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Heat Transfer Enhancement in Shell and Tube Heat Exchanger by using Iron Oxide Nanofluid

[1]Sunny Rach,[2]Pratik patel,[3]Dr. Dipak A. Deore
[1]PG student,[2]PG student,[3]Head of the department
[1]S'ad VidyaMandal Institute of Technology, Bharuch-392001, Gujarat,India
[1]sunny.rach@yahoo.com, [2]pratik.mech21@gmail.com, dipakdeore@gmail.com

***Abstract*—The main aim of the present experimental investigation is to study the heat transfer characteristics of nanofluids mixed with base fluid in certain proportion flowing in a tube, under constant heat flux boundary conditions in laminar and transition flow regimes. The use of inserts with nanofluids to further compound the heat transfer enhancement is a new technique.The experiment is carried out on Shell and tube heat exchanger and nanofluid used is Iron Oxide. In the experiment Iron oxide nanofluid is used by mixed it with base fluid i.e. water at different volume concentrations. After that checking the change in the convective heat transfer coefficient by using nanofluid with compare to plain water. At the end it is conclude from the experiment that the value of convective heat transfer coefficient increases with increase in the mass flow rate and gives enhancement in between 2% to 48% Also it will increase with increasing volume concentration of nanofluid but only up to 4% concentration. Again it will start decreasing at around 4% concentration. Also experiment shows that the 3% volume concentration gives highest value of % increment in convective heat transfer coefficient with compare to 2% and 4% volume concentration.**

***Index Terms*— Heat Exchanger, Shell and Tube, Iron oxide Nanofluid, Enhancement in convective heat transfer coefficient**

I. INTRODUCTION

Heat Typical heat exchangers experienced by us in our daily lives include condensers and evaporators used in air conditioning units and refrigerators. Boilers and condensers in thermal power plants are examples of large industrial heat exchangers. There are heat exchangers in our automobiles in the form of radiators and oil coolers. Heat exchangers are also abundant in chemical and process industries.

The nanofluids are considered to be new generation fluids characterized by better heat transfer capabilities over traditional heat transfer fluids. The nanofluid is an emerging area of research and has lot of potential in heat transfer applications. A nanofluid is a two phase fluid of solid-liquid mixture and heat transfer performance of nanofluids are expected to be significantly higher than the conventional single phase fluids. Development of the nanomaterial's technology has made it possible to structure a new type of heat transfer fluids formed by suspending nanoparticles (diameter less than 100nm) in conventional base fluids like water and ethylene glycol.

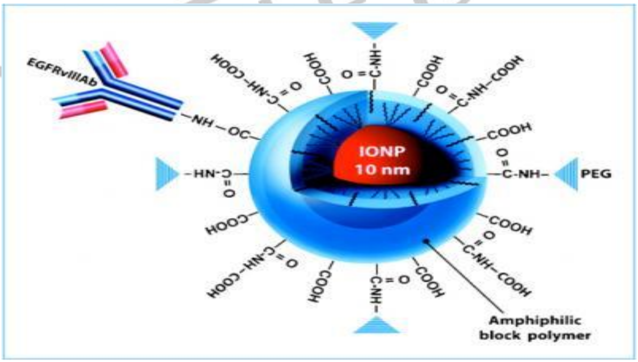


FIG. 1 Nano particle polymer formation

The main purpose of using Nano fluid is to enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water.The application of nanofluids or fluids containing suspensions of metallic nanoparticles toconfront heat transfer problems in thermal management is one of technological uses of nanoparticles that hold enormous promise today. Experiments have shown that nanofluids have improved thermal conductivities when compared to the base fluids and enhancement in the heat transfer coefficient.

II. LITERATURE REVIEW

Masuda et al. (1993) studied the possibility of altering the properties of conventional heat transfer fluids by suspending submicron particles of water based $Al_2O_3$and $Ti0_2$ and reported that the enhancement in the effective thermal conductivities are about 32% and11%, respectively for the nanofluids of 4.3% volume concentration.[9]

Eastman et al. (1997) observed that oxide nanoparticles, such as Al2O3 and CuO have excellent dispersion properties in water, oil and ethylene glycol and form stable suspensions.Experimental results indicated higher thermal conductivities in fluid mixture than those of the base fluids and the measured thermal conductivity values are higher for nanofluids and the mixture formula under predicted experimental thermal conductivity of the above nanofluids.

S.M.Peyghambarzadehevaluatedheat transfer performance of the automobile radiator experimentally by calculating the overall heat transfer coefficient (U) according to the Conventional €-NTU technique. Copper oxide (CuO) and Iron oxide (Fe_2O_3) nanoparticles are added to the water at three concentrations 0.15, 0.4 and 0.65 vol. % with considering the best pH for longer stability.Results demonstrate that both nanofluids show greater overall heat transfer coefficient in comparison with water up to 9%. Furthermore, increasing the nanoparticle concentration, air velocity, and nanofluid velocity enhances the overall heat transfer coefficient.[2]

K.Y. Leongstudied and focused on the application of ethylene glycol based copper nanofluids in an automotive cooling system.. It was observed that, overall heat transfer coefficient and heat transfer rate in engine cooling system increased with the usage of nanofluids (with ethylene glycol the basefluid) compared to ethylene glycol (i.e. base fluid) alone. It is observed that, about 3.8% of heat transfer enhancement could be achieved with the addition of 2% copper particles in a base fluid at the Reynolds number of 6000 and 5000 for air and coolant respectively.[7]

S.P. Tayal studiedheat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of Al_2O_3nanofluid (0.3-2) % flowing in a counter flow horizontal shell and tube heat exchangerThe results show that the convective heat transfer coefficient of nanofluid is slightly higher than that of the base liquid at same mass flow rate and at same inlet temperature. The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate, also the heat transfer coefficient increases with the increase of the volume concentration of the Al_2O_3nanofluid[4]

A.A. RabienatajDarziinvestigated heated helically corrugated tube numerically for pure water and water–alumina nanofluid. The Results show that the heat transfer enhancement is promoted extremely by increasing the volume fraction of nano-particles. Adding 2% and 4% nano-particles by volume to water enhances the heat transfer by 21% and 58%, respectively.[5]

M.A. Khairul presentedthe thermodynamic second law analysis of a helical coil heat exchanger using three different types of nanofluids (e.g. CuO/water, Al2O3/water and ZnO/water).Amongst the three nanofluids, CuO/water nanofluid, the heat transfer enhancement and reduction of entropy generation rate were obtained about 7.14% and 6.14% respectively. Furthermore, heat transfer coefficient was improved with the increasing of nanoparticles volume concentration and volume flow rate, while entropy generation rate went down.[8]

M.M. Elias studied the effect of different nanoparticle shapes (such as cylindrical, bricks, blades, platelets, and spherical) on the performance of a shell and tube heat exchanger operating with nanofluid analytically.The results show entropy generation for nanofluids containing cylindrical shaped nanoparticles was higher in comparison with the other nanoparticle shapes and also an increase in both the heat transfer and thermodynamic performance of the system.So cylindrical shaped nanoparticles are recommended to be utilized in heat exchanger systems working with nanofluids.

III. NANOFLUIDS

1. Basic information

Nano fluids are dilute liquid suspended nano particles which have only one critical dimension smaller than ~100nm. The thermal behaviour of nano fluids could provide a basis for an huge innovation for heat transfer, which is a major importance to number of industrial sectors including transportation, power generation, micro manufacturing, thermal therapy for cancer treatment, chemical and metallurgical sectors, as well as heating, cooling, ventilation and air-conditioning. Nano fluids are also important for the production of nano structured materials (Kinloch et al. 2002), for the engineering of complex fluids (Tohver et al.2001), as well as for cleaning oil from surfaces due to their excellent wetting and spreading behavior (Wasan&Nikolov 2003).

Nanofluids are quasi single phase medium containing stable colloidal dispersion of ultrafine or Nano metric metallic or ceramic particles in a given fluid. Despite almost a negligible concentration (< 1 vol%) of the solid dispersion, nanofluids register an extraordinarily high level of thermal conductivity, which largely depends on identity (composition), amount (volume percentage), size and shape of the dispersoid and viscosity, density and related thermo-physical parameters of the base fluid. Nanofluids possess immense potential of application to improve heat transfer and energy efficiency in several areas including vehicular cooling in transportation, power generation, defense, nuclear, space, microelectronics and biomedical devices.

2. Synthesis of Nanofluid

The optimization of nanofluid thermal properties requires successful synthesis procedures for creating stable suspensions of nanoparticles in liquids. Depending on the requirements of a particular application, many combinations of particle materials and fluids are of potential interest. For example, nanoparticles of oxides, nitrides, metals, metal carbides, and non-metals with or without surfactant molecules can be dispersed into fluids such as water, ethylene glycol, or oils. Studies to date have used one or more of several possible methods for nanoparticle production and dispersion

(a) One step method - In this method nanofluids containing dispersed metal nanoparticles have been produced by a 'direct evaporation' technique. As with the inert gas condensation technique, this involves the vaporization of a source material under vacuum conditions. An advantage of this technique is that nanoparticle agglomeration is minimized, while a disadvantage is that it will not be use for a wide range of applications, including studies of thermal transport.Few other methods also exist for the preparation of nanofluids through a one step process. These methods include the thermal decomposition of an organometallic precursor in the presence of a stabilizer, chemical reduction, and polyol synthesis. The polyol method is one of the most well-known pathways to noble metal nanoparticles. In the polyol process, a metal precursor is dissolved in a liquid polyol (usually ethylene glycol), after which the experimental conditions are adjusted to achieve the reduction of the metallic precursor by the polyol, followed by atomic metal nucleation and metal particle growth. The direct-evaporation technique was developed by Choi etal.It consists of a cylinder containing a fluid which is rotated. In the middle of the cylinder, a source material is vaporized. The vapour condenses once it comes into contact with the cooled liquid (Figure 2). The drawbacks of this technique however, are that the use of low vapour pressure liquids are essential and only limited quantities can be produced.[3]

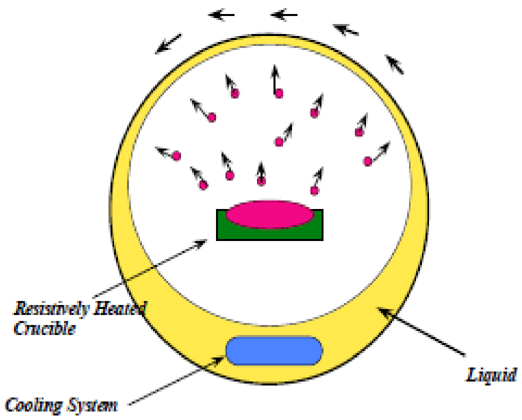


FIG. 2 One-step Nanofluid production system

A submerged arc nanoparticle synthesis system (SANSS) was developed to prepare CuO nanoparticles dispersed uniformly in a dielectric liquid (deionized water). The method successfully produced stable nanofluids. In principle, a pure copper rod is submerged in a dielectric liquid in a vacuum chamber. A suitable electric power source is used to produce an arc between 6000-12000 °C which melts and vaporizes the metal rod in the region where the arc is generated. At the same time, the deionized water is also vaporized by the arc. The vaporized metal undergoes nucleation, growth and condensation resulting in nanoparticles dispersed in deionized water. Nanofluids containing CuO particles of size 49.1 ± 38.9 nm were obtained.

(b) Two step method - A two-step process in which nanoparticles or nanotubes are first produced as a dry powder, often by inert gas condensation. Chemical vapour deposition has also been used to produce materials for use in nanofluids, particularly multiwall carbon nanotubes. The nanoparticles or nanotubes are then dispersed into a fluid in a second processing step. Simple techniques such as ultrasonic agitation or the addition of surfactants to the fluids are sometimes used to minimize particle aggregation and improve dispersion behaviour.

The preparation of nanofluids begins by direct mixing of the base fluid with the Nano materials. In the first step, nanomaterials are synthesized and obtained as powders, which are then introduced to the base fluid in a second step. Nanoparticles can be produced from several processes which can be categorized into one of five general synthetic methods. These five methods are: (i) transition metal salt reduction (ii) thermal decomposition and photochemical methods (iii) ligand reduction and displacement from organometallics (iv) metal vapour synthesis and (v) electrochemical synthesis.

The two-step process is commonly used for the synthesis of carbon nanotube based nanofluids. Single-wall carbon nanotubes (SWCNTs) and Multi-walled carbon nanotubes (MWCNTs) are cylindrical allotropes of carbon. SWCNTs consist of a single cylinder of graphene, while MWCNTs contain multiple graphene cylinders nesting within each other. The carbon nanotubes are usually produced by a pyrolysis method and then suspended in a base fluid with or without use of surfactant

3. Nano Particle Size Statistic Report

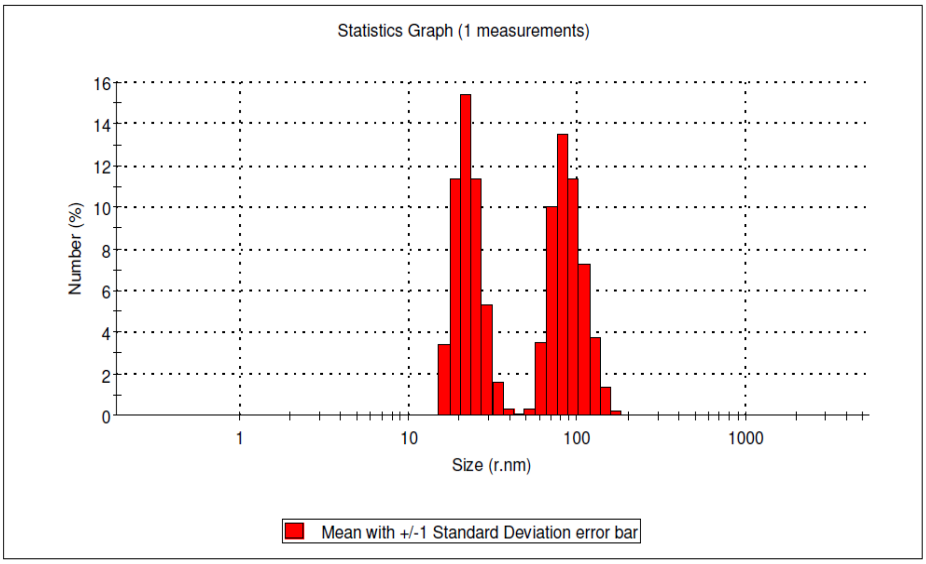
Z-Average (nm): 279.9... **Derived Count Rate (kcps):** 763.2. **Diffusion Coefficient (µ²/s):** 1

Standard Deviation: 0 **Standard Deviation:** 0

%Std Deviation: 0 **%Std Deviation:** 0

Variance: 0 **Variance:** 0

Size r.nm	Mean Number %	Std Dev Number %	Size r.nm	Mean Number %	Std Dev Number %	Size r.nm	Mean Number %	Std Dev Number %	Size r.nm	Mean Number %	Std Dev Number %
0.2000	0.0		2.807	0.0		39.41	0.3		553.2	0.0	
0.2316	0.0		3.251	0.0		45.64	0.1		640.7	0.0	
0.2682	0.0		3.765	0.0		52.85	0.3		741.9	0.0	
0.3106	0.0		4.360	0.0		61.21	3.5		859.2	0.0	
0.3597	0.0		5.050	0.0		70.89	10.0		995.1	0.0	
0.4166	0.0		5.848	0.0		82.09	13.5		1152	0.0	
0.4825	0.0		6.772	0.0		95.07	11.4		1335	0.0	
0.5587	0.0		7.843	0.0		110.1	7.3		1545	0.0	
0.6470	0.0		9.083	0.0		127.5	3.7		1790	0.0	
0.7493	0.0		10.52	0.0		147.7	1.3		2073	0.0	
0.8678	0.0		12.18	0.0		171.0	0.3		2400	0.0	
1.005	0.0		14.11	0.0		198.0	0.0		2780	0.0	
1.164	0.0		16.34	3.4		229.3	0.0		3219	0.0	
1.348	0.0		18.92	11.4		265.6	0.0		3728	0.0	
1.561	0.0		21.91	15.4		307.6	0.0		4317	0.0	
1.808	0.0		25.37	11.4		356.2	0.0		5000	0.0	
2.093	0.0		29.39	5.3		412.5	0.0				
2.424	0.0		34.03	1.6		477.7	0.0				



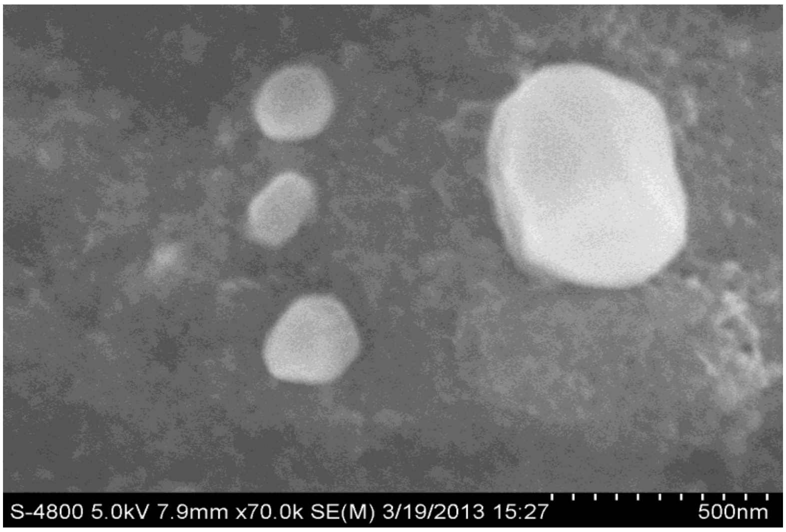


FIG 3 Microscopic image of Iron oxide Nanoparticle

IV. EXPERIMENTAL WORK

Shell and Tube Heat Exchanger

The shell and tube heat exchanger is two pass heat exchanger. The hot fluid is hot water obtained from the electric geyser and cold fluid is tap water. Cold water or nano fluid enters in the lower side of the end box, flows through the tubes in lower half of the shell where it reverse its direction, flows through tubes in upper half of the shell and leaves out. The hot water enters lower part of the shell passes over the tubes between the baffles and leaves out the shell through outlet at upper surface of shell. The flow rates are measured with the help of rota meters. The temperatures at various points in heat exchanger are measured by using Resistance Temperature Detector (RTD). Thus the heat transfer rate, heat transfer coefficient, L.M.T.D and effectiveness of heat exchanger can be calculated.

1. Specifications

- Shell-150 NB, 750mm long provided with end box
    - One end box with divider plate.
    - 25% cut baffles- 4 in Nos. in the shell.
- Tubes- 4.5 I.D., 6.35 O.D., 750 mm long copper tubes with triangular pitch(36 Nos.)
- Instantaneous water heater, 3Kw capacity, to supply hot water.
- Resistance temperature detector for measuring temperature at different points.
- Ball Valves to control the flow rate of hot and cold water.
- Roatameters (2 Nos.) for measuring flow rates of hot and cold fluid.
- Centrifugal pump (Tullu 30 AC) for supplying and recirculating of cold water and nanofluid inside the tubes.

2. Experimental setup

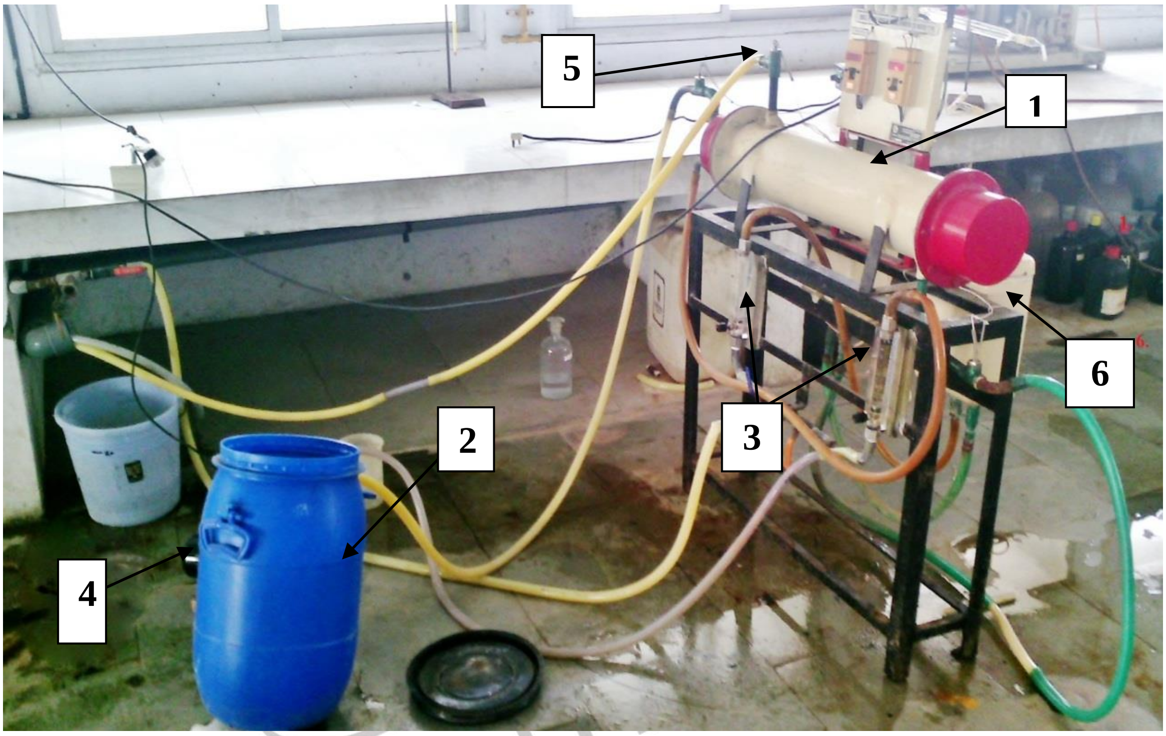


FIG 4 Experimental setup of Shell and tube heat exchanger

Nomenclature:

1. Shell and tube Heat exchanger
2. Nanofluid tank
3. Rota meters
4. Centrifugal pump
5. Resistance Temperature Detector
6. Electric Geyser

3. Experimental Procedure

1. Connect the water supply and start water flow from tap for hot water inside the shell.
2. Keep the flow rate of hot water constant to 100LPH and 200LPH
3. Connect the main electric supply (250V, 15A) and switch 'ON' the water heater.
4. Note down the inlet temperature of hot water coming out from the water heater (T_{hi}) and outlet temperature of hot water going out from the shell (T_{ho}) with the help of Resistance Temperature Detector (RTD)
5. Supply the cold water and mixture of nanofluid and base fluid from the tank provided through centrifugal pump inside the tubes of heat exchanger.
6. Change the flow rate of nanofluid from rotameter in the range of 50LPH to 250 LPH
7. Measure the inlet temperature of nanofluid (T_{ci}) and outlet temperature of nanofluid (T_{co}) by RTD.

4.Sample Calculations

1) Hot water inlet temperature $T_{h1} = 65.8°C$
Hot water outlet temperature T_{h2} =41.0°C
2) Cold water inlet temperature T_{c1} =28.0°C
Cold water outlet temperature T_{c2} =38.2°C
3) Hot water flow rate m_h= 0.02777 kg/sec
Cold water flow rate m_c= 0.02083 kg/sec
4)Heat given by hot water
$q_h = m_{h.} c_p.(T_{h1}\text{-}T_{h2})$
= 0.02777 X 4.2 X (65.8-41.0)
= 2.892523 KW
5) Heat gain by cold water
$q_c = m_{c.} c_p.(T_{c2}\text{-}T_{c1})$
= 0.02083 X 4.2 X (38.2-28.0)
= 0.892357 KW
6) Logarithmic Mean Temperature Difference (LMTD)[10]

For shell and tube heat exchanger,
LMTD = F*$LMTD_{eff}$
Where, $LMTD_{eff}$= LMTD for counter flow
F= Correction factor

$$LMTD_{eff} = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})}$$

$\Delta T_1 = T_{h1}\text{-}T_{c2}$ = 65.8-38.2 = 27.6 ℃
$\Delta T_2 = T_{h2}\text{-}T_{c1}$ = 41-28 = 13.0 ℃

$$LMTD_{eff} = \frac{27.6-13.0}{\ln(\frac{27.6}{13.0})}$$
= 19.3925 °C

For finding out correction factor F, values of P and R are required.
Where,

$$P = \frac{T_{c2}-T_{c1}}{T_{h1}-T_{c1}} = \frac{38.2-28}{65.8-28} = 0.2698$$

$$R = \frac{T_{h1}-T_{h2}}{T_{c2}-T_{c1}} = \frac{65.8-41}{38.2-28} = 2.4313$$

The value of will be find out from the following graph,[11]

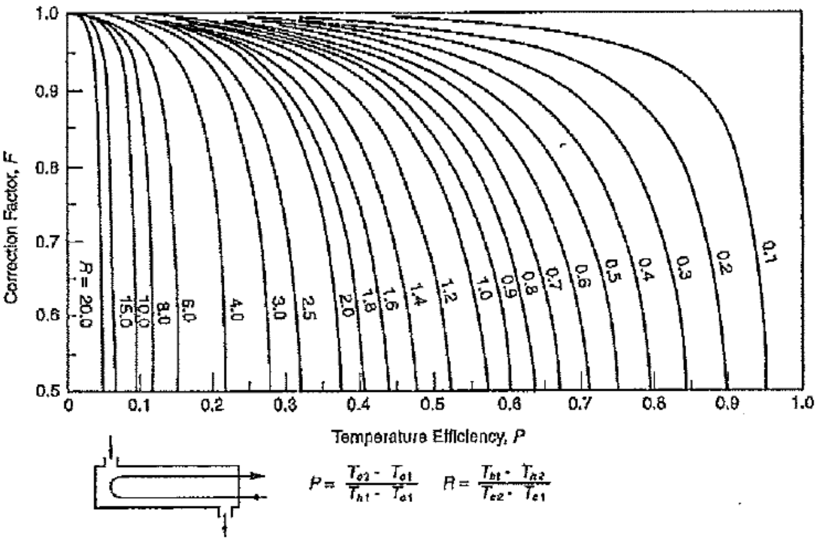


FIG. 5 LMTD correction factor F chart for one pass and multiple passes

So from graph F = 0.85

LMTD = F x $LMTD_{eff}$
= 0.85 x 19.3925
= 16.4836 °C
7) Inside surface Area of the tube
$A_i = \pi \; x \; D \; x \; L$ No of tubes

$= \pi$ x 0.0045 x 0.75 x 32

$= 0.34\ m^2$

8) Outside surface area of the tube

$A_o = \pi$x D x L x No of tubes

$= \pi$ x 0.00635 x 0.75 x 32

$= 0.48\ m^2$

9) Inside convective heat transfer coefficient cold side (U_C)

$$U_C = \frac{q_c}{(\text{LMTD} * A_i)}$$

$$= \frac{0.8923}{16.4836 * 0.34}$$

$= 0.1592$ KW $/m^2$°C

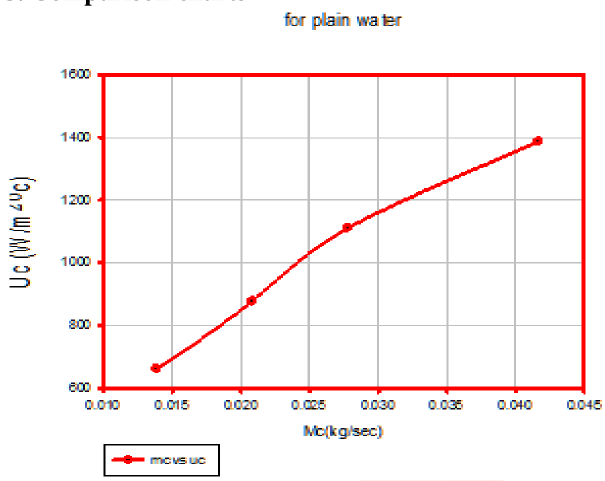
10) Outside convective heat transfer coefficient hot side (U_H)

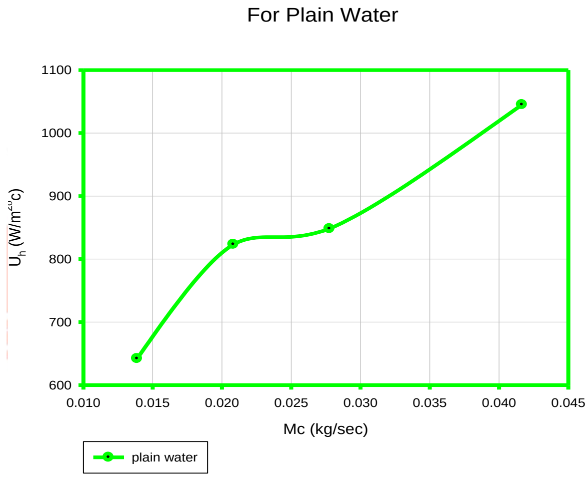
$$U_H = \frac{q_h}{(\text{LMTD x } A_o)}$$

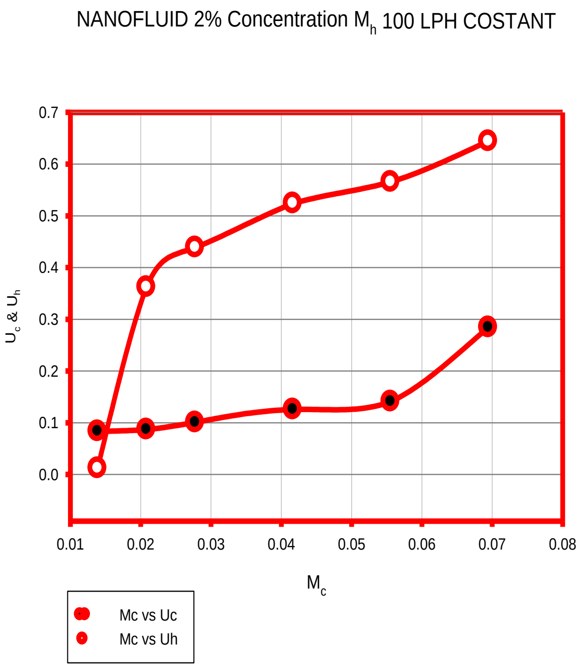
$$= \frac{2.8925}{17.23 * 0.48}$$

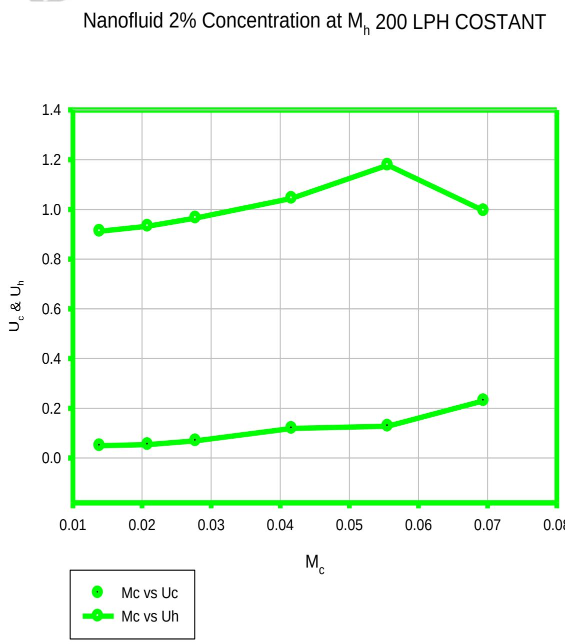
$= 0.3655$ KW / m^2°C

5. Comparison charts

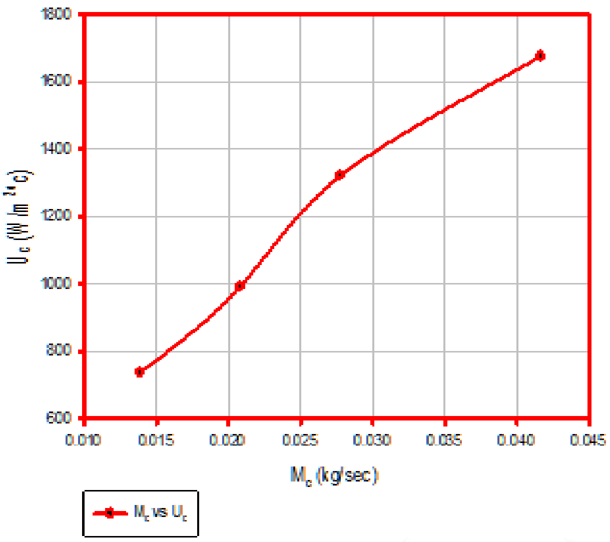




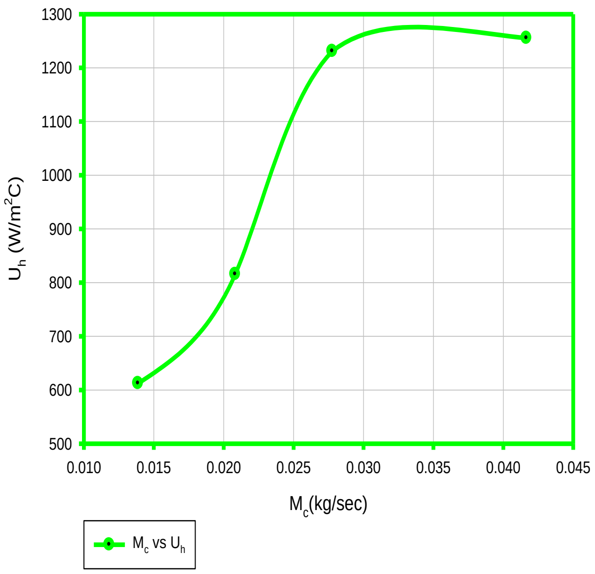




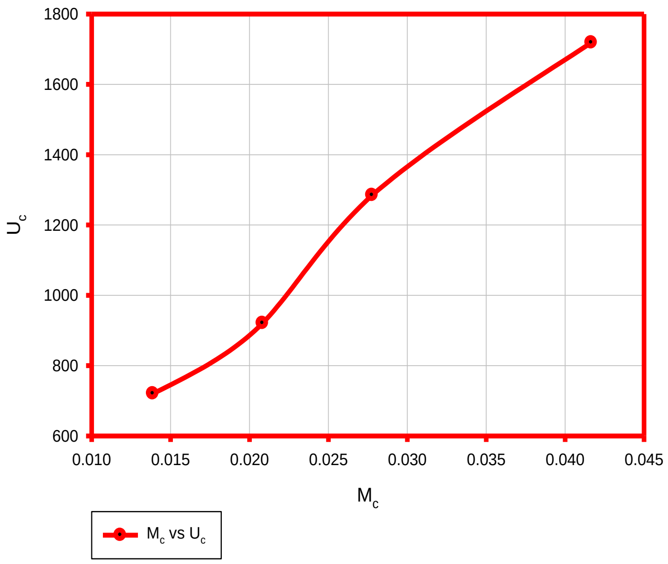
for 3% concentration of iron oxide nanofluid



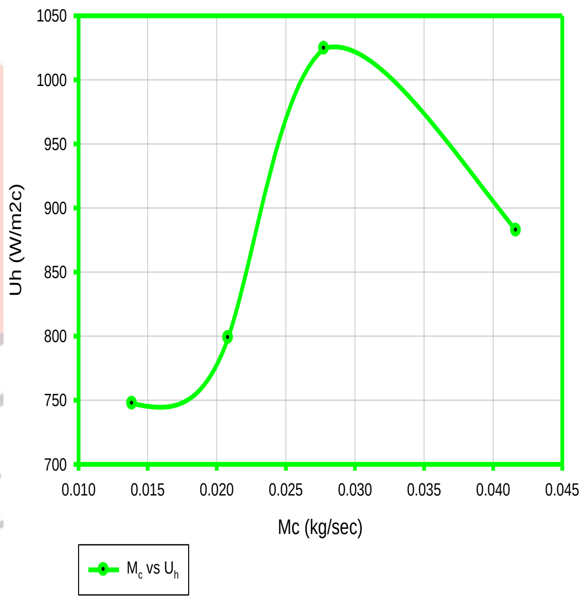
for 3% concentration of iron oxide nanofluid



For 4% concentration of Iron Oxide nanofluid



For 4% concentration of Iron Oxide Nanofluid



V. RESULTS AND DISCUSSIONS

The experimental results of Shell and tube heat exchanger are below:

Table-1 Experimental Results of Shell and tube heat exchanger when mass flow rate of hot fluid M_h=100 LPH constant

Q Cold LPH	Plain water	2% concentration of Nanofluid		3% concentration of Nanofluid		4% concentration of Nanofluid	
	U_c KW/m^2°C	U_c KW/m^2°C	% increase	U_c KW/m^2°C	% increase	U_c KW/m^2°C	% increase
50	0.338	0.365	**7.52**	0.382	**11.69**	0.342	**2.08**
75	0.345	0.379	**9.14**	0.451	**23.52**	0.394	**12.44**
100	0.350	0.481	**27.27**	0.505	**30.75**	0.403	**13.21**
150	0.371	0.580	**36.14**	0.641	**42.16**	0.413	**10.25**

200	0.385	0.629	**38.83**	0.743	**48.24**	0.425	**9.48**

- From the above table we can conclude that the value of convective heat transfer coefficient increases with increase in mass flow rate of cold fluid while keeping the hot side flow rate constant.
- Also it is shown that the % increase in the convective heat transfer coefficient after using the nanofluid with compare to plain water is in the range of **7% to 39%** for 2% volume concentration of Iron Oxide nanofluid, it is in the range of **11% to 49%** for 3% volume concentration of nanofluid and its **2% to 14%** for the 4% volume concentration of nanofluid
- Also value of % increase in convective heat transfer coefficient is gradually increasing with increasing mass flow rate in case of 2% and 3% volume concentration while it is unpredictable & irregular for 4% volume concentration.

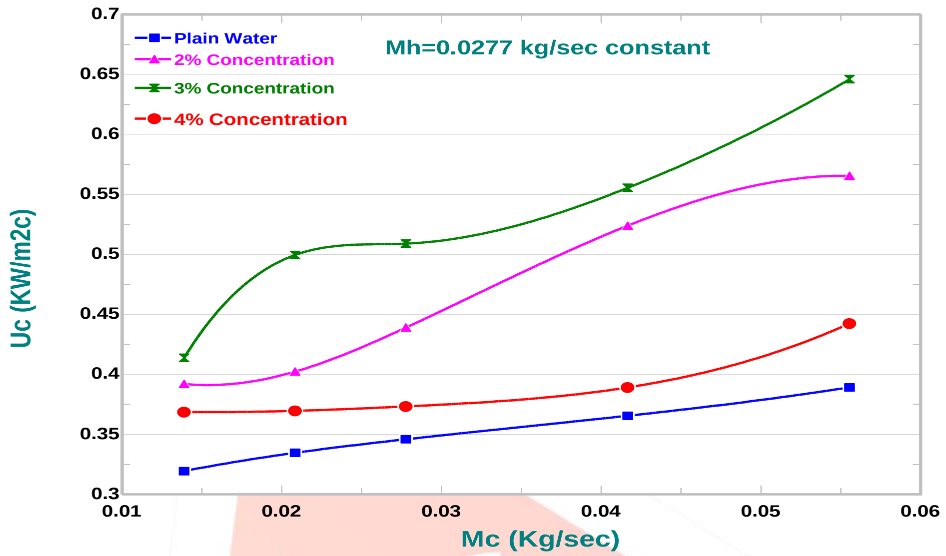


FIG. 6 Variation in Convective heat transfer coefficient with mass flow rate in Shell and tube heat exchanger when M_h=100LPH constant

- From the above graph it is conclude that the value of convective heat transfer coefficient increases gradually with increase in the mass flow rate of the nanofluid i.e. Cold fluid.
- Also the value of Convective heat transfer coefficient has highest value in case of the 3% volume concentration while the values for 2% concentration is slightly lower than the 3% concentration. Also value of 4% concentration is comparatively lower than 2% and 3% volume concentration.
- It is clearly noticeable that the heat transfer coefficient by using nanofluid having comparatively higher values than values for plain water.

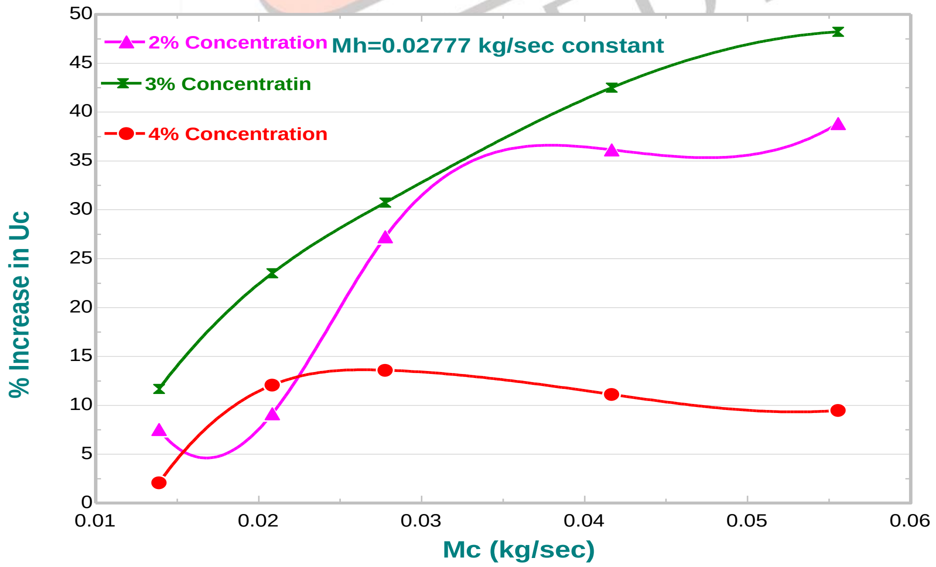


FIG.7 % Increment in Convective heat transfer coefficient with mass flow rate in Shell and Tube heat exchanger when M_h=100 LPH constant

- The above graph shows % the increase in convective heat transfer coefficient by changing mass flow rate of nanofluid with compare to the plain water.

- It is shown from the graph that heat transfer enhancement in case of 2% & 3% volume concentration is gradually increases with increase in the mass flow rate while for 4% volume concentration, it increases with mass flow rate up to certain limit but after that it starts decreasing.

Table-1 Experimental Results of Shell and tube heat exchanger when mass flow rate of hot fluid M_h=100 LPH constant

Q Cold LPH	Plain water	3% concentration		4% concentration	
	U_c KW/m^2°C	U_c KW/m^2°C	% increase	U_c KW/m^2°C	% increase
50	0.536	0.913	**27.60**	0.594	**9.73**
75	0.644	0.932	**42.48**	0.722	**10.04**
100	0.682	0.965	**25.23**	0.776	**21.92**
150	0.698	0.994	**29.24**	0.813	**16.10**
200	0.711	1.044	**39.71**	0.873	**10.94**
250	0.738	1.177	**35.23**	0.881	**12.49**

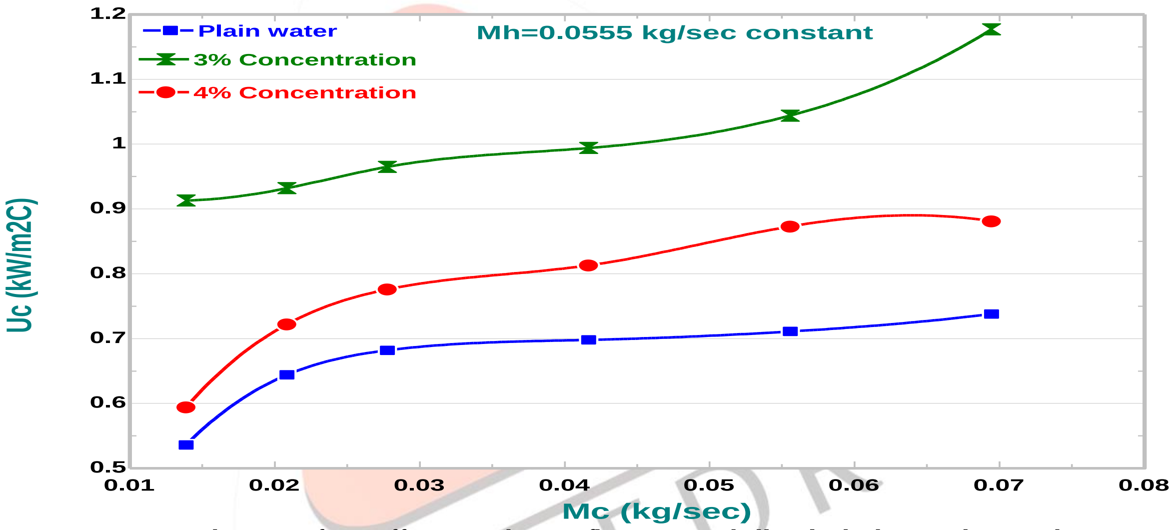


FIG. 8 Variation in Convective heat transfer coefficient with mass flow rate in Shell and tube heat exchangerwhen M_h=200 LPH constant

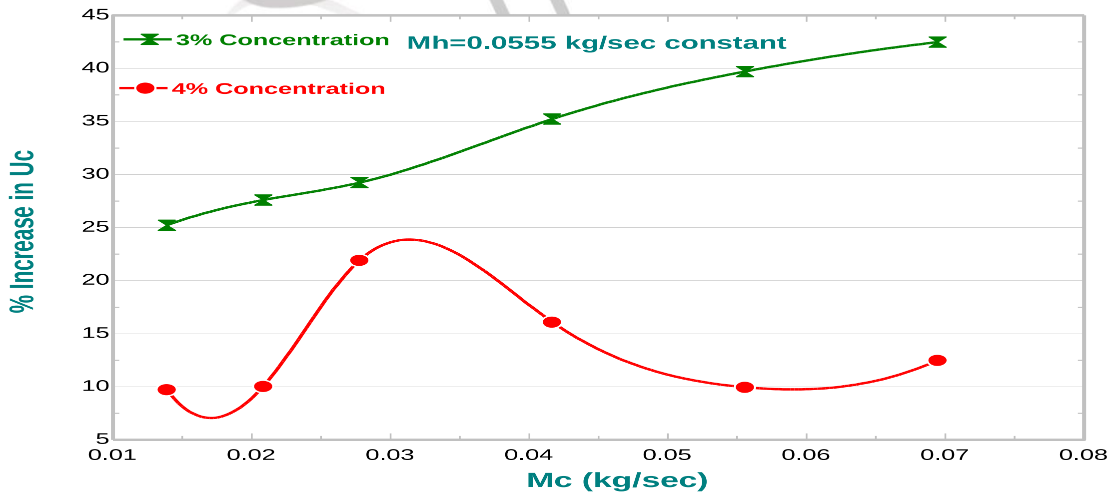


FIG. 9 % Increment in Convective heat transfer coefficient with mass flow rate in Shell and Tube heat exchanger when M_h=200 LPH constant

VI. CONCLUSIONS

- From the results of shell and tube heat exchanger the value of convective heat transfer coefficient shows good result while hot water flow rate is 100 LPH constant while the results during hot water flow rate 200 LPH constant is quite unpredictable in also decreases at higher flow rates of cold fluid.
- From the comparison graphs of shell and tube heat exchanger we conclude that the increase in convective heat transfer coefficient is in the range of 2% to 40% and it is clearly noticeable that the 3% volume concentration gives highest and consistent increment in convective heat transfer coefficients than 2% and 4% volume concentrations.
- Also it is seen that the convective heat transfer coefficient decreases at volume concentration of 4% nanofluid at the higher flow rates.

VII. ABBREVIATIONS AND NOMENCLATURE

Nomenclature:

T- Temperatures °c
K- Thermal conductivity W/m k
U_c- Convective heat transfer coefficient cold sideW/m^2 °c
U_h- Convective heat transfer coefficient hot sideW/m^2 °c
C_p- Specific heat at constant pressure KJ/kg k
Mc- Mass flow rate of cold fluid kg/sec
Mh- Mass flow rate of hot fluid kg/sec
A_i–Inside surface area of tube m^2
A_o– Outside surface area of tube m^2
q_c- Heat gain by cold fluid
q_h-Heat given by hot fluid
T_{c1}- Inlet temperature of cold fluid
T_{c2}- Outlet temperature of cold fluid
T_{h1}- Inlet temperature of hot fluid
T_{h2}- Outlet temperature of hot fluid
LMTD- Logarithmic Mean Temperature Difference

Subscripts:

i-Inlet
o- Outlet
c- cold side
h- Hot side
eff- Effective

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