Design and Analysis of Hair Pin Heat Exchanger using TiC, MgO, Ag/Water-Glycerin Nano Fluids

MLR Chaitanya Lahari[1]
Assistant Professor
Dept. of Mechanical Engineering
Malla Reddy College of Engineering & Technology
Hyderabad. Telangana., India.

Harish Makena[2]
PG Scholar (Machine Design)
Dept. of Mechanical Engineering
Malla Reddy College of Engineering & Technology
Hyderabad. Telangana. India.

Dr. PHV Sesha Talpa Sai[3]
Professor & HOD
Dept. of Mechanical Engineering
Malla Reddy College of Engineering & Technology
Hyderabad. Telangana, India.

Dr. K.S. Narayana Swamy[4]
Professor & Director
School of Mechanical Engineering
REVA University
Bangalore, Karnataka, India.

***Abstract*—Heat Transfer Enhancement or intensification is one of the most important technical challenges faced by numerous industries like manufacturing, automobiles, etc. It is one of the key factors in heat exchangers design while working to design the compact devices. The requirement of the compact heat exchangers like hair pin heat exchanger is very concern where the heat transfer area is low. The conventional methods of cooling like fins and micro channels have already extended to their limits. As the traditional fluids of heat transfer such as water, oil and ethylene glycol are innately poor heat transfer fluids, the new technique of dispersing the nano particles in the base fluid called nano fluids have emerged in enhancing the heat transfer rate**.

This paper presents the analytical investigations are carried on the hair pin heat exchanger using forced convective heat transfer. Three different types of nano particles TiC, MgO and Ag individually at different volume concentrations of 0.1%, 0.3%, 0.5%, 0.8% using water and glycerin as base fluid were used. The fluid flow is considered to be turbulent. CFD analysis is performed on the hair pin heat exchanger by applying the properties of the above nano fluid concentrations to obtain the heat transfer coefficient and heat transfer rate. For this a 3D model of the heat exchanger is done in CREO 3.0 and imported to the ANSYS(FLUENT).Theoretical calculations were carried to obtain the properties for nano fluids which are used as inputs for analysis. From the results it was found that the Ag/water-glycerin nano fluid shows the best heat transfer rate compared with the other two nano fluids

Keywords*— *Convective Heat Transfer, Hair pin Heat Exchanger, Nano fluids, Turbulent, CFD Analysis, Heat Transfer Coefficient, Heat transfer Rate.

I. INTRODUCTION

Heat Exchangers are the devices which are used to transfer the thermal energy between hot fluid and the cold fluid with maximum rate. Typical applications of heat exchangers include condensers and evaporators used in air conditioning units and refrigerators in daily life. The industrial applications involve the boilers and condensers in thermal power, in the form of radiators and oil coolers in automobiles. They are abundant in chemical and process industries. They are named in different manners based on the purpose of utility. For example, if they are being used to condense the fluids then they are known as condensers, for boiling purpose they are known as boilers.

There many types of heat exchangers inexistence according to their application or the features. The single pass double tube heat exchanger is one such kind which is classified according to the flow of the fluid. And also these double tube heat exchangers are of many kinds like spiral, hair pin etc.,

A hairpin heat exchanger can be described as a single-pass shell-and-tube heat exchanger that is bent at the half to give a hair pin appearance or a U shape. It is distinguished with its closures from the traditional shell-and-tube heat exchanger. They are allowed for a removable tube bundle and accommodate thermal expansion without expanding or packed joints. In addition to countercurrent flow, heat exchangers used with hairpin designs can increase heat transfer coefficients.

Hairpin heat exchangers offer the following advantages of both mechanical and maintenance engineer with their design. The advantages include such things as:

- Independent tubesheets for high terminal temperature differences.
- Thermal shock.
- Cycling.
- Long radius U-bends for effective thermal expansion.
- High temperature differences.
- Ease of cleaning.
- All-welded baffle cages for durability.
- High pressure closures for pressures up to 10,000 psi.
- No internal bolting.

Heat Transfer Enhancement

The Heat Transfer Enhancement or intensification can be defined as the way to improve heat transfer performance. It is one of the key factors in heat exchangers design while working to design the compact devices.
The hat transfer enhancement techniques are broadly classified into three:

- Active method

The method which involves some external power in intensifying the heat transfer is known as active method. It has not shown much potential due its complexity in design. The induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc. are some examples of Active method.

- Passive method

The method which does not use any external power input in intensifying the heat transfer but the additional power needed to do so is taken from the power available in the system is termed as the passive method. Some examples of passive method of intensification are Treated surfaces, Rough surfaces, Extended surfaces, Displaced enhancement devices, Swirl flow devices coiled tubes surface tension devices, Additives for fluids.

Mechanisms of Heat Transfer Intensification

There are a wide number of mechanisms developed by the researchers that are mentioned below. As per the authors one of the following mechanisms can be used or the heat transfer intensification

1) Use of a secondary heat transfer surface
2) Disruption of the unenhanced fluid velocity
3) Disruption of the laminar sublayer in the turbulent boundary layer.
4) Introducing secondary flows
5) Promoting flow attachments/reattachment
6) Promoting boundary layer separation
7) Enhancing effective thermal conductivity of the fluid under static conditions
8) Enhancing effective thermal conductivity of the fluid under dynamic conditions
9) Delaying the boundary layer development
10) Thermal dispersion
11) Redistribution of the flow
12) Increasing the order of the fluid molecules
13) Modification of radiative property of the convective medium
14) Increasing the difference between the surface and fluid temperature
15) Increasing the fluid flow rate passively
16) Increasing the thermal conductivity of the solid phase using special nanotechnology fabrications

Among the above, mechanisms 7 to 13 are associated with fully or partially filing the fluidic volume by the porous medium.The above mentioned mechanisms cannot be achieved without the presence of the enhancing elements. These elements are known as "heat transfer enhancers".

Heat Transfer Enhancement using Nano Fluids

It is a new kind of heat transfer technique in which the nano fluids containing nano sized particles which are uniformly and stably dispersed in the base fluid. Generally a high thermally conductive materials like metals, metal oxides and carbides mixes with the base fluids like water, ethylene glycol, oil, and glycerol to improve the overall thermal conductivity. The nano sized particles are usually of 100nm or less in order. The effective thermal conductivity of the fluids increases by the suspensions of nano particles in the nano fluids. The basic structure of the nanofluids can be demonstrated as shown in the Figure where it can be defined that the nano fluid is a mixture if a base fluid and nano particle.

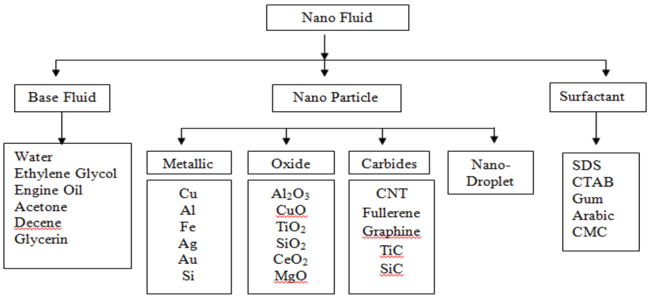


Fig.:1 Basic Structure of the Nano fluid

II. LITERATURE REVIEW

Heris et al., (2007)[1] presented an investigation of the laminar flow convective heat transfer of Al_2O_3- water under constant wall temperature with 0.2 to 2.5 vol.% of nanoparticle for Reynolds number varying between 700 to 2050. They presented again the Nusselt number for the nano fluid which is greater than the base fluid.

Ho et al., (2010)[2] conducted an experiment for cooling in horizontal tube in laminar flow Al_2O_3- water and 1 and 2 vol.% concentrations and concluded the interesting enhancement of 51% in heat transfer coefficient.

Xie et al., (2010) [3] reported the convective heat transfer enhancement of nano fluids as coolants in laminar flows inside a circular copper tube with constant wall temperature. Different nano fluids consisting of Al_2O_3, ZnO, TiO_2 and MgO nanoparticles were prepared with a mixture of 55 vol.% distilled water and 45 vol.% EG as base fluid. MgO, Al_2O_3 and ZnO nano fluids exhibited superior enhancements of heat transfer coefficient, with the highest enhancement up to 252% at a Reynolds number of 1000 for MgO nano fluid.

Salman et al., (2013) [4] reported that SiO_2-EG nanofluid has the highest Nusselt number, followed by ZnO-EG, Cu-EG, Al_2O_3-EG, and lastly purely EG. The Nusselt number for all cases increases with the volume fraction but it decreases with the rise in diameter of nano particles.

The maximum Nusselt number is the main target of such research. Many other researchers such as Nguyen et al., (2007), Sharma et al., (2009), [5] have also studied on the convective heat transfer performance and pressure drop of using various size and concentration of nano particles flowing in various size and dimension of double tube heat exchangers.

Measurements showed that heat transfer coefficient increases significantly with different size and concentration of nano particles.

Dhiraj Tiwar (2015) [6] investigated effects of temperature and fow characteristics on a orizontal double tube counter flow heat exchanger under turbulent flow with Al_2O_3 nano fluid. The results shows that the convective heat transfer coefficient of nano fluid slightly higher than that of the base liquid at same mass flow rate. At same inlet temperature, heat transfer coefficient of the nano fluid increases in the mass flow rate, also the heat transfer coefficient increases with the increase of the volume concentration of the Al_2O_3 nano fluid.

M Kumar (2015) [7] conducted experiments on the enhancement of heat transport in laminar and turbulent flow of varying composition of ethylene glycol mix with water in double tube hair-pin heat exchanger. Obtained results indicated that the heat transfer coefficient os a mixture of ethylene glycol and water increases with Reynolds number and ethylene glycol concentration.

Pak and Cho(1998) [8] presented an experimental investigation of the convective turbulent heat transfer characteristics of nanofluids(Al_2O_3-water and TiO_2-water) with 1-3 volume percent.

Choi et al., (2008) [9] showed that nano fluids have the potential to be the next generation of coolants for vehicle thermal management due to their significantly higher thermal conductivities. Several researchers showed that convective heat transfer coefficient increases substantially for nano fluids. The heat rejection requirements of automobiles and trucks are continually increasing due to trends toward more powerful outputs.

Mushtaq et al., investigated the effect of channels geometry (the size and shape of channels) on performance of counter flow micro channel heat exchanger and used liquid water as a cooling fluid. They found that the effectiveness of heat exchanger and pressure drop were increased by decreasing the size of channels and claimed depending on the application of which type of heat exchanger is used.

III. PROBLEM FORMULATION

In our study we considered the double tube U shaped heat exchanger or hair pin heat exchanger. As it has a high heat transfer coefficient and rate. For simplification of heat transfer analysis in practical way, the virtual simulation using CFD method is chosen with different nano fluid mixtures like TiC, MgO, and Silver at different weight ratios of 0.1, 0.3, 0.5, 0.8 with the base fluid as water and glycerin. For this the experimental model of a hair pin heat exchanger(Test Section) is considered as shown in the fig. the schematic diagram of the experimental setup consists of a hair pin heat exchanger., hot fluid reservoir, cold fluid reservoir, manometer, centrifugal pumps. For this study we consider only the test section. In which the effective length of double tube Hair-pin heat exchanger across which heat is being transferred is 450 mm. The perimeter of U-type return bend is 90 mm. This test section is being operated in counter flow manners with cold stream flowing inside the tube is made of copper material with 9.5 mm outer diameter (d_o) and 8.43 mm inner diameter (d_i), while the outer tube is made of Galvanized Iron has 22 mm outer diameter (D_o) and 19.05 mm inner diameter (D_i). And a mixture is water and glycerin in 60:40 ratio by volume is considered as the base fluid in which different nano materials(TiC, MgO, Silver) are used as additives in different volume fractions of 0.1,0.3,0.5,0.8 to make nano fluid mixture which is used as cold fluid. The hot fluid (water) at 70^0C is continuously made to flow at a constant flow rate of 3lit/min in annulus.

Basic Assumptions

- Flow through the hair pin heat exchanger is considered as Turbulent Flow.
- Steady state heat transfer conditions were assumed.
- Natural convention and Radiation is neglected.
- Conjugate heat transfer between the two fluids is considered.
- Counter flow heat exchanger is considered.

Calculations of the Nano Fluid

The calculations of nanofluid include the density, Specific heat, Viscosity, Thermal Conductivity of the fluid. These are obtained by substituting the properties of each nano particle namely TiC, MgO, Ag mixed with the base fluid which is the mixture of both water and glycerin.

i. Density

$$\rho_{nf} = \emptyset \text{ x } \rho_s + [(1-\emptyset) \text{ x } \rho_w] \quad (3.1)$$

ii. Specific Heat

$$C_{p\,nf} = \frac{\emptyset \text{ x } \rho_s x C_{ps} + (1-\emptyset)(\rho_w \text{ x } C_{p\,w})}{\emptyset \text{ x } \rho_s + (1-\emptyset) x \rho_w} \quad (3.2)$$

iii. Viscosity

$$\mu_{nf} = \mu_w(1+2.5\emptyset)$$

iv. Thermal Conductivity

$$K_{nf} = \frac{K_s + 2K_w + 2(K_s - K_w)(1+\beta)^2 x \emptyset}{K_s + 2K_w - 2(K_s - K_w)(1+\beta)^2 x \emptyset} \text{ x } K_w$$

NOMECLATURE

ρ_{nf} = Density of nano fluid(kg/m^3)
ρ_s = Density of solid material(kg/m^3)
ρ_w = Density of Fluid material(water-glycerin)(kg/m^3)
$\emptyset$ = Volume Fraction
μ_w = Viscosity of Fluid(water-glycerin)(kg/m-s)
μ_{nf} = Viscosity of Nano Fluid(kg/m-s)
C_{pw} = Specific heat of fluid material(water-glycerin)(j/kg-k)
C_{ps} = Specific heat of Solid material (j/kg-k)
K_w = Thermal conductivity of fluid material(water-glycerin)(W/m-k)
K_s = Thermal conductivity of Solid material(W/m-k)

IV. MODELING AND CFD ANALYSIS

Considering all the parameters in the concept of Creo, the modeling of heat exchanger is mentioned in this section in a detailed way. The modeling of the heat exchanger is done according to the requirement of the design.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 01, January-2018

Table:1 Dimensions of the Hair Pin Heat Exchanger

Outer pipe specification	Inner tube specification
Galvanized iron pipe	Copper Tube of U bend
I.D of shell = 19.05 mm	I.D of tube = 8.4 mm
Galvanized iron pipe	Copper Tube of U bend
I.D of shell = 19.05 mm	I.D of tube = 8.4 mm
O.D of shell = 22 mm	O.D of tube = 9.5 mm
Center to center distance is taken	Wall thickness = 0.55 mm
1.5 – 1.8 times of outer dia of shell	Thermal conductivity of wall = 385 w/m^2K
Length of G.I pipe = 228.6 mm	Effective length of copper tube through which heat transfer could take place = 450 mm
Total length of the copper tube = straight part (510 mm) + U- Shaped bend part (90 mm) = 600 mm	

Using the above dimensions indicated in the Table, the modeling of Hair-Pin Heat exchanger has been done in the Part module as individual parts namely Inner tube and the Outer Tube with an overall length of 600mm and the outer shell with length of 228.6mm and then assembled in the assembly module in the CREO software that is shown in the Figure2.

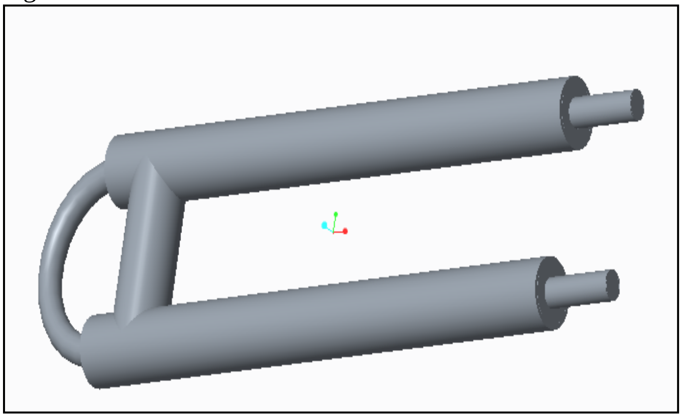


Figure:2 3D model of hair pin heat exchanger

After modeling in the Creo Software the test section is imported by the FLUENT for the analysis of the fluid flow to obtain the required results like Heat Transfer Coefficient and the Heat Transfer Rate. This analysis is carried out using the Energy and the continuity equations.

V. RESULTS AND DISCUSSIONS

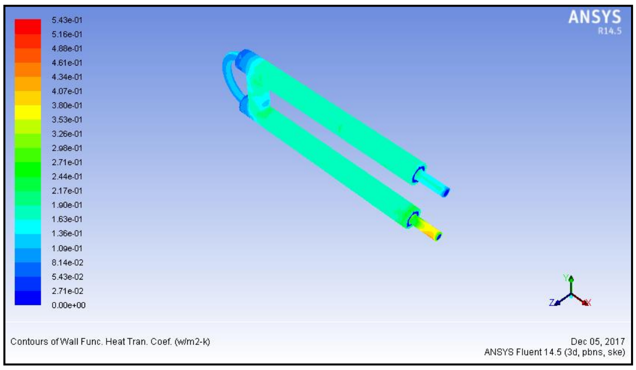
The Analysed results are figured out in terms of contours and are also tabulated as shown below.

NanoFluid: TiC/Water-glycerin

The below contours shows the heat transfer coefficient of the hair pin heat exchanger using the TiC/ water-glycerin as the nano fluids at different volume fractions. All the respective results are mentioned for the above said nano fluid at different volume fractions namely 0.1 0.3,0.5, 0.8%. The below stated results explain about the how the heat transfer rate is varied with change in the volume of the nano particle in the based fluid.

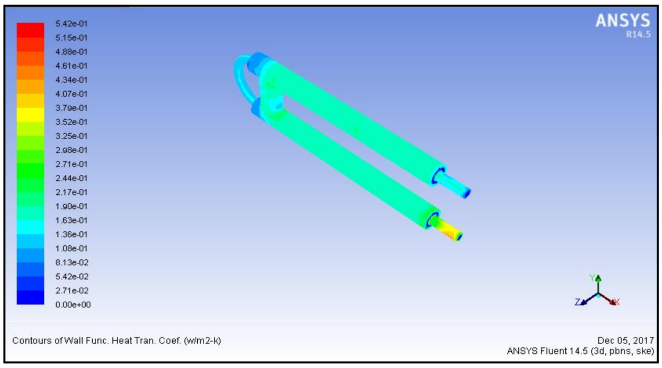
Volume Fraction: 0.1%

Heat Transfer Coefficient



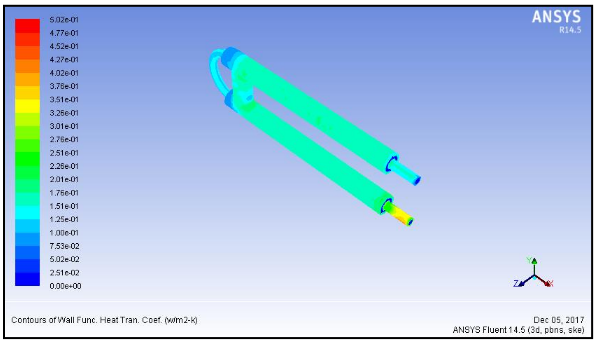
Volume Fraction: 0.3%

Heat Transfer Coefficient



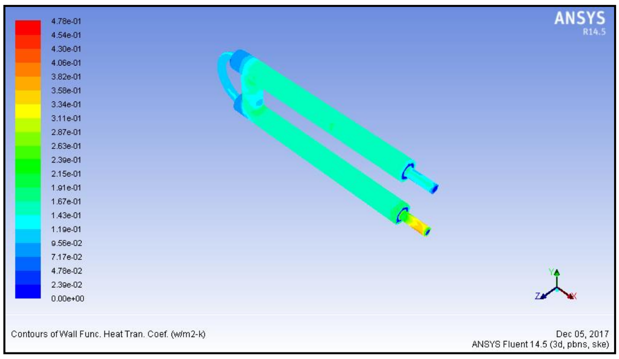
Volume Fraction: 0.5%

Heat Transfer Coefficient



Volume Fraction: 0.8%

Heat Transfer Coefficient



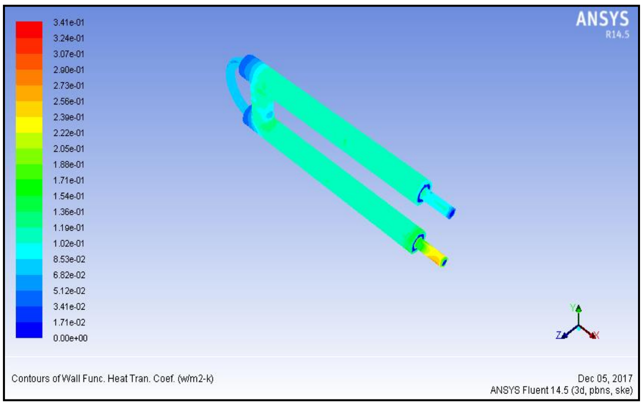
NanoFluid: MgO/Water-glycerin

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 01, January-2018

The below contours shows the heat transfer coefficient of the hair pin heat exchanger using the MgO/ water-glycerin as the nano fluids at different volume fractions. All the respective results are mentioned for the above said nano fluid at different volume fractions namely 0.1 0.3,0.5, 0.8%. The below stated results explain about the how the heat transfer rate is varied with change in the volume of the nano particle in the based fluid.

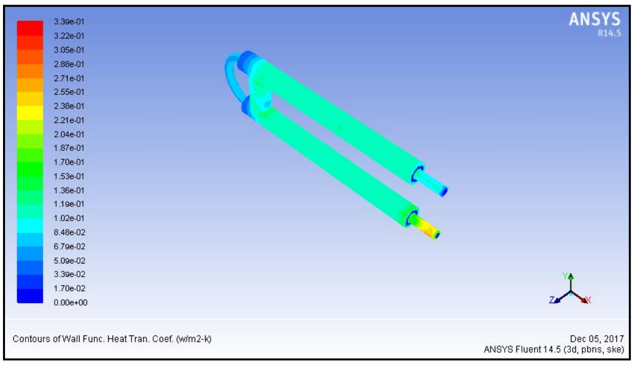
Volume Fraction: 0.1%

Heat Transfer Coefficient



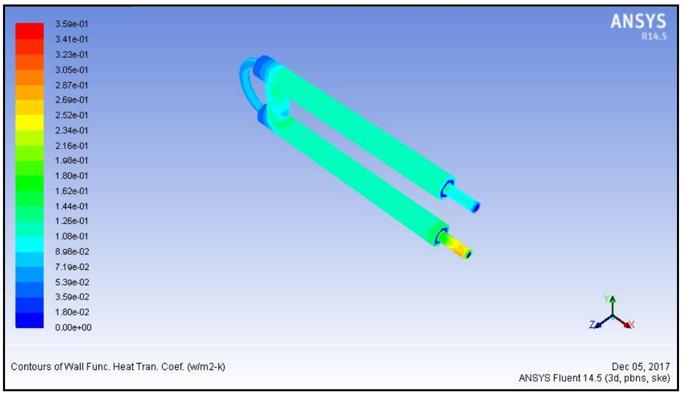
Volume Fraction: 0.3%

Heat Transfer Coefficient



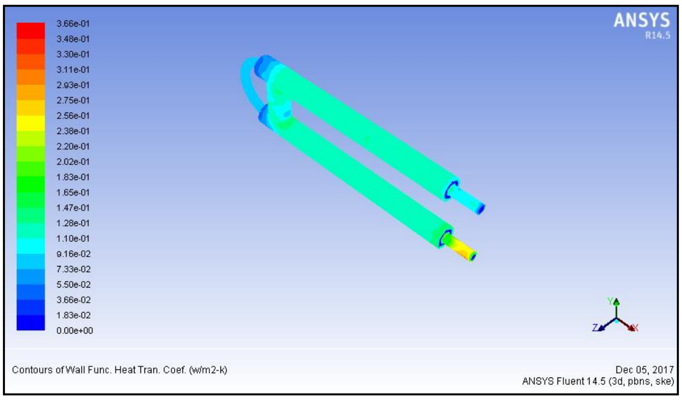
Volume Fraction: 0.5%

Heat Transfer Coefficient



Volume Fraction: 0.8%

Heat Transfer Coefficient

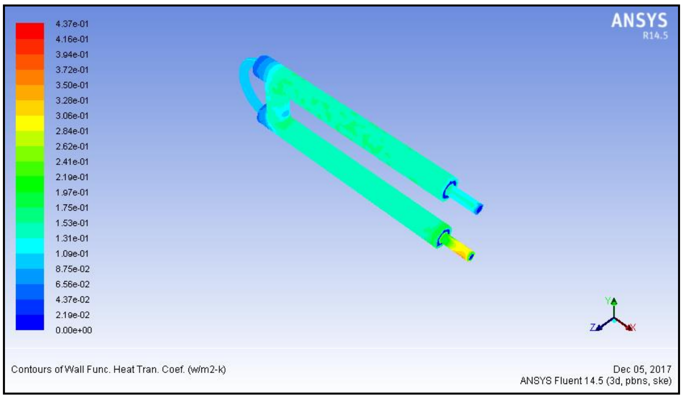


NanoFluid: Ag/Water-glycerin

The below contours shows the heat transfer coefficient of the hair pin heat exchanger using the Ag/ water-glycerin as the nano fluids at different volume fractions. All the respective results are mentioned for the above said nano fluid at different volume fractions namely 0.1 0.3,0.5, 0.8%. The below stated results explain about the how the heat transfer rate is varied with change in the volume of the nano particle in the based fluid.

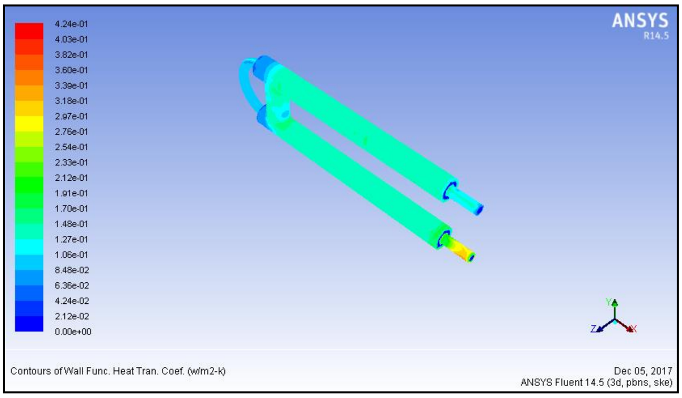
Volume Fraction: 0.1%

Heat Transfer Coefficient



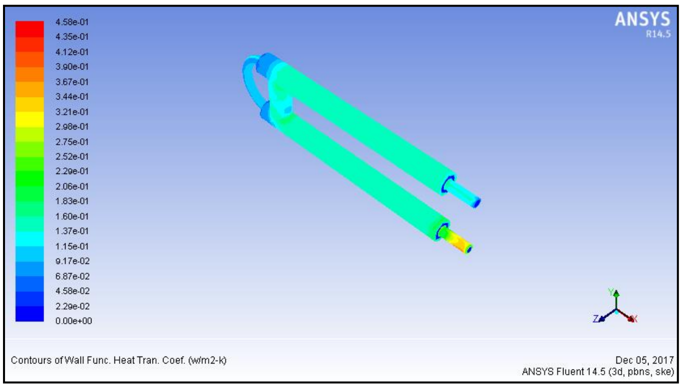
Volume Fraction: 0.3%

Heat Transfer Coefficient



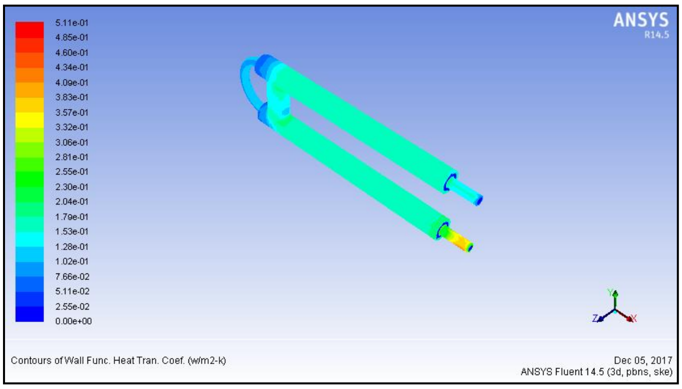
Volume Fraction: 0.5%

Heat Transfer Coefficient



Volume Fraction: 0.8%

Heat Transfer Coefficient



Result Tables

The above obtained results are tabulated according to the nano fluid volume fraction. The below show table gives the detailed results of the heat transfer coefficient and the heat transfer rate at different volume fractions of different nano fluids. By observing the results tabulated, it can be concluded that the heat transfer rate in the Ag/water-glycerin nano fluid is being increased uniformly compared with the other two fluids. The below Graphs I & II compares the Heat Transfer Coefficient and the Heat Transfer Rate for the TiC, MgO and Ag Nano fluids at different Volume Fraction. The below comparison it observed that the Ag/water-glycerin nano fluid shows very high heat transfer rate when compared to the other two fluids at a volume fraction of 0.8%.

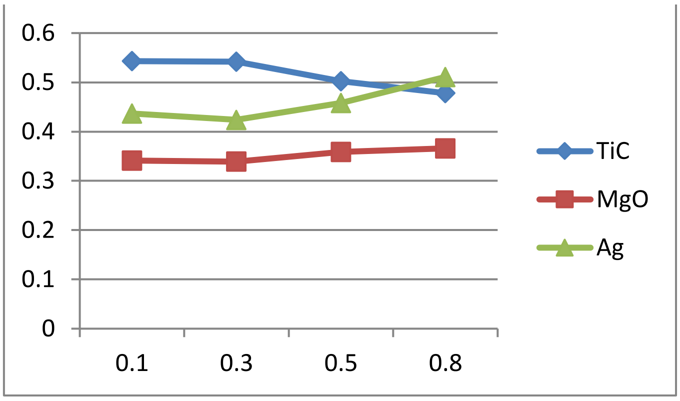
Table:II Dimensions of the Hair Pin Heat Exchanger

Fluid	Heat transfer coefficient (w/m2-k)	Heat transfer rate(W)
Tic (0.1%)	5.43e-01	4249.3604
Tic (0.3%)	5.42e-01	1501.1453
Tic (0.5 %)	5.02e-01	866.03149
Tic (0.8%)	4.78e-01	2116.966
MgO (0.1%)	3.41e-01	1870.842
MgO (0.3%)	3.39e-01	5086.1448
MgO (0.5 %)	3.59e-01	5267.2834
MgO (0.8%)	3.66e-01	2363.6135
Silver (0.1%)	4.37e-01	1194.8652
Silver (0.3%)	4.24e-01	2254.1187
Silver (0.5 %)	4.58e-01	5029.21
Silver (0.8%)	5.11e-01	11198.48

From the above Table II it was observed that all the three nano fluids shows appreciable values of heat transfer out of which the MgO/water-glycerin nano fluid has an increasing heat transfer whereas it takes a negative direction of enhancement from 0.5 volume fraction due to increment in the viscosity

The Graph I indicates the same as mentioned above regarding the Three nano fluids in respect to heat transfer enhancement.

Graph I : Comparison of Heat Transfer Coefficient at different volume fractions.



VI. CONCLUSIONS

The analytical investigations that are carried on the hair pin heat exchanger using forced convective heat transfer are obtained with the results related to the three different types of nano particles TiC, MgO and Ag individually at different volume concentrations of 0.1%, 0.3%, 0.5%, 0.8% using water and glycerin as base fluid were used. The fluid flow is considered to be a turbulent one. CFD analysis is performed on the hair pin heat exchanger by applying the properties of the above nano fluid concentrations to obtain the heat transfer coefficient and heat transfer rate. For this a 3D model of the heat exchanger is done in CREO 3.0 and imported to the ANSYS(FLUENT).Theoretical calculations were carried to obtain the properties for nano fluids which are used as inputs for analysis.

From the results it was observed that all the three nano fluids shows appreciable values of heat transfer out of which the MgO/water-glycerin nano fluid has an increasing heat transfer whereas it takes a negative direction of enhancement from 0.5 volume fraction due to increment in the viscosity. Comparing all the results the Ag/water- glycerin nano fluid shows the best heat transfer rate compared with the other two nano fluids.

The above work can be utilized as the preliminary test that can be performed on the virtual heat exchanger as the experimentation process is not an economic. So hoping that this work becomes base of enhancing the heat transfer.

REFERENCES

[1] S. Zeinali Heris, M. Nasr Esfahany, and S. G. Etemad, “Experimental investigation of convective heat transfer of Al2O3/water nanofluid in circular tube,” *Int. J. Heat Fluid Flow*, vol. 28, no. 2, pp. 203–210, 2007.

[2] C. J. Ho, L. C. Wei, and Z. W. Li, “An experimental investigation of forced convective cooling performance of a microchannel heat sink with Al2O3/water nanofluid,” *Appl. Therm. Eng.*, vol. 30, no. 2–3, pp. 96–103, 2010.

[3] T. Yousefi, F. Veisy, E. Shojaeizadeh, and S. Zinadini, “An experimental investigation on the effect of MWCNT-H 2O nanofluid on the efficiency of flat-plate solar collectors,” *Exp. Therm. Fluid Sci.*, vol. 39, pp. 207–212, 2012.

[4] B. H. Salman, H. A. Mohammed, K. M. Munisamy, and A. S. Kherbeet, “Characteristics of heat transfer and fl uid fl ow in microtube and microchannel using conventional fl uids and nano fl uids : A review,” vol. 28, pp. 848–880, 2013.

[5] K. V Sharma, L. S. Sundar, and P. K. Sarma, “Estimation of heat transfer coef fi cient and friction factor in the transition fl ow with low volume concentration of Al 2 O 3 nano fl uid fl owing in a circular tube and with twisted tape insert ☆,” *Int. Commun. Heat Mass Transf.*, vol. 36, no. 5, pp. 503–507, 2009.

[6] D. Tiwari and P. A. Paul, “Experimental Study On Heat Transfer Enhancement By Using Water – Alumina Nanofluid In A Heat Exchanger,” vol. m, no. 4, pp. 192–200, 2015.

[7] M. Kumar, V. K. Yadav, B. Verma, and K. K. Srivastava, “Experimental Study of Friction Factor During Convective Heat Transfer in Miniature Double Tube Hair-pin Heat Exchanger,” *Procedia Technol.*, vol. 24, no. 2001, pp. 669–676, 2016.

[8] B. C. Pak and Y. I. Cho, “Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles,” *Exp. Heat Transf.*, vol. 11, no. 2, pp. 151–170, 1998.

[9] Eastman, J.A, Choi, S.U.S.,Li, S.; Yu, W.; Thomson L.J., (2001). Anonalously increased effective thermal conductivities of ethylene glycol based nanofluids contaiining copper nanoparticles. Applied Physics Letters; 78,718-20.

[10] Hari Haran, Ravindra Reddy and Sreehari,“Thermal Analysis of Shell and Tube Heat Exchanger Using C and Ansys”, International Journal of Computer Trends and Technology (IJCTT) –volume 4 Issue 7–July 2013.

[11] R.H Perry. 1984. Perry's Chemical Engineer’s Handbook (6th Edition ed.). McGraw-Hill. ISBN 0-07-049479-7

[12] Ender Ozden, Ilker Tari, “Shell Side CFD Analysis of A Small Shell And Tube Heat Exchanger”, Middle East Technical University,2010.

[13] V. K. Yadava et al, ”Experimental study of friction factor during convective heat transfer in miniature double tube Hair-pin heat exchanger”, ICETEST – 2015

[14] Rajagapal Thundil Karuppa Raj and Srikanth GANNE, “Shell side numerical analysis of a shell and tube heat exchanger considering the effects of baffle inclination angle on fluid flow”, ,THERMAL SCIENCE: Year 2012, Vol. 16, No. 4, pp. 1165-1174.