Enhancement of Heat Transfer in Concentric Tube Heat Exchanger using Water Based Nano Fluid (Al_2O_3)

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Abstract - *In the present day study, the heat transfer characteristics of Al2O3 – water based nanofluids as a coolant used in concentric tube heat exchanger are presented. The heat exchanger is manufactured from copper inner tube. The nanofluids are the mixture of water as base fluid and Al2O3 particles. The results obtained from the nanofluids cooling in concentric tube heat exchanger are compared with those from base fluids. The effects of inlet flow rate of hot fluids, temperatures and composition of nanofluids on concentric tube heat exchanger are studied. It is observed that average heat transfer rates for nanofluids as cooling media are higher than those for the water as cooling media, and this increases with concentration of nanofluids' composition. The results of this study have technological importance for the efficient design of concentric tube heat exchanger to enhance cooling performance at low heat flux cooling systems.*

***Key Words*: Nanofluid, Al_2O_3, Nanoparticles, Concentric tube heat exchanger, Convective heat transfer.**

1.INTRODUCTION

In engineering applications, a concentric tube heat exchanger has played a very important part, since it is used in engineering industry such as; power plant, air-conditioning, refrigeration, process industry, solar water heater, chemical industries and nuclear power plant, hence convective heat transfer in a concentric tube heat exchanger had been a subject of interest in many research have been carried out over the past few years. The most frequently used working fluids in the heat-transfer setup study are air, water, the heat transfer capability is restricted by the working fluid properties. To reduce the size and cost of the heat exchanger devices and saving up the energy, many new engineering techniques were invented to improve the heat transfer rate from the surface in heat exchangers. One of the methods for the heat transfer enhancement is the application of additives(nanoparticles) to the working fluids to change the fluid properties and flow features. Thermal performance of heat transfer equipment, the concept of use of nanofluids is proposed.

Mixture of conventional heat transfer fluids and nanoparticles called nanofluid. A nanofluid is advance heat transfer fluids and can overcome a limitation of poor thermophysical properties (lower thermal conductivity, higher friction factor) of conventional fluids such as; pure water, ethylene glycol.

2.EXPERIMENTAL SETUP

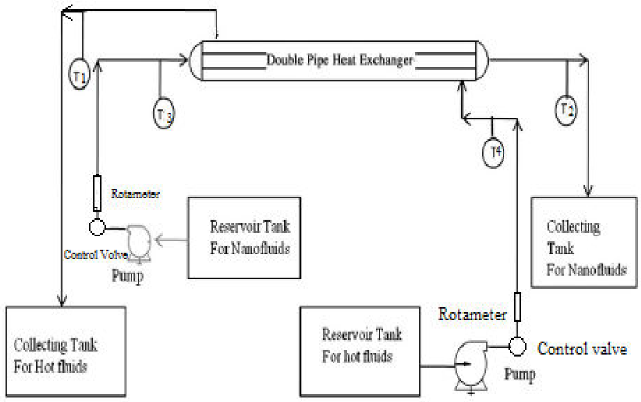


Fig.1: Schematic of experimental setup

T1= Hot water outlet temperature.

T2=Cold fluid outlet temperature.

T3= Cold fluid inlet temperature.

T4= Hot water inlet temperature.

3. CONSTRUCTION:

3.1 Manufacturing of heat exchanger:

On 1m length of tube we mount end closure of 3mm thickness and 90mm diameter with 30mm concentric hole at distance of 10cm from one end by brazing.

2 holes of 12.7 mm are drilled on 60mm diameter and 0.8 m length tube at a distance of 10cm from both ends, where female hose nipple of 12.7 mm is welded. Male hose nipples are mounted on female and to this assembly 3mm diameter holes are drilled.

Above assembly is then welded to previously brazed end closure. Then another end closure is welded to outer tube and brazed to inner tube.

Outer tube is insulated by using Glass Wool of 3mm thickness.

4 sensors are installed within the 3 mm holes drilled on both inner and outer pipes at inlet and outlet at respective positions.

3.2 Manufacturing of frame

Frame of Mild steel rods of 900mm x 700mm x 400mm is manufactured by MIG welding process.

3.3 Manufacturing of reservoir

Reservoir of 0.3m x 0.3m x 0.3m is manufactured by Mild Steel sheet with the Cutting, drilling, punching, bending and MIG welding processes respectively. It is Powder Coated to prevent corrosion. Then thermostat and heater is mounted in respective holes.

3.4 Piping

Components like flow control valve, rotameter, are mounted between reservoir and heat exchanger with the help of ½ inch PVC and flexible pipe.

4TESTING AND ANALYSIS

4.1 To compare the Heat transfer coefficient and Effectiveness between water and water based nano fluid(Al_2O_3).

4.1.1 Methodology

Steps 1: Turn ON the main switch and maintain the temperature of each fluid.

Step 2: Turn on the motor .with the help of flow control valve adjust the flow rate to required lpm.

Step 3: Monitor temperature indicator and note down temperature reading till steady state is achieved.

Step 4: Change volume flow rate of cold fluid by control valve and measure it by rotameter.

Step 5: Repeat **Step 3.**

4.1.2 Nomenclature

Cp- specific heat, J/kg K

D- tube diameter, m

U- overall heat transfer coefficient, W/m2 K

m- mass flow rate, L/s

Q- heat transfer, W

T- temperature, °C

V- mean velocity m/sec

Ø- volume concentration, %
ρ- density, kg/m3

4.1.3 Subscripts

v_f- Specific volume m^3 /Kg.

ρ_w- Density of water Kg/m^3.

ρ_p- Density of nano-particle Kg/m^3.

ρ_{nf}- Density of nanofluid Kg/m^3.

ρ_f- Density of base fluid Kg/m^3.

c_{pw}- Specific heat of water KJ/(KgK).

c_{pp}- Specific heat of nano-particle KJ/(KgK).

$(c_p)_{nf}$- Specific heat of nanofluid KJ/(KgK).

$(c_p)_f$- Specific heat of base fluid KJ/(KgK).

m_c- Mass flow rate of cold fluid Kg/Sec.

m_h- Mass flow rate of hot fluid Kg/Sec.

Q_c- Volume flow rate of cold fluid lpm.

Q_h- Volume flow rate of hot fluid lpm.

T_{co}- Outlet temperature of cold fluid °C.

T_{ci}- Inlet temperature of cold fluid °C.

T_{ho}- Outlet temperature of hot fluid °C.

T_{hi}- Inlet temperature of hot fluid °C.

∈- Effectiveness.

4.1.4 Formulae

1. $\rho_{nf}=\rho_f(1\text{-}\Phi)+\Phi\rho_p$

2. (ρc_p)nf $=(1\text{-}\Phi)(\rho c_p)f+\Phi(\rho c_p)\rho$

3. Area of inner tube=πdL

4. $m_c=\rho Q_c$

5. $m_h=\rho Q_h$

6. $\rho_w=\frac{1}{vf}$

7. LMTD=$(\theta_1\text{-}\theta_2)/\ln(\theta_1/\theta_2)$

8. $(m_c c_c)$nf*$(T_{co}\text{-}T_{ci})$nano=U.A.LMTD

9. ∈={[$m_c(T_{in}\text{-}T_{out})$]hot/cold}/[$C_{min}(T_{hi}\text{-}T_{ci})$]

4.2 Observation Tables-

Table. 1 Hot Fluid inlet - Water (45°C) Cold Fluid-Water m_h=2 lpm

Q_c(lpm)	T1(°C)	T2(°C)	T3(°C)	T4(°C)
1	34	43	31	45
1.66	34	43	31	45
2	33	43	31	45
2.5	33	43	31	45
3	32	42	31	45

Table. 2 Hot Fluid inlet -Water (55°C) Cold Fluid-Water m_h=2 lpm

Q_c(lpm)	T1(°C)	T2(°C)	T3(°C)	T4(°C)
1	37	53	31	55
1.66	36	53	31	55
2	35	52	31	55
2.5	34	52	31	55
3	33	52	31	55

Table. 3 Hot Fluid inlet -Water (65°C) Cold Fluid-Water m_h=2 lpm

Q_c(lpm)	T1(°C)	T2(°C)	T3(°C)	T4(°C)
1	40	61	31	65
1.66	38	60	31	65
2	37	60	31	65
2.5	36	59	31	65
3	35	59	31	65

Table. 4 Hot Fluid inlet -Water (55°C) Cold Fluid-0.2% (nanofluid) m_h=2 lpm

Q_c(lpm)	T1(°C)	T2(°C)	T3(°C)	T4(°C)
1	38	53	31	55
1.66	37	53	31	55
2	35	52	31	55
2.5	34	52	31	55
3	33	52	31	55

Table. 5 Hot Fluid inlet -Water (55°C) Cold Fluid-0.4% (nanofluid) m_h=2 lpm

Q_c(lpm)	T1(°C)	T2(°C)	T3(°C)	T4(°C)
1	42	61	31	65
1.66	40	60	31	65
2	38	60	31	65
2.5	37	59	31	65
3	36	58	31	65

4.3 Calculations

For cold water at (31°C);

From steam table v_f (at 31°C)=0.00105 m^3/Kg

$\rho_w=\frac{1}{vf}$=995.0248 kg/m^3

c_{pw} (at 31°C)=4178.2 J/kgK

Nano fluid (0.2%)

$\rho_{nf}=\rho_f(1\text{-}\Phi)+\Phi\rho_p$

ρ_p=3970 kg/m^3

Φ=0.002

$(c_p)_p$=765

ρ_f=ρ_w=995.0248

$(c_p)_w$=$(c_p)_f$=4178.2

ρ_{nf}=995.0248*(1-0.002)+0.002*3970

ρ_{nf}=1000.9748

(ρc_p)nf =(1-Φ)(ρc_p)f+ Φ$(\rho c_p)\rho$

1000.97*(c_p)nf=(1-0.002)(995.0248*4178.2)+(0.002*1000.97*765)=4151.125

Nano fluid (0.4%)

ρ_{nf}=995.0248*(1-0.004)+0.004*3970=1006.9247

1006.9247*(c_p)nf=995.0248*4178.2*(1-0.004)+0.004*1006.92*765

(c_p)nf=4124.34

Area of inner tube=πdL=3.14*0.01*1.3=0.04084 m^2

4.3.1 Sample calculations

For 45°C(0.4% nano fluid)

Reading no.1

Q_c=lpm/(60*10^3)

=1.666*10^{-5} m^3/s

m_c=ρQ_c

=1006.9247*1.666*10^{-5} Kg/s

Q_h=2/(60*10^3)

=3.32*10^{-5} m^3/s

m_h=ρQ_h

=3.32*10^{-5}*990.09

=0.033003 Kg/s

θ_1=Hot water inlet-Cold water outlet

θ_2=Hot water oulet-Cold water inlet

θ_1=45-35=10 °C

θ_2=43-31 =12 °C

LMTD=$(\theta_1$-$\theta_2)$/ln$(\theta_1/\ \theta_2)$

=(10-12)/ln $\left(\frac{10}{12}\right)$

=10.9696 °C

To find overall heat transfer coefficient,

Heat gained by nano fluid=convective heat transfer to nano fluid

$(m_c c_c)$nf*$(T_{co}$-$T_{ci})$nano=U.A.LMTD

69.2155*4=0.04084*U*10.9696

U=$\frac{69.2155*4}{10.9696*0.04084}$

U=617.995 W/m^{2}k

∈={[m_c(T_{in}-T_{out})]hot/cold}/[C_{min}(T_{hi}-T_{ci})]

$(m_h c_h)$=$(\frac{2*10^{-3}}{60})$*990.09*4302

$m_h c_h$=141.978 KJ/Ks

$(m_c c_c)$=$(\frac{1*10^{-3}}{60})$*995.024*1006.9247

$(m_c c_c)$=69.2155 KJ/Ks

$m_h c_h > m_c c_c$

$C_{min} = m_c c_c$

$\in = \{[m*c* (T_{co} - T_{ci})\}/[C_{min}(T_{hi} - T_{ci})]$

$\in = \frac{(T_{co} - T_{ci})}{(T_{hi} - T_{ci})}$

$\in = \frac{(35-31)}{(45-31)}$

$\in = 0.285$

5.1Result Table-

Table. 6 Hot Fluid inlet - Water (45°C) Cold Fluid-Water m_h=2 lpm

Q_c (lpm)	θ_1(°C)	θ_2(°C)	LMTD (°C)	$m_c.c_{pc}$ KJ/Ks	U W/m²k	ε
1	11	12	11.492	69.29	441.3669	0.214
1.66	12	12	12	115.45	469.65	0.214
2	12	12	12	138.58	563.58	0.142
2.5	12	12	12	173.225	704.476	0.142
3	13	11	11.972	207.87	423.67	0.214

Table. 7 Hot Fluid inlet - Water (55°C) Cold Fluid-Water m_h=2 lpm

Q_c (lpm)	θ_1(°C)	θ_2(°C)	LMTD(°C)	$m_c.c_{pc}$ KJ/Ks	U W/m²k	ε
1	18	22	19.93	69.29	595.51	0.25
1.66	19	22	20.46	115.45	690.73	0.208
2	20	21	20.46	138.58	662.664	0.166
2.5	21	21	21	173.225	605.93	0.125
3	22	21	21.49	207.87	475.65	0.125

Table. 8 Hot Fluid inlet - Water (65°C) Cold Fluid-Water m_h=2 lpm

Q_c (lpm)	θ_1(°C)	θ_2(°C)	LMTD(°C)	$m_c.c_{pc}$ KJ/Ks	U W/m²k	ε
1	25	30	27.424	69.29	556.746	0.264
1.66	27	29	27.988	115.45	707.467	0.205
2	28	29	28.497	138.58	741.079	0.176
2.5	29	28	28.497	173.225	743.80	0.176
3	30	28	28.98	207.87	720.73	0.176

Table. 9 Hot Fluid inlet -Water (55°C) Cold Fluid-0.2 %(nanofluid) m_h=2 lpm

Q_c (lpm)	θ_1(°C)	θ_2(°C)	LMTD(°C)	$m_c.c_{pc}$ KJ/Ks	U W/m²k	ε
1	17	22	19.39	69.0539	612.08	0.2916
1.66	18	22	19.93	115.083	708.90	0.25
2	20	21	20.49	138.10	661.868	0.166
2.5	21	21	21	172.625	604.73	0.125
3	22	21	21.49	207.151	473.305	0.125

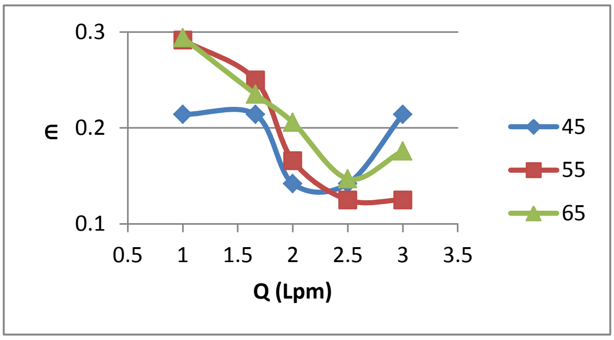
Table. 10 Hot Fluid inlet -Water (55°C) Cold Fluid-0.4% (nanofluid) m_h=2 lpm

Q_c (lpm)	θ_1(°C)	θ_2(°C)	LMTD(°C)	$m_c.c_{pc}$ KJ/Ks	U W/m²k	ε
1	16	22	18.84	69.2155	719.619	0.33
1.66	18	21	19.46	115.3	870.8	0.2

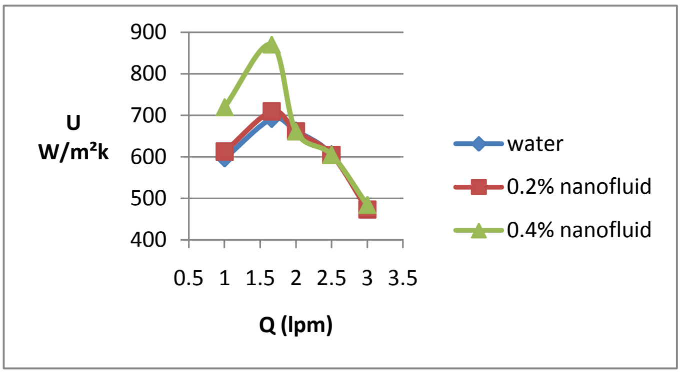
				59	45	15
2	20	21	20.49	138.431	661.515	0.166
2.5	21	21	21	173.038	605.281	0.125
3	22	20	20.98	207.646	484.592	0.166

5.2 GRAPHS

Graph. 1-Variation of effectiveness at different volumetric flow rate of cold water and different temperatures of hot water (45°C,55°C,65°C).(From result table 1,2,3)



Graph. 2-Variation of overall heat transfer coefficient at different volumetric flow rate of water, 0.2% nanofluid and 0.4% nanofluid at 55°C temperature of hot water. (From result table 3,4,5)



DISCUSSION

The effectiveness of heat exchanger decreases upto 2 to 2.5 lpm as seen from effectiveness vs Q (lpm) graphs. The reason for this trend is decrease in temperature drop of cold fluid and $m_h c_h > m_c c_c$. Hence, $C_{min} = m_c c_c$.The effectiveness of heat exchanger begins to increase after 2 to 2.5 lpm or remains constant.The reason for this trend is $m_h c_h < m_c c_c$. Hence, $C_{min} = m_h c_h$.

The effectiveness of heat exchanger is found to increase with increase in concentration of nano fluids. This happens because temperature gain of cold fluid and temperature drop of hot fluid increases with increase in concentration of nano fluid.

The temperature drop of hot fluid and temperature gain of cold fluid increases with increase in inlet temperature of hot fluid. Hence, the effectiveness is found to increase with increase in inlet temperature of hot fluid.

The rate of increase of temperature gain of cold fluid is greater than the rate of increase of LMTD with increase in temperature. Hence, the value of overall heat transfer coefficient increases with increase in inlet temperature of hot fluid.

At low volume flow rates (upto 2 lpm), the overall heat transfer coefficient increases with increase in concentration of nano fluid.This is because the temperature gain of cold fluid is significant at low volume flow rates as compared to higher volume flow rate

CONCLUSION

From graphs we have concluded that,

Effectiveness increases with increase in temperature.

As mass flow rate increases, effectiveness decreases up to certain limit and increases or remains constant.

Effectiveness increases with increase in nano fluid concentration.

Overall heat transfer coefficient increases with increase in temperature.

As mass flow rate increases, overall heat transfer coefficient increases up to certain limit and decreases up to certain point, then increases or remains constant.

Overall heat transfer coefficient increases with increase in nano fluid concentration.

Overall heat transfer coefficient is more at low mass flow rates of nano fluid as compared to water. Whereas, at high mass flow rates the overall heat transfer coefficient of nano fluid is similar to that of water.

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