wongwises, S. [7] have carried out an experimental study on the forced convective heat transfer coefficient and friction factor of a nanofluid consisting of water and 0.2 vol.% TiO2 nanoparticles of about 21 nm diameter flowing in a horizontal double-tube counter flow heat exchanger under turbulent flow conditions. They have found that the heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate of the hot water and nanofluid, and increases with a decrease in the nanofluid temperature. They have also observed that the Gnielinski equation failed to predict the heat transfer coefficient of the nanofluid.

Khedkar, R. S. and et. al. [8] have studied the heat-transfer characteristics of TiO2–water nanofluids as a coolant in concentric tube heat exchanger. They considered the effects of inlet flow rate of hot fluids, Reynold's number and composition of nanofluids on concentric tube heat exchanger. They found that the average heat transfer rates increases with concentration of nanofluid composition. Bahiraei, M. and Hangi, M. [9] have investigated the performance of water based Mn–Zn ferrite magnetic nanofluid in a counter-flow double-pipe heat exchanger under quadrupole magnetic field using the two-phase Euler–Lagrange method. They have examined the effects of different parameters including concentration, size of the particles, magnitude of the magnetic field and Reynolds number. Chandra Sekhara Reddy, M. and Veeredhi Vasudeva Rao [10] have investigated the heat transfer coefficient and friction factor of TiO2 nanofluid having volume concentration range from 0.0004% to 0.02% in a base fluid having 40% of ethylene glycol and 60% of distilled water, flowing in a double pipe heat exchanger with and without helical coil inserts.

Liu, L and et. al. [11] have reported the potential benefit of using nanofluids in heat-exchanger applications is explored using an α-NTU analysis. They have found that among all flow arrangements investigated, the concentric-tube, counterflow arrangement shows highest improvement in heat duty for a prescribed convective heat-transfer enhancement. Elias, M. M. and et. al. [12] have 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 shell and tube heat exchanger with different baffle angles and segmental baffle.

Albadr, J. and et. al. [13], Lotfi, R. and et. al. [14], Leong, K. Y. and et. al. [15], Bahiraei, M. and et. al. [16] and Shahrul, I. M. and et. al. [17] have presented experimental studies on application of nanofluid in shell and tube heat exchanger. Various researchers have studied the effect of nanofluid on plate heat exhchanger [18, 21, 22], micro-pin-fin heat exchanger [19], an air-finned heat exchanger [20], corrugated plate heat exchanger [23], plate-fin channels [24], helical coil heat exchanger [25, 28], multi-channel heat exchanger [26] and micro-heat pipe array heat exchanger [27].

The review of literature reveals the facts related to the application of nanofluid in heat exchanger for enhancement of heat transfer rate that (1) Nanofluids are the relatively recent practice to enhance the heat transfer rate, (2) There are different types of nanofluids which can be used to enhance the heat transfer rate and (3) Many researchers have carried out numerical and experimental analysis on application of nanofluid in enhancement of heat transfer rate under different conditions. Extensive experiments have been carried out on double pipe heat exchanger to determine the effect of different type of nanofluids (having nanoparticles of Al_2O_3 and CuO.) and concentration of nanoparticles in nanofluid during parallel and counter flow condition. In the part I of the paper, effect of Al_2O_3 nanofluid has been presented and in the part II of the paper effect of CuO nanofluid has been presented.

2. EXPERIMENT SETUP AND PROCEDURE

Apparatus for double pipe heat exchanger is shown in Figure 1. The outer pipe is made up of SS 304 material having outer diameter, inner diameter and length of 36 mm, 32 mm and 3 m respectively. The inner pipe is also made up of SS 304 having outer diameter, inner diameter and length of 18 mm, 15 mm and 3 m respectively. Cladding of mineral wool having 25 mm thickness is carried out which acts as insulation over outer pipe. Two valves are provided on each pipe which can be open and closed alternatively for counter and parallel flow operation. Two water tanks viz. (1) Cold Water and (2) Hot Water are provided with separate SS 304 mono-block type centrifugal pump to circulate cold and hot water through pipes respectively. Three immersion type heaters, each of 6 kW capacity are located in hot water tank to heat the water. Two Fitzer make rotameters, each of 0.5 – 5.0 lpm range are connected to measure the flow rate of cold water and hot water from the pipes. J type thermocouples are used to measure the inlet and outlet temperatures of cold and hot water flowing through the pipes. Digital temperature indicator is provided to indicate the temperature.

Fig 1: Experimental Setup: Double Pipe Heat Exchanger Apparatus

2.1 Experimental Procedure for Double Pipe Heat Exchanger

(1) Fill water in cold and hot water tank.
(2) Switch on the immersion type heater provided in the hot water tank and heat the water to the desired temperature.
(3) Switch “ON” the pump provided in hot water tank with bypass line valve fully open and supply valve fully closed to ensure thorough mixing of water in the tank to ensure uniform temperature.
(4) Operate valves out of four valves provided on the panel in such a manner that the heat exchanger operates in parallel flow mode.
(5) Allow the hot water to flow through inner pipe side. Adjust the flow rate to the desired value using the rotameter.
(6) Start the cold water supply on the outer pipe side. Adjust the flow rate to the desired value using rotameter.
(7) Observe the inlet and outlet temperature of both cold and hot water streams and record them after they achieve steady state condition.
(8) Record the flow rates of hot water and cold water with the help of rotameters.
(9) Repeat the procedure step number 6 to 9 for different flow rates of cold and hot water.
(10) Alter the opening of valves out of four valves provided on the panel in such a manner that now, the heat exchanger operates in parallel flow mode.
(11) Repeat the procedure step number 6 to 10 for counter flow arrangement of double pipe heat exchanger.
(12) Drain the water from both the tanks after completion of experiments.

2.2 Calculation Steps for Double Pipe Heat Exchanger

The methodology adopted for calculation for experimentation and theoretical evaluation of overall heat transfer coefficient for double pipe heat exchanger for parallel and counter flow arrangements are described in sub-section 2.2.1 and 2.2.2 respectively.

2.2.1 Calculation Steps for Experimental Evaluation of Overall Heat Transfer Coefficient

(1) Flow Rate of Hot Water

$$\mathrm{m_H = m_h \times \frac{\rho_h}{60}}$$

(2) Flow Rate of Cold Water

$$\mathrm{m_C = m_c \times \frac{\rho_c}{60}}$$

(3) Heat Transferred by Hot to Cold Water

$$\mathrm{Q_h = m_H \times C_{p,h}(T_{hi} - T_{ho})}$$

(4) Heat Transferred by Cold to Hot Water

$$\mathrm{Q_c = m_C \times C_{p,c}(T_{co} - T_{ci})}$$

(5) Average Heat Transfer

$$Q_{avg} = \frac{Q_h + Q_c}{2}$$

(6) Outer Surface Area of Inner Pipe

$$\mathrm{A_{os,ip} = \pi \times d_{0,ip} \times L}$$

(7) Inner Surface Area of Inner Pipe

$$\mathrm{A_{is,ip} = \pi \times d_{i,ip} \times L}$$

(8) Logarithmic Mean Temp. Difference

For Parallel Flow Arrangement

$$\mathrm{LMTD = \frac{(T_{hi} - T_{ci}) - (T_{h0} - T_{co})}{\ln\left\{\frac{(T_{hi} - T_{ci})}{(T_{h0} - T_{co})}\right\}}}$$

For Counter Flow Arrangement

$$\mathrm{LMTD = \frac{(T_{hi} - T_{c0}) - (T_{h0} - T_{ci})}{\ln\left\{\frac{(T_{hi} - T_{c0})}{(T_{h0} - T_{ci})}\right\}}}$$

(9) Overall Heat Transfer Coefficient based on Outer Surface Area of Inner Pipe

$$\mathrm{U_{o,pract} = \frac{Q_{avg}}{A_{os,ip} \times LMTD}}$$

(10) Overall Heat Transfer Coefficient based on Inner Surface Area of Inner Pipe

$$\mathrm{U_{i,pract} = \frac{Q_{avg}}{A_{is,ip} \times LMTD}}$$

2.2.2 Calculation Steps for Theoretical Evaluation of Overall Heat Transfer Coefficient

(1) Average Temperature of Cold Water

$$\mathrm{T_{avg,c} = \frac{T_{ci} + T_{co}}{2}}$$

(2) Average Temperature of Hot Water

$$\mathrm{T_{avg,h} = \frac{T_{hi} + T_{ho}}{2}}$$

(3) Obtain Following Parameters of Cold Water at Average Temperature of Cold Water

$$Density, \rho_c;\ \ Specific\ Heat, C_{p,c};$$

$$Dynamic\ Viscosity, \mu_c;\ \ Prandtl\ No., P_{r,c}$$

$$and\ Thermal\ Conductivity, k_c.$$

(4) Obtain Following Parameters of Hot Water at Average Temperature of Hot Water

$$Density, \rho_h;\ \ Specific\ Heat, C_{p,h};$$

$$Dynamic\ Viscosity, \mu_h;\ \ Prandtl\ No., P_{r,h}$$

$$and\ Thermal\ Conductivity, k_h.$$

(5) Heat Capacity Flow Rate of Cold Water

$$\mathrm{C_c = m_C \times C_{p,c}}$$

(6) Heat Capacity Flow Rate of Hot Water

$$\mathrm{C_h = m_H \times C_{p,h}}$$

(7) Minimum Heat Capacity Flow Rate

$$\mathrm{C_{min} = Minimum\ Value\ out\ of\ C_c\ and\ C_h}$$

(8) Minimum Heat Capacity Flow Rate

$$\mathrm{C_{max} = Maximum\ Value\ out\ of\ C_c\ and\ C_h}$$

(9) Maximum Possible Heat Transfer

$$Q_{max} = C_{min}(T_{hi} - T_{ci})$$

(10) Effectiveness of the Heat Exchanger

$$\in = \frac{Q_{avg}}{Q_{max}}$$

(11) Cross Sectional Area of Annulus through which Cold Water Flows

$$A_{annulus} = \frac{\pi}{4} \times ({d_{i,op}}^2 - {d_{o,ip}}^2)$$

(12) Velocity of Cold Water

$$V_c = \frac{m_C}{\rho_c \times A_{annulus}}$$

(13) Characteristics Diameter of Cold Water

$$D_c = (d_{i,op} - d_{o,ip})$$

(14) Reynolds Number for Cold Water Flow

$$R_{e,c} = \frac{\rho_c \times V_c \times D_c}{\mu_c}$$

(15) Nusselt Number for Cold Water Flow

$$N_{u,c=}3.657 + \frac{0.0677 \times (R_{e,c} \times P_{r,c} \times \frac{D_c}{L})^{1.33}}{1 + (0.1 \times P_{r,c}) \times (R_{e,c} \times \frac{D_c}{L})^{0.33}}$$

for $R_{e,c} < 2300$

$$N_{u,c=} \frac{\frac{f}{8} \times \left(R_{e,c} - 1000\right) \times P_{r,c}}{1 + 12.7 \times \left\{\frac{f}{8}\right\}^{0.5} \times \left\{(P_{r,c})^{0.666} - 1\right\}}$$

for $R_{e,c} > 2300$

where, $f = \left(1.82 \times \log_{10} R_{e,c} - 1.64\right)^{-2}$

(16) Nusselt Number for Al_2O_3 Nanofluid Flow [31]

$$N_{u,c=}4.36 + \left\{a \times x_{new}^{-b} \times (1 + \emptyset^c) \times \exp^{-d \times x_{new}}\right\} \times \left\{1 + \text{valueof"e"} \times \left(\frac{d_{nanoparticle}}{d_{ref}}\right)^{-f}\right\}$$

$500 < R_{ec} < 2000$ & $\emptyset$ upto4%

Where,

a = 6.219 X 10^{-3}	d = 2.5228	d_{ref} = 100 nm
b = 1.1522	e = 0.57825	d_{np} = Dia. of Nano Particles = 50 nm
c = 0.1533	f = 0.2183	$x_{new} = x/(R_e{*}P_r{*}D_c)$

$$N_u = \frac{\left\{\left(\frac{f}{8}\right) \times (R_e - 1000) \times P_r\right\}}{1 + \left\{\delta V_{new} \times \left(\frac{f}{8}\right)^{0.5} \times \left({P_r}^{0.666} - 1\right)\right\}}$$

$5000 < R_{ec} < 65000$ *and* $\emptyset$ *upto* 3.6%

where, $f = \left(1.82 \times \log_{10} R_{e,c} - 1.64\right)^{-2}$
and $\delta V_{new} = 15.5$

(17) Heat Transfer Coefficient for Cold Water (Outside Heat Transfer Coefficient)

$$h_c = \frac{N_{u,c} \times k_c}{D_c}$$

(18) Cross Sectional Area of Inner Pipe through which Hot Water Flows

$$A_{cs,ip} = \frac{\pi}{4} \times \left(d_{i,ip}\right)^2$$

(19) Velocity of Hot Water

$$V_h = \frac{m_H}{\rho_h \times A_{cs,ip}}$$

(20) Characteristics Diameter of Hot Water

$$D_h = d_{i,ip}$$

(21) Reynolds Number for Hot Water Flow

$$R_{e,h} = \frac{\rho_h \times V_h \times D_h}{\mu_h}$$

(22) Nusselt Number for Hot Water Flow

$$N_{u,h=}3.657 + \frac{\left\{0.0677 \times (R_{e,h} \times P_{r,h} \times \frac{D_h}{L})^{1.33}\right\}}{\left\{1 + \left(0.1 \times P_{r,h}\right) \times (R_{e,h} \times \frac{D_h}{L})^{0.33}\right\}}$$

for $R_{e,h} < 2300$

$$N_{u,h=} \frac{\frac{f}{8} \times \left(R_{e,h} - 1000\right) \times P_{r,h}}{1 + 12.7 \times \left\{\frac{f}{8}\right\}^{0.5} \times \left\{(P_{r,h})^{0.666} - 1\right\}}$$

for $R_{e,h} > 2300$

where, $f = \left(1.82 \times \log_{10} R_{e,h} - 1.64\right)^{-2}$

(23) Heat Transfer Coefficient for Hot Water (Inside Heat Transfer Coefficient)

$$h_h = \frac{N_{u,h} \times k_h}{D_h}$$

(24) Inner Overall Heat Transfer Coefficient

$$U_{i,theo} = \frac{1}{\left\{\frac{1}{h_h}\right\} + \left\{\frac{d_{i,ip}/2}{k_{ip}} \times \ln\left\{\frac{d_{o,ip}/2}{d_{i,ip}/2}\right\}\right\} + \left\{\frac{d_{i,ip}/2}{d_{o,ip}/2} \times \frac{1}{h_c}\right\}}$$

(25) Outer Overall Heat Transfer Coefficient

$$U_{o,theo} = \frac{1}{\left\{\frac{1}{h_c}\right\} + \left\{\frac{d_{o,ip}/2}{k_{ip}} \times \ln\left\{\frac{d_{o,ip}/2}{d_{i,ip}/2}\right\}\right\} + \left\{\frac{d_{o,ip}/2}{d_{i,ip}/2} \times \frac{1}{h_h}\right\}}$$

3. PREPARATION AND CHARACTERIZATION OF NANOFLUID

There are two techniques to prepare nanofluids viz. (1) the single-step method, in which nanoparticles are evaporated and directly dispersed into the base fluids and (2) the two-step method in which nanoparticles are made first and then disperses them into the base fluids. The basic requirement of preparation of nanofluid is to obtaine a well-mixed and uniformly dispersed nanofluid for successful reproduction of properties and interpretation of experimental data.

Two-step method has been employed to prepare nanofluid. Al_2O_3 nano-dispersion (AlO(OH)) has been purchased from M/s. Jyotirmay Overseas, Rajkot. Al_2O_3 nano-dispersion of 50 nm size has 1190 kg/m^3 density and 10 cps viscosity. The proportion of Al_2O_3 nano-dispersion to be mixed with the base fluid i.e. water for different volume concentration is calculated using following equation. For different volume concentrations, the mass of nanoparticle to mix with the water is presented in Table 1.

$$\emptyset = \frac{\left\{\begin{matrix}\text{Volume of} \\ \text{Nanoparticle}\end{matrix}\right\}}{\left\{\begin{matrix}\text{Volume of Nanoparticle} \\ +\text{Volume of water}\end{matrix}\right\}} \times 100$$

$$\emptyset = \frac{\frac{W_{nanoparticle}}{\rho_{nanoparticle}}}{\frac{W_{nanoparticle}}{\rho_{nanoparticle}} + \frac{W_{water}}{\rho_{water}}} \times 100$$

Table 1: Mass of Al_2O_3 Nano-dispersion to Mix with Water for Different Volume Concentration

Volume Concentration, φ in %	*Mass of Al_2O_3 Nano-dispersion into be mixed with water in grams*	*Quantity of Base Fluid i.e. Water in litres*
0.001	*0.833*	*70*
0.002	*1.666*	*70*
0.003	*2.499*	*70*
0.004	*3.332*	*70*
0.005	*4.165*	*70*
0.006	*4.998*	*70*
0.007	*5.831*	*70*
0.008	*6.665*	*70*
0.009	*7.498*	*70*
0.01	*8.331*	*70*

The following equations are used to determine the density, specific heat, dynamic viscosity, thermal conductivity and prandtl number of nanofluid respectively.

$$\rho_{nanofluid} = \{\emptyset \times \rho_{nanoparticle}\} + \{(1-\emptyset)\rho_{water}\}$$

$$C_{p,nanofluid} = \frac{\left[\begin{matrix}\emptyset \times \{\rho_{nanoparticle} \times C_{p,nanoparticle}\} \\ +(1-\emptyset) \times \{\rho_{water} \times C_{p,water}\}\end{matrix}\right]}{\rho_{nanofluid}}$$

$$\mu_{nanofluid} = \{1 + (7.3 \times \emptyset) + (123 \times \emptyset^2)\}\mu_{water}$$

$$k_{nanofluid} = \frac{\left[\begin{matrix}\{k_{nanoparticle}\} + \{2 \times k_{water}\} \\ +\{2 \times (k_{nanoparticle} - k_{water}) \times \emptyset\}\end{matrix}\right]}{\left[\begin{matrix}\{k_{nanoparticle}\} + \{2 \times k_{water}\} \\ -\{(k_{nanoparticle} - k_{water}) \times \emptyset\}\end{matrix}\right]}$$

$$P_{r,nanofluid} = \frac{\mu_{nanofluid} \times C_{p,nanofluid}}{k_{nanofluid}}$$

4. INTEGRATED RESEARCH METHODOLOGY

The integrated methodology adopted to evaluate the effect of nanofluid on heat transfer characteristics of double pipe heat exchanger is presented below.

(1) Conduct the experiment using water as cold and hot fluid in double pipe heat exchanger as per the experimental procedure for double pipe heat exchanger.

(2) Calculate the practical value of overall heat transfer coefficient as per calculation steps for experimental evaluation of overall heat transfer coefficient for water as cold and hot fluid.
(3) Calculate the theoretical value of overall heat transfer coefficient as per calculation steps for theoretical evaluation of overall heat transfer coefficient for water as cold and hot fluid.
(4) Empty the water from the tanks of the double pipe heat exchanger.
(5) For 0.001 % volume concentration, prepare the nanofluid by mixing 0.833 grams of Al_2O_3 nano-dispersion in water of 70 liters.
(6) Fill the nanofluid of 0.001 % volume concentration into cold water tank. Now the nanofluid will work as cold fluid.
(7) Fill the water in hot water tank.
(8) Perform the experimentation and evaluate the overall heat transfer coefficient with nanofluid of 0.001 % volume concentration as cold fluid and water as hot fluid as per the step number 1 to 4 of integrated research methodology.
(9) Perform the experimentation and evaluate overall heat transfer coefficient with nanofluid of 0.002 %, 0.003 %, 0.004 %, 0.005 %, 0.006 %, 0.007 %, 0.008 %, 0.009 % and 0.01 % volume concentration as per the step number 1 to 4 of integrated research methodology.
(10) Compare the overall heat transfer coefficient of water with nanofluid for different volume concentration.

5. RESULTS AND DISCUSSION

Actual experimentation on double pipe heat exchanger has been carried out as per integrated research methodology. The results for parallel flow and counter flow arrangements are presented in Table 2 and Table 3 respectively. The overall heat transfer coefficients obtained practically and theoretically are plotted for parallel flow arrangement in Figure 2 and 3 respectively and the same are plotted for counter flow arrangement in Figure 4 and Figure 5 respectively.

Table 2: Result for Parallel Flow Arrangement

Heat Transfer Media	**Case Number**	**Average Overall Heat Transfer Coefficient, kW/m^{2O}C (Practical)**		**Average Overall Heat Transfer Coefficient, kW/m^{2O}C (Theoretical)**	
		Uo	Ui	Uo	Ui
Water to Water	A	0.27	0.32	16.13	19.35
Nanofluid of φ=0.001 to Water	B	0.28	0.34	19.48	23.38
Nanofluid of φ=0.002 to Water	C	0.31	0.37	19.45	23.34
Nanofluid of φ=0.003 to Water	D	0.36	0.43	19.49	23.39
Nanofluid of φ=0.004 to Water	E	0.38	0.49	19.43	23.32
Nanofluid of φ=0.005 to Water	F	0.42	0.55	19.47	23.36
Nanofluid of φ=0.006 to Water	G	0.51	0.61	19.49	23.39
Nanofluid of φ=0.007 to Water	H	0.53	0.65	19.50	23.40
Nanofluid of φ=0.008 to Water	I	0.54	0.68	19.43	23.31
Nanofluid of φ=0.009 to Water	J	0.54	0.60	19.49	23.38
Nanofluid of φ=0.01 to Water	K	0.50	0.57	19.49	23.39

Table 3: Result for Parallel Counter Arrangement

Heat Transfer Media	**Case Number**	**Average Overall Heat Transfer Coefficient, kW/m^{2O}C (Practical)**		**Average Overall Heat Transfer Coefficient, kW/m^{2O}C (Theoretical)**	
		Uo	Ui	Uo	Ui
Water to Water	A	0.36	0.43	19.21	23.05
Nanofluid of φ=0.001 to Water	B	0.42	0.52	23.49	19.57
Nanofluid of φ=0.002 to Water	C	0.49	0.61	23.48	19.57
Nanofluid of φ=0.003 to Water	D	0.54	0.69	23.51	19.59
Nanofluid of φ=0.004 to Water	E	0.59	0.76	23.28	19.40
Nanofluid of φ=0.005 to Water	F	0.68	0.81	23.33	19.44

Nanofluid of φ=0.006 to Water	G	0.75	0.90	23.51	19.59
Nanofluid of φ=0.007 to Water	H	0.83	0.99	23.47	19.56
Nanofluid of φ=0.008 to Water	I	0.84	1.01	23.28	19.40
Nanofluid of φ=0.009 to Water	J	0.82	0.98	23.31	19.43
Nanofluid of φ=0.01 to Water	K	0.80	0.96	23.32	19.43

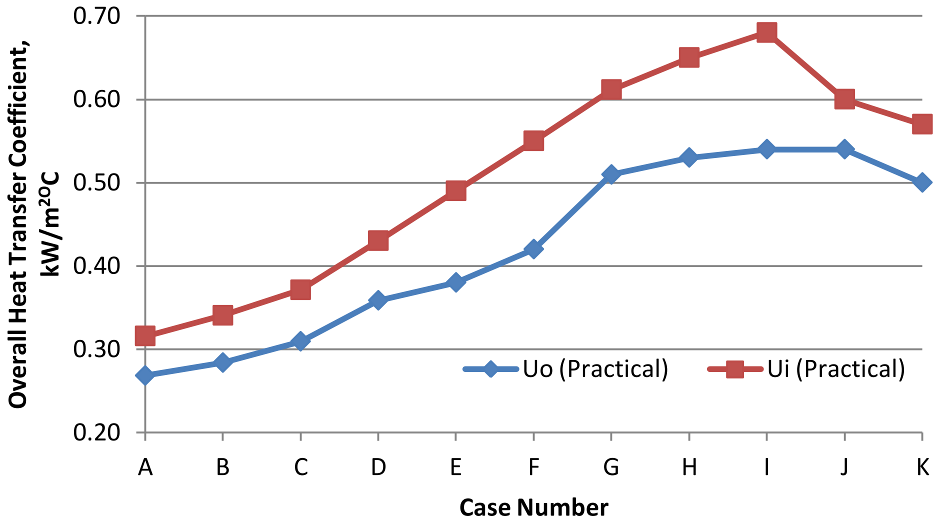

Fig 2: Practical Overall Heat Transfer Coefficients for Parallel Flow Arrangement

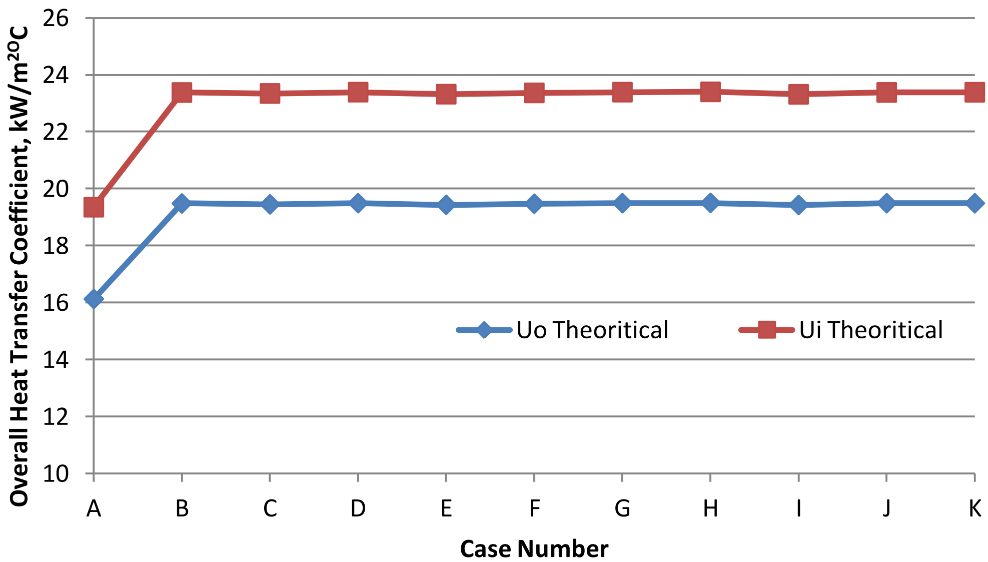

Fig 3: Theoretical Overall Heat Transfer Coefficients for Parallel Flow Arrangement

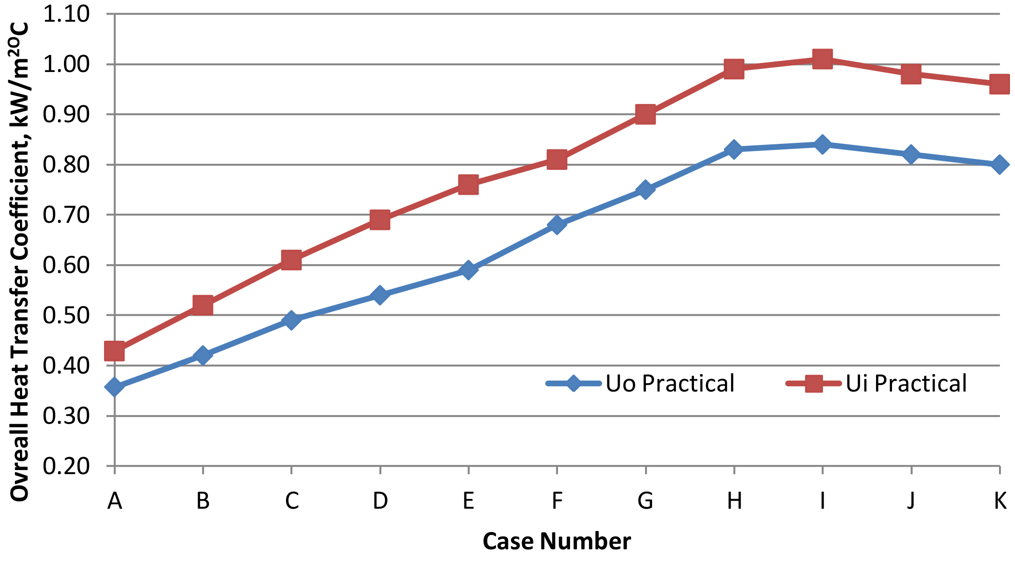

Fig 4: Practical Overall Heat Transfer Coefficients for Counter Flow Arrangement

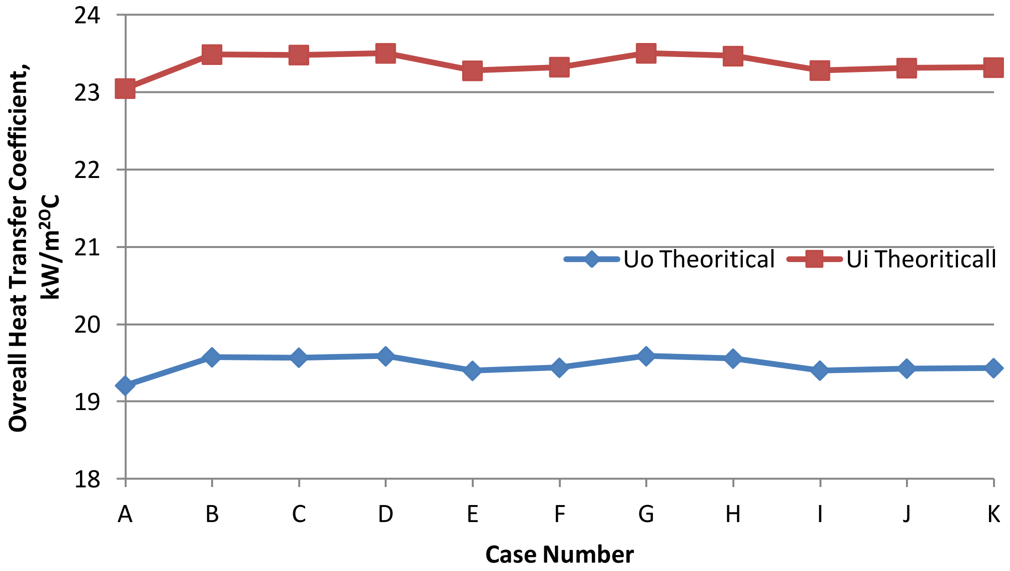

Fig 5: Theoretical Overall Heat Transfer Coefficients for Counter Flow Arrangement

The value of overall heat transfer coefficient increases in case of nanofluid of different volume concentrations to water heat transfer as compared to water to water heat transfer for parallel flow as well as counter flow arrangement for double pipe heat exchanger. The increase in outer and inner overall heat transfer coefficient is found to 101 % and 115 % in case of nanofluid having volume concentration of 0.008 % for parallel flow and the same is found to be 135 % and 136 % in case of nanofluid having volume concentration of 0.008 % for counter flow arrangement. It has been also observed that overall heat transfer coefficient increases up to nanofluid having volume concentration of 0.008 % and then decreases for parallel flow and counter flow arrangement for double pipe heat exchanger.

6. CONCLUSION

An experimental investigation is carried out to determine the effect of various concentration of Al_2O_3 nano-dispersion mixed in water as base fluid on heat transfer characteristics of double pipe heat exchanger for parallel and counter flow arrangment. The volume concentrations of Al_2O_3 nanofluid prepared are 0.001 % to 0.01 %. The conclusion derived for the study is that overall heat transfer coefficient increase with increase in volume concentration of Al_2O_3 nano-dispersion compared to water up to volume concentration of 0.008 % and then decreases. The effect of CuO nanoparticles on heat transfer characteristics of double pipe heat exchanger for parallel and counter flow arrangement are presented in part II of the paper.

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