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A Comparative Study and Analysis of Thermal Distribution in Heavy Duty Track Radiator Using Nano Fluids

KEYWORDS: Base Fluids, FLUENT 6.3(CFD), Heat Flux Wall, Heat Transfer, Nano Fluids, Radiator

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ABSTRACT *The cooling nature of the automobile radiators in the presence of some coolants (water, ethylene glycol) has been investigated in the process of heat transfer enhancement process with Nano particles (Aluminum, copper). In order to analyze the thermal conductivity of the base fluid and nano fluid FLUENT 6.3 software is used. The nano fluids and the base fluids are analyzed and also a comparative work is done between the thermal conductivity models under the same Reynolds number, Maxwell, Hamilton and Crosser,Jeffrey, Davis, Bruggeman and Suresh models. The modeling section chosen for the project work is a uniform heated tube of radius 25.4mm and length 1000mm. The modeling work is done in ANSYS WORKBENCH 11.0 software. GAMBIT 2.2.30 and FLUENT 6.3(CFD) is used to construct and mesh models by means of its graphical user interface (GUI). Meshing is an integral part of the Computer-Aided Engineering (CAE) simulation process.*

Introduction:
Many researches are carried out to improve the heat transfer rate of base fluids using nano fluids. VisineeTrisakri [1] shows the use of additives is a technique applied to enhance the heat transfer performance of base fluids. The suspended metallic or non-metallic nanoparticles change the transport properties and heat transfer characteristics of base fluid. Eastman Et.Al [2] showed that 10mm copper particles in ethylene glycol could enhance the conductivity by 40% with small particle loading fraction. This results clearly show the effect of particle size on the conductivity enhancement. Das Et.Al [3] measured the conductivities of alumina and cupric oxide at different temperature ranging from 200°C to 500°C and found linear increase in the conductivity ratio with temperature. Lee et al. [4] (1999) reported a substantial enhancement of thermal conductivity of water and ethylene glycol based nano- fluids with Al2O3 or Cu nano-particles. In present authors have shown that the enhancement of thermal conductivity of nano fluids increases even more at elevated temperature which makes it more attractive for cooling at high heat flux applications [3]. This enhancement of thermal conductivity received an impressive breakthrough when Eastman et al. (2001) reported an increase of thermal conductivity by an outstanding 40% with only 0.04% of nano-particles of pure copper having average size less than 10 nm. [2] The above works indicate that usual theories of thermal conductivity of suspensions such as the Hamilton and Crosser (1962) model fail in case of nano- fluids. Pak and Cho [5] studied the heat transfer performance of Al2O3 and TiO2nano particles suspended in water and expressed that convective heat transfer coefficient is 12% smaller than that of pure water at 3% volume fraction. Yulong Ding [6] concludes that at given particle concentration and flow conditions aqueous based carbon nano tube nano fluids gives the highest enhancement of convective heat transfer coefficient followed by aqueous based titania nano fluids, aqueous based alumina nano fluids. Eden mamut [7] shows simple empirical correlationo predict thermal conductivity of Al2O3+H2O, Al2O3+ethylene glycol, Cu+ H2O, TiO2+ H2O and TiO2+ethylene glycol nano fluid mixtures considering the effect of temperature, volume fraction and particle size is presented and good agreement with experimental results. Wen.d. and Ding.y. [8] shows Laminar heat transfer in the entrance region of a tube flow that was using alumina water nano fluids was the focus of the work; viscosity of nano fluid was not measured and was assumed to follow the Einstein equation. For nano fluids that contained 1.6% nano particles by volume, the local heat transfer coefficient at the entrance region was 41% higher than at the base fluid with same flow rate. So it was observed that the enhancement is particularly significant in the entrance region and decreases with axial distance. The thermal developing length of nano fluids was greater than that of the pure base liquid and increased with an increase in particular concentration. Conventional fluids such as water, ethylene glycol are normally used as heat transfer fluids. Based on the reference taken the research work has been done and comparison between nano particles to enhance the cooling effect of the radiators and finally high efficiency is obtained with liquid sodium nano particle.

ANALYSING TECHNIQUES:

1. THERMAL AND PHYSICAL PROPERTIES OF NANO-PARTICLES AND BASE FLUIDS:
The thermal conductivity measurement of nano fluids was the main focus in the early stages of nano fluid research. Recently studies have been carried out on the heat transfer coefficient of nano fluids in natural and forced flow. Most studies carried out to date are limited to the thermal characterization of nano fluids without phase change. However, nano particles in nano fluids play a vital role in two-phase heat transfer systems and there is a great need to characterize nano fluids in boiling and condensation heat transfer. In any case the heat transfer coefficient depends not only on the thermal conductivity but also on the other properties such as the specific heat, density and dynamic viscosity of a nano fluid. The thermo physical properties of nano particles are listed in the table I and thermo physical properties of the base fluids are listed in table II.

S. No	Property	Aluminum	Copper	Silver
1	Thermal conductivity (K_S)W/mK	237	400	429
2	Density (ρp) kg/m^3	2710	8933	10500
3	Specific heat (C_P) J/kg K	900	385	234

Table I- Properties of nano particles

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S.No	Property	Water	Liquid Sodium	Ethylene glycol
1	Thermal conductivity (K_L) W/Mk	0.605	76	0.252
2	Density (ρp)kg/m³	997.1	880	1111
3	Specific heat (Cf) J/kg-K	4179	1300	2415
4	Dynamic viscosity (μ_0) Kg/m³	0.001003	0.34	0.0157

Table II-Properties of base fluids

1.1 DENSITY OF NANO FLUIDS AND SAMPLE CALCULATION

For typical nano fluids with nano particles at a value of volume fraction less than 1%, a change of less than 5% in the fluid density is expected. For one percent nano particles of aluminum oxide mixes with the base fluid water the sample calculation for density is shown below:

$\rho nf = (1-\phi S)\,\rho f + \phi S\,\rho p$ …………….(1)

$= (1-0.01) * 997.1 + 0.01 * 3970$

$= 1027.11\ Kg/m^3$

Where, ρnf- Density of nano fluids (kg/m), ϕS - nano particles percentage (%), ρ_f - Density of Base fluids(kg/m3), ρp - Density of nano Particles (kg/m)

Here we are using the formula in equation 1 the density is calculated for nano particles percentages from one to thirty. The density of nano fluids is listed below

1) The combinations of a) aluminum +water (Nano fluid) b) copper + water (Nano fluid) c)silver + water (Nano fluid) are calculated.
2) The density of nano fluids i.e. the combinations of a) aluminum + ethylene glycol (Nano fluid) b) copper + ethylene glycol (Nano fluid) c) silver + ethylene glycol (Nano fluid) are also calculated.
3) The density of nano fluids i.e. the combinations of a) aluminum +Sodium (Nano fluid) b) copper + Sodium (Nano fluid) c) silver + Sodium (Nano fluid) is calculated.

1.2 SPECIFIC HEAT OF NANO FLUIDS AND SAMPLE CALCULATION

For one percent nano particles of aluminum mixes with the base fluid water the sample calculation for specific heat is shown below:

Specific heat of nano fluids,

$$Cnf = \frac{(1-\Phi_S)\rho_f C_f + \Phi_s \rho_p C_P}{\rho nf} \quad ………………(2)$$

$$= \frac{(1-0.01) * 997.1 * 4179 + 0.01*3970*765}{1027.11}$$

$= 4144.86$ J/Kg K

Where C_{nf} - specific heat of nano fluids (J/Kg K), C_f - specific heat of base fluids (J/Kg K), C_P - specific heat of nano particles (J/Kg K)

Using the above specific heat of nano fluids equation one can predict that small decreases in specific heat will typically result when solid particles are dispersed in liquids. Using the formula in equation 2 the specific heat is calculated for nano particles percentages , calculations of nano fluid by using water as a base fluid, calculations of nano fluid by using ethylene glycol as a base fluid and calculations of nano fluid by using sodium as a base fluid is calculated.

1.3 DYNAMIC VISCOSITY OF NANO FLUIDS AND SAMPLE CALCULATION

For one percent nano particles of aluminum oxide mixes with the base fluid water the sample calculation for specific heat is shown below:

$\mu = \mu_0 (123\,\phi_S^2 + 7.3\phi_S + 1)$ ………………… (3)

$= 0.001003*(123*0.01^2+7.3*0.01+1)$

$= 0.0010885$ kg/ms

Where, μ - dynamic viscosity of nano fluids (kg/ms), μ_0 - viscosity of nano fluids (kg/ms).

The effective dynamic viscosity of nano fluids can be calculated using different existing formulas that have been obtained for two-phase mixtures. Using the formula in equation (3) the dynamic viscosity is calculated for nano particles percentages. The dynamic viscosity of nano fluids is calculated for the combinations of nano particle with water, the combination of nano particle with ethylene glycol and the combination of nano particle with sodium. Using the formula the thermal conductivity is calculated for nano particles percentages from one to thirty for all the six models.

- The thermal conductivity of nano fluids for the combinations of a) aluminum +water (Nano fluid) b) copper + water (Nano fluid) c) silver + water (Nano fluid).
- The thermal conductivity of nano fluids for the combinations of a) aluminum + ethylene glycol (Nano fluid) b) copper + ethylene glycol (Nano fluid) c) silver + ethylene glycol (Nano fluid).
- The thermal conductivity of nano fluids for the combinations of a) aluminum +Sodium (Nano fluid) b) copper + Sodium (Nano fluid) c) silver + Sodium (Nano fluid).

1.4 Models Vs Graph:

Nano fluids containing small amounts of nano particles have substantially higher thermal conductivity than those of base fluids. The thermal conductivity enhancement of nano fluids depends on the particle volume fraction, size and shape of nano particles, type of base fluid and nano particles, pH value of nano fluids and type of particle coating. It is still not clear which is the best model to use for the thermal conductivity of nano fluids. From the above graphs and tables it is well find out that Maxwell model shows some regular variations compared to other models. Suresh and Davis model shows higher thermal conductivity values whereas Suresh model shows large thermal conductivity value than all other models. Bruggeman model gives somewhat higher thermal conductivity models compare to Suresh and Davis model. Hamilton and crosser model gives some closer values to the Jeffrey model. So comparing all these models we take Maxwell model for finding thermal conductivity of nano fluids for the present work.

HAMILTON AND CROSSER JEFFREY
DAVIS BRUGGEMAN
SURESH
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Nano particle percentage

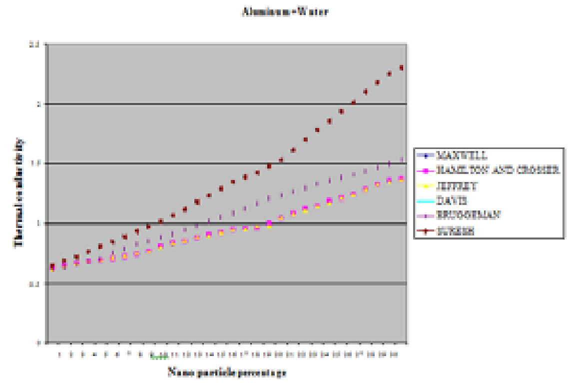

Figure 1.1- Thermal conductivity (W/Mk)of nanofluids (Water + Aluminum)

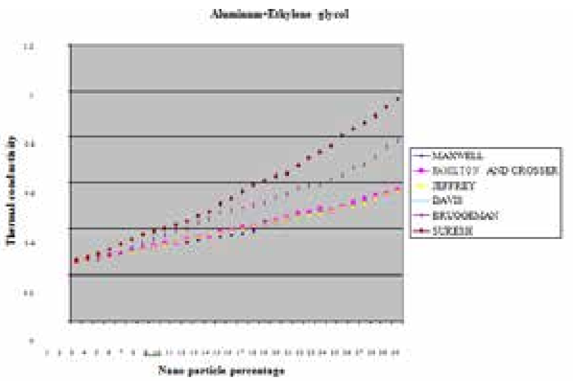

Figure 1.2- Thermal conductivity (W/Mk)of nanofluids (Ethylene glycol + Aluminum)

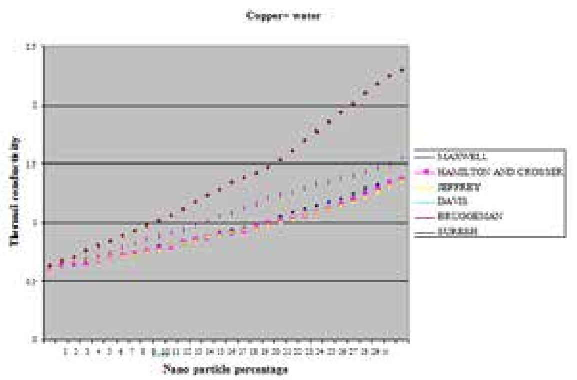

Figure 1.3- Thermal conductivity (W/Mk)of nanofluids (Water + Copper)

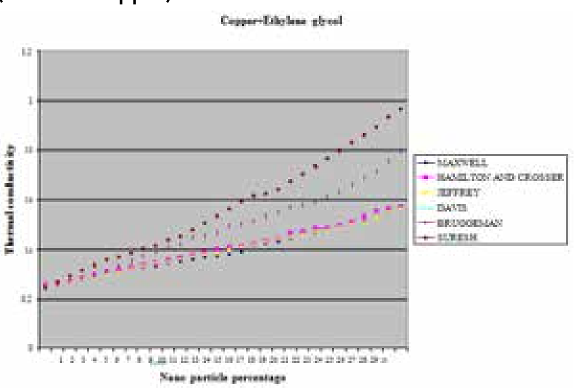

Figure 1.4- Thermal conductivity (W/Mk)of nano fluids (Ethylene glycol + Copper)

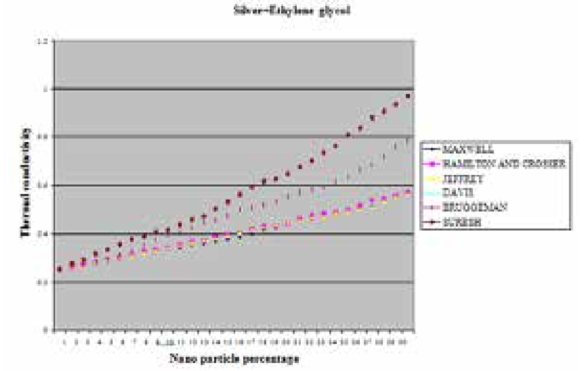

Figure 1.5- Thermal conductivity (W/Mk)of nanofluids (Ethylene glycol + Silver)

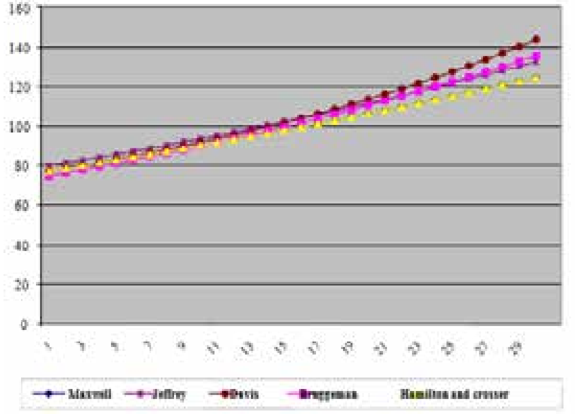

Figure 1.6- Thermal conductivity (W/Mk) of nano fluids (Sodium + copper)

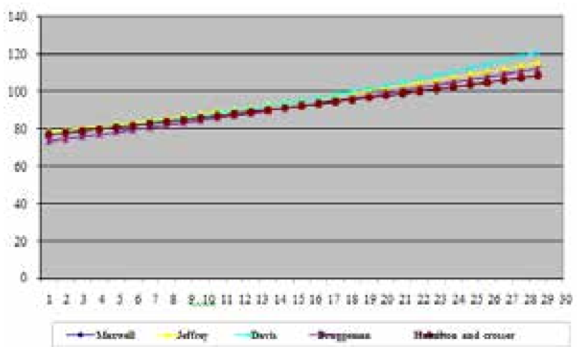

Figure 1.7- Thermal conductivity (W/Mk)of nanofluids (Sodium + Aluminum)

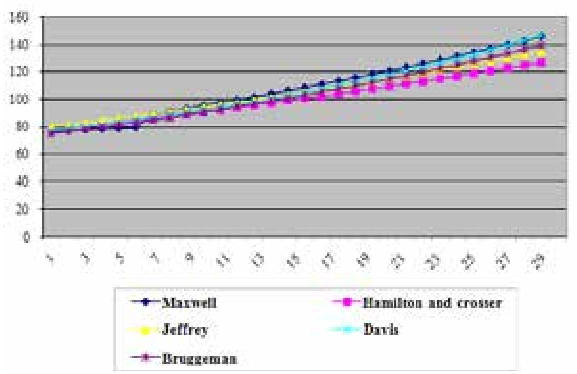

Figure 1.8- Thermal conductivity (W/Mk)of nanofluids (Sodium + Silver)

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We have considered the problem of forced convection flow of fluid inside a uniformly heated tube that is submitted to a constant and uniform heat flux at the wall. The modeling section chosen for the project work is a uniform heated tube of radius 25.4mm and length 1000mm. The modeling work is done in ANSYS WORKBENCH 11.0 software. And using another software we analysed using GAMBIT 2.2.30 allows us to construct and mesh models by means of its graphical user interface (GUI). Finally the result was found. In this analytical work we have considered the problem of forced convection flow of liquid inside a uniformly heated tube that is submitted to a constant and uniform heat flux at the wall. The heat transfer rates are analyzed for both the base fluids and the nano fluids under the same Reynolds number and uniform heat flux in the uniform heated pipe and the analytical work is done in FLUENT 6.3 software.

2. MODELLING AND MESHING DIAGRAMS:

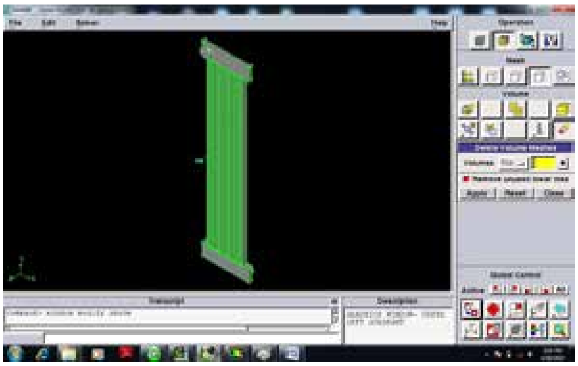

Figure M1-Modelling section –A (BEFORE MESH)

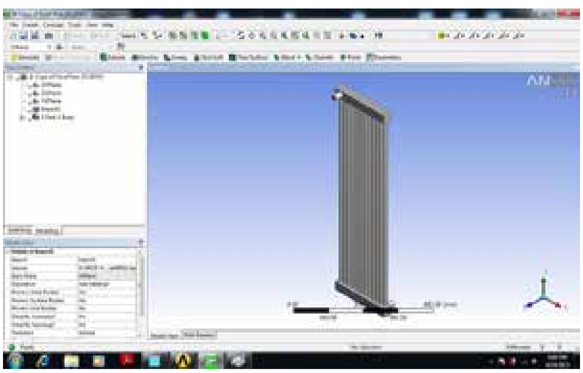

Figure M2-Modelling section –B (BEFORE MESH)

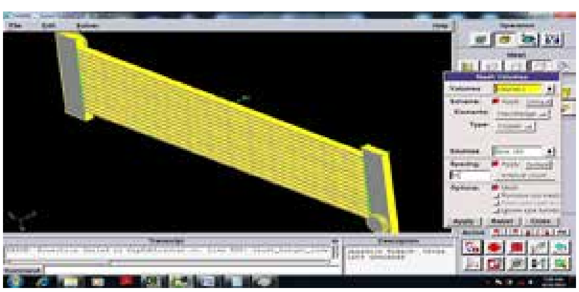

Figure M3-Modelling section (After meshing)

After the mesh completes we close the GAMBIT 2.2.30 software and import this modeling for the analysis work in FLUENT 6.3 software.

3. Results and Discussion

3.1 THERMAL CONDUCTIVITY OF NANO FLUID WHEN THE TEMPERATURE AT PIPE'S WALL IS 453 k (FOR WATER WITH COPPER)

The 453k temperature applied at the pipe's wall surface is shown below

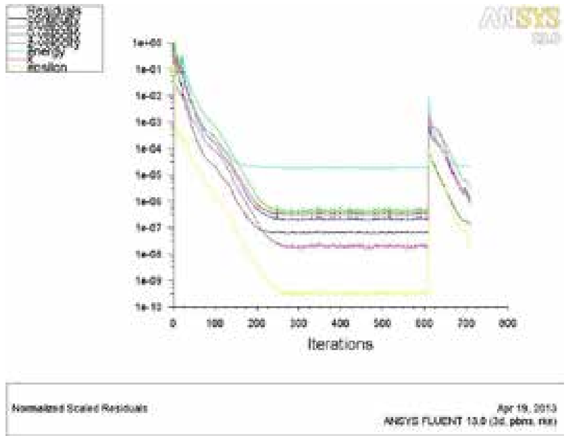

Figure 3.1 Thermal analysis

Heat transfer co-efficient of water (At 40^0 c) = 31785.81 kW/(m^2.K). The result obtained from the FLUENT software is given below

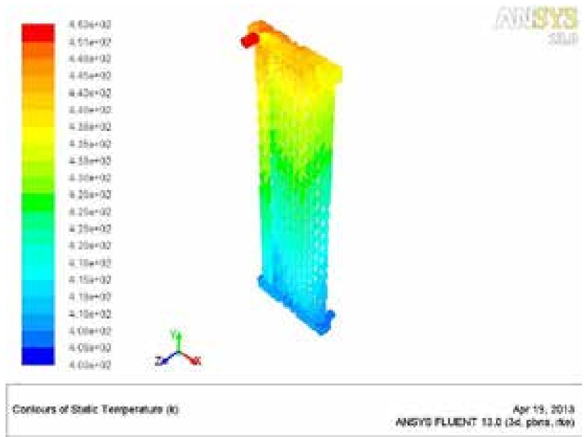

Figure 3.2-Contours of static temperatures

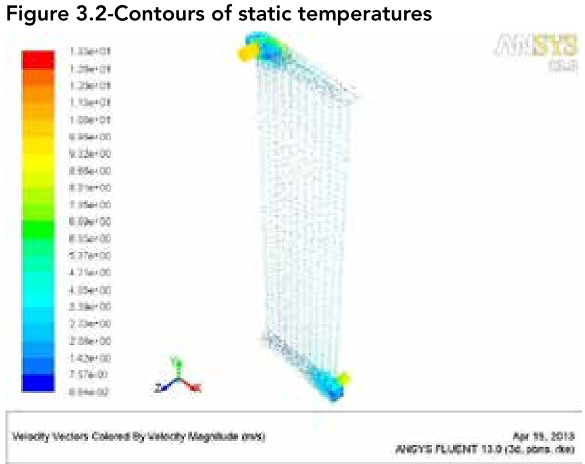

Figure 3.3Velocity magnitude

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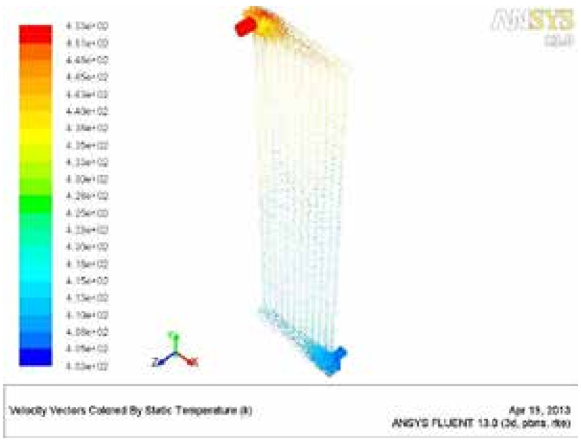

Figure 3.4- vector -static temperatures

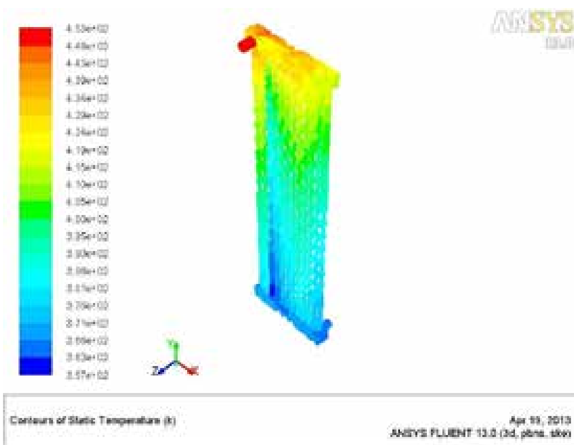

Figure 3.5- thermal conductivity of nano fluids (water + copper)

The thermal conductivity obtained in the FLUENT software for the Water + copper nano fluid combination at 300k of inlet nano fluid temperature is 1.06w/mk.

3.2 THERMAL CONDUCTIVITY OF NANO FLUID WHEN THE TEMPERATURE AT PIPE'S WALL IS 453 k (FOR ETHYLENE GLYCOL WITH COPPER)

The 453k temperature applied at the pipe's wall surface is shown in the following figure.

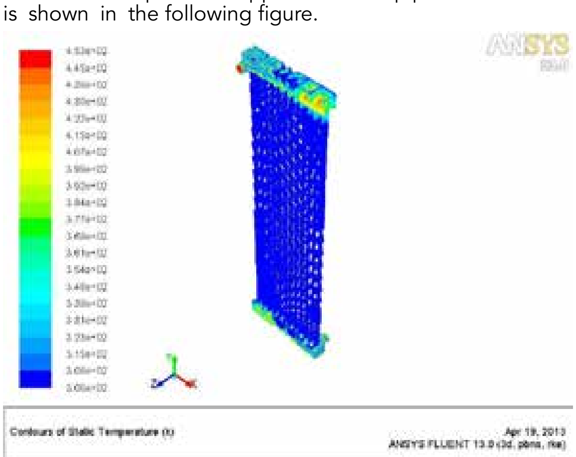

Figure 3.2.1 Thermal conductivity

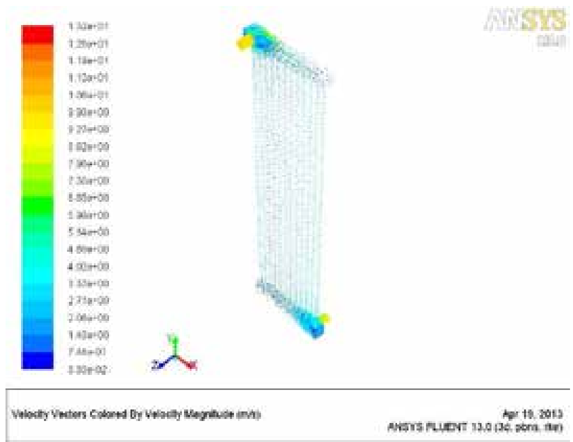

Figure 3.2.2 - Thermal conductivity

The thermal conductivity obtained in the FLUENT software for the Ethylene glycol + copper nano fluid combination at 453k of inlet nano fluid temperature is 0.45w/mk.

3.3 THERMAL CONDUCTIVITY OF NANO FLUID WHEN THE TEMPERATURE AT PIPE'S WALL IS 453K (FOR SODIUM WITH SILVER)

The 453k temperature applied at the pipe's wall surface is shown below

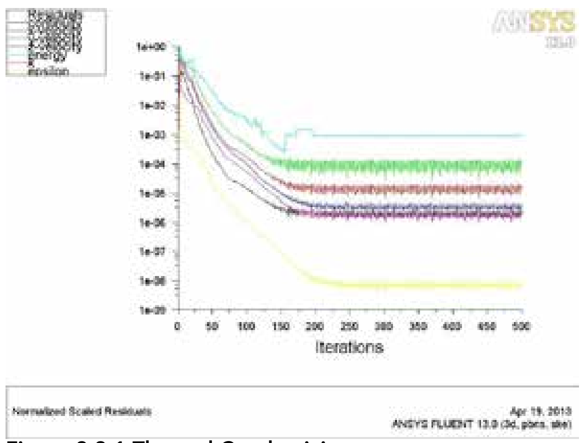

Figure 3.3.1 Thermal Conductivity

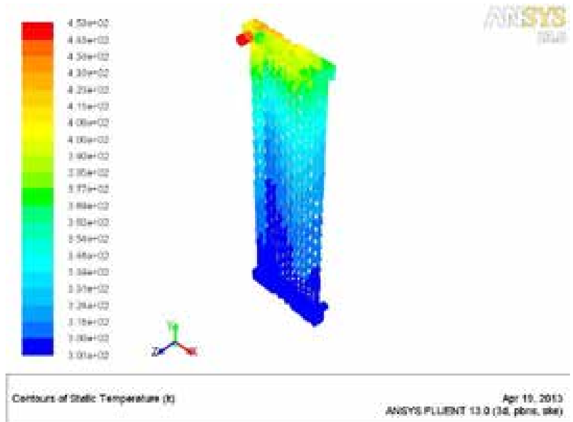

Figure 3.3.2 Thermal conductivity

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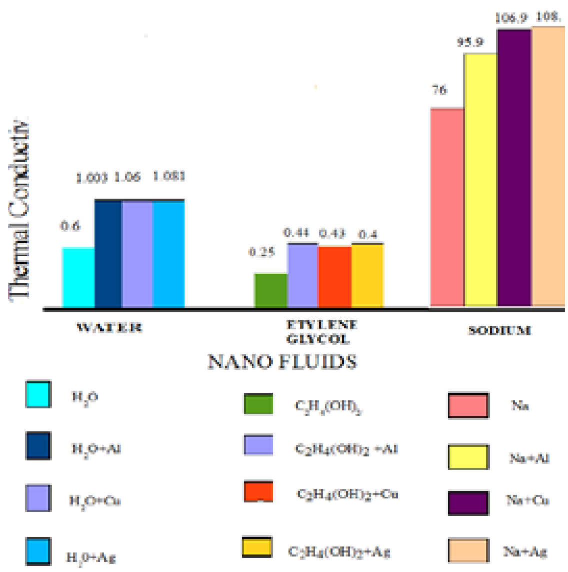
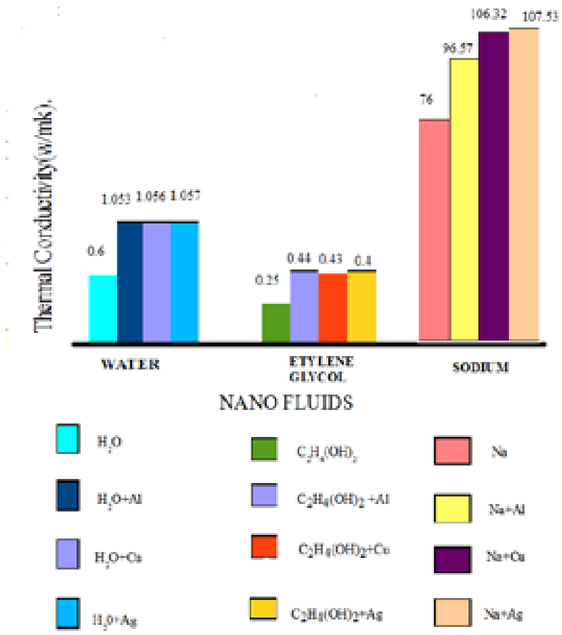
3.5 DISCUSSION

For enhancing the thermal conductivity conventional heat transfer fluids (base fluids) such as water, ethylene glycol and sodium the solid particles (Aluminum, copper & silver) were mixed with those base fluids. By using the thermal conductivity models such as maxwell model, hamiltom and grosser model, jeffrey model, davis model, and bruggeman model the thermal conductivity was found for the following combination of nano fluids Water + Nano particles of Aluminum, Water + Nano particles of Copper, Water + Nano particles of Silver, Ethylene glycol + Nano particles of Aluminum, Ethylene glycol + Nano particles of Copper, Ethylene glycol + Nano particles of Silver, Sodium + Nano particles of Aluminum, Sodium + Nano particles of Copper, Sodium + Nano particles of Silver. ***By comparing all thermal conductivity models the maxwell model showed the regular thermal conductivity variations sO the maxwell model thermal conductivity value at 20% of nano particle percentage is taken for analyzing the nano fluids.The thermal conductivity was found for the following combination of nano fluids Water + Nano particles of Aluminum, Water + Nano particles of Copper, Water + Nano particles of Silver, Ethylene glycol + Nano particles of Aluminum, Ethylene glycol + Nano particles of Copper, Ethylene glycol + Nano particles of Silver, Sodium + Nano particles of Aluminum, Sodium + Nano particles of Copper, Sodium + Nano particles of Silver by using the FLUENT software at 20% of nano particle volume fraction,300k inlet nano fluid temperature and 400k temperature at pipe's wall. The result is showed by the following bar chart. The resultant thermal conductivity values for all combination of nano fluids at 20% nano particle volume fraction by using the FLUENT software is showed by the following bar chart.***



The theoretical thermal conductivity values for all combination of nano fluids at 20% nano particle volume fraction are showed by the following bar chart.



CONCLUSION

The convective heat transfer features of,

a. Water + Nano particles of Aluminum (Nano fluid)

b. Water + Nano particles of Copper (Nano fluid)

c. Water + Nano particles of Silver (Nano fluid)

d. Ethylene glycol + Nano particles of Aluminum (Nano fluid)

e. Ethylene glycol + Nano particles of Copper (Nano fluid)

f. Ethylene glycol + Nano particles of Silver (Nano fluid)

g. Sodium + Nano particles of Aluminum (Nano fluid)

h. Sodium + Nano particles of Copper (Nano fluid)

i. Sodium + Nano particles of Silver (Nano fluid)

Were analyzed in a uniform heated tube at inlet nano fluid temperature of 301 ^{o}C. The results show that the nano fluids have large thermal conductivity than the original base fluids under the same Reynolds number. The suspended nano particles remarkably increased the forced convective heat transfer performance of the base fluid. At the same Reynolds number the heat transfer of the nano fluid increased with the particle volume fraction.

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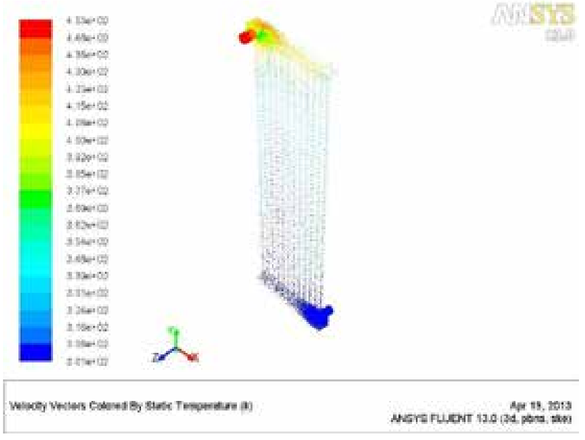


Figure 3.3.3 Thermal conductivity

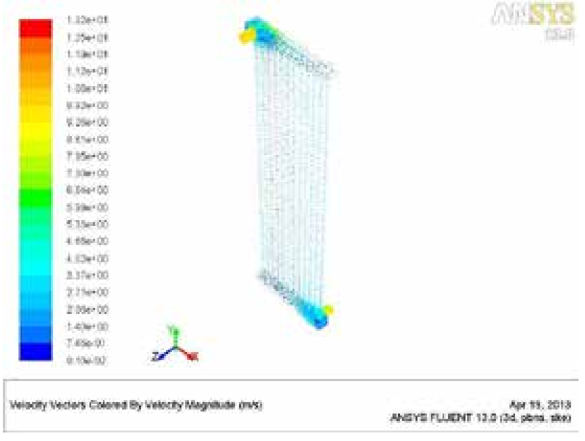


Figure 3.3.4 Thermal conductivity

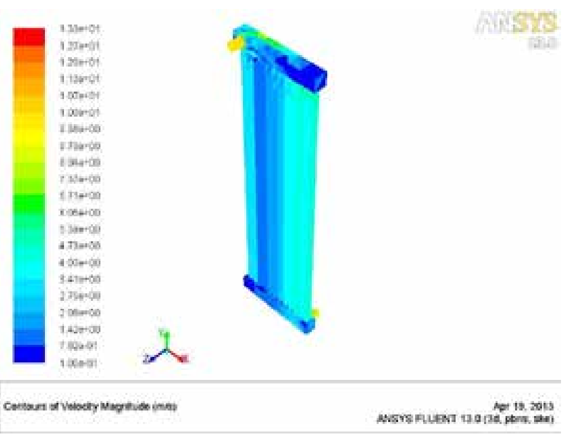
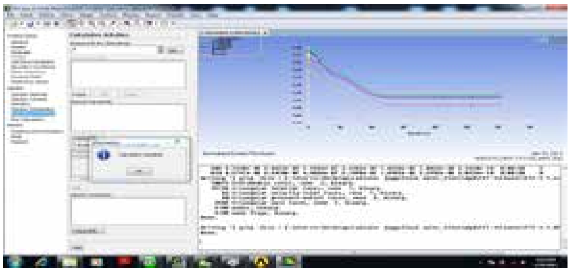


Figure 3.3.5 Thermal conductivity

3.4 CALCULATIONS IN FLUENT SOFTWARE



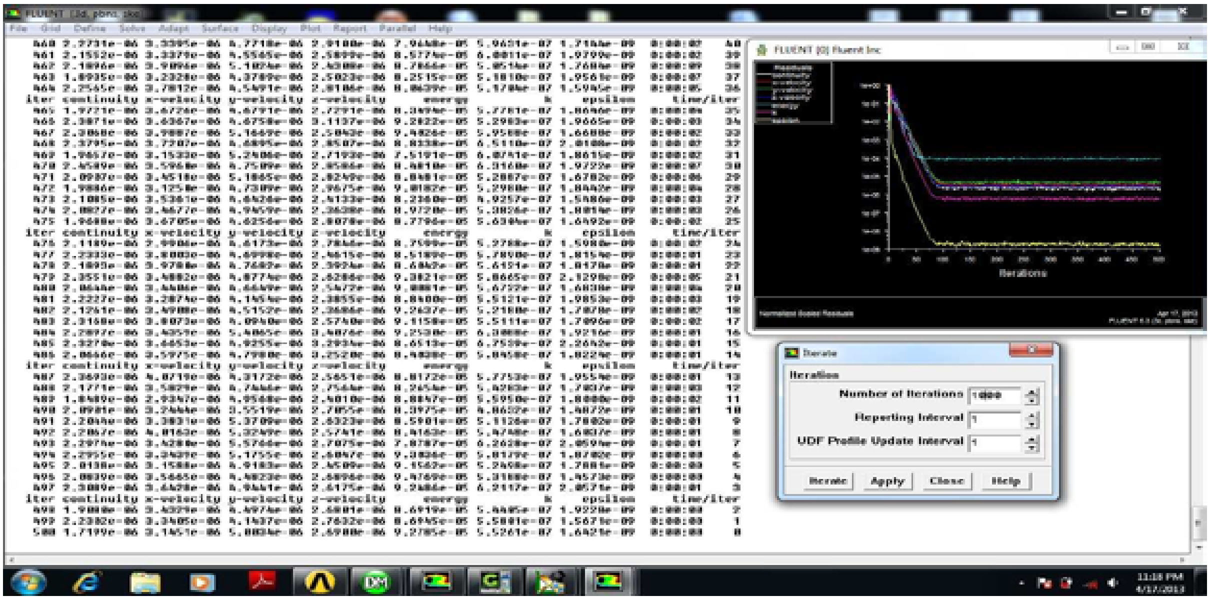


Figure 3.4.1 Calculation in FLUENT software

The heat transfer co-efficient obtained from the FLUENT software is 20.1w/m2k.

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