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Investigation Of Heat Transfer Enhancement In The Flat Plate Solar Collector Using Nano Fluid

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Abstract:-This research presents overview about Nano fluid with solar collector applications, an existing emerging class of heat transfer fluid, in terms of barriers, future research and environmental challenges. Nano fluids are used to increase the performance of many thermal engineering systems.

By referring the experimental investigation [55], the main objective is to prepare a CFD model and using Nano fluid as flowing fluid, which investigate the efficiency of square flat plate solar collector and enhancement in heat transfer with the use of different Nano fluid as compare to water . Therefore we are adopting the simulation method to resolve the problem of Use of Nano fluid in the flat plate collector and to get the improved results by using computational fluid analysis in ANSYS 15.0 by FLUID FLOW FLUENT solver.

The center point was to evaluate the use of different Nano fluid in the developed region of the tube flow containing water + Nano fluid (Al_20_3 and Ti_2O, CuO, and SiO2) on heat transfer characteristics. It was perceived that all Nano fluids (Al_20_3 and Ti_2O, CuO, and SiO2) revealed higher heat transfer characteristics than that of the base fluid (water). Furthermore the Nusselt number and the surface heat transfer coefficient is higher for CuO + Water Nano fluid as compare to other Nano fluid which are investigated on the basis of Reynolds and Nusselt number. Moreover we investigate the heat transfer characteristics with different pipe diameter for the (CuO + water) Nano fluid.
Keywords: CAD model of flat plate solar collector, Nano fluid, Reynolds number, Nusselt number, heat transfer.

I. INTRODUCTION

A. Nanofluids

Nanofluids demote to a solid-liquid mixture or suspensions produced by dispersing tiny metallic or nonmetallic solid Nano particles in liquids. Nanofluids are a new class of fluids engineered by dispersing nanometer sized materials (Nano-particles, Nano-fibers, Nano-tubes, Nano-wires and Nano-rods) in base fluids. The size of nanoparticles (usually less than 100nm) in liquids mixture gives them the ability to interact with liquids at the molecular level and so conduct heat better than today's heat transfer fluids depending on Nano particles. Nanofluids can display enhanced heat transfer because of the combination of convection & conduction and also an additional energy transfer through γ-particles dynamics and collisions. Metallic nanofluids have been found to possess 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. In current years, nanofluids established greater potential in many fields like solar collector and solar thermal storage. Even though some review articles involving the progress of nanofluids investigations were published in the past several years [14, 15], most of the reviews are concerned with the experimental and theoretical studies of the thermo physical properties or the convective heat transfer of nanofluids.

B. Classification of Nanofluids

Nanofluids can be normally classified into two categories metallic nanofluids and non-metallic nanofluids. Eastman et al, [16] theoretically studied the atomic and micro scale-level characteristic behavior of nanofluids. The result shows that the enhancement of thermal conductivity, temperature dependent effects and significant raise in critical heat flux. Metallic nanofluids often refer to those containing metallic nanoparticles such as (Cu, Al, Zn, Ni, Si, Fe, Ti, Au and Ag), while nanofluids containing non-metallic nanoparticles such as aluminum oxide (Al2O3), copper oxide (CuO) and silicon carbide (SiC, ZnO,TiO2) are often considered as non-metallic nanofluids, semiconductors (TiO2), Carbon Nanotubes (SWCNT, DWCNT and MWCNT) and composites materials such as nanoparticles core polymer shell composites. In addition, new materials and structure are attractive for use in nanofluids where the particle liquid interface is doped with various molecules.

II. LITERATURE SURVEY

A. Application of Nanofluids in Solar Collectors

The previous researchers review by Omidmahian et.al [17] gives a noble awareness about enhanced the efficiency and performance of the solar thermal system, solar water heater, thermal energy storage, solar cells and solar stills, there is a very limited number of research works in the area of solar collectors augmented with nanofluids.

Basically, low temperature nanofluids based direct absorption solar collectors (DASC) were investigated theoretically by Tyagi et.al [18]. They studied Al2O3 water based nanofluids was used for the investigation where the particle volume fraction (0.1% to 5%) influenced the collectors efficiency. Significant increase in the collector's efficiency was observed not only varying the particles volume fraction, but also the glass cover transitivity & collector height. It is reported, efficiency increases by 8% for volume fraction ranging from 0.8% to 1.6% and the effect of size of Nano particles in increasing efficiency is marginal.

Taylor et.al [19] investigated experimentally, by using graphite/ terminal VP-1 nanofluids for 10- 100MW solar power tower collectors and observed potential improvement in efficiency. Theoretically 10% in efficiency can be observed when compared with the conventional solar collectors, when using solar concentration ratio of 10-1000. Experimental results shown that 5-10% increase in efficiency can be achieved while using the nanofluids in the receiver section. The authors also estimated that $3.5 million/year more revenue can be attained by proper implementation.

Li et.al [20] carried out studies similar to Taylor et.al [19] by using three different nanofluids (Al2O3/water, ZnO/water &MgO/water) on the tubular solar collectors. The performance results showed that 95% of the incoming sunlight can be absorbed effectively while using the Nano fluid of volume fraction less than 10 ppm.

Efficiency of the flat plate solar collector was experimentally investigated by Yousefi et.al [21] using Al2O3 /water Nano fluid with weight concentration of 0.2% & 0.4% and particle size of 15nm. The investigation was carried out with Triton X-100 as surfactant as well as without it. The results presented 28.3% increase in the efficiency is obtained with 0.2% weight fraction Nano fluid. Additionally 15.63% increase in efficiency is observed by increasing mass flow rate and using the surfactant.

The researchers further investigated MWCNT/water nanofluids in the flat plate solar collector with 0.2% weight fraction, pH of 3.5, 6.5 & 9.5 respectively and Triton X-100 as surfactant by [22]. The results revealed that the surfactant influences the efficiency and pH of isoelectric point enhances the efficiency of the collector. Finally, the review of all existing experimental and numerical data results for the prediction of the solar collector.

Khullar et.al [23] investigated aluminum based Nano fluid both theoretically & experimentally on concentrating parabolic solar collector (CPSC). The aluminum based Nano particles were suspended in Terminal VP-1 base fluid with 0.05% volume concentration. The results were compared with the conventional concentric parabolic solar collector which reveals that increase in 5-10% of thermal efficiency was observed.

Currently, Titan C.Paul,et.al [24] summarized their experimental investigation on next generation solar collectors (CSP) using NEILS (Nanoparticle Enhanced Ionic Liquids) as working fluids their results revealed that thermal conductivity was enhanced around 5% depending on the base fluid and ionic concentration. The heat capacity of Nano fluid using Al2O3 Nano particles was enhanced by 23% and 26% for nanofluids using silica Nano particles and similarly 20% enhancement in convective heat transfer capacity was also observed.

Nanofluids (CNT, Graphite & Silver) based direct absorption solar collectors (DASC) were studied experimentally and numerically by Otanicar et.al [25], the effects of nanofluids on the efficiency improvement up to 5% were observed, using nanofluids as the absorption medium. The author compared the experimental data's with their respective numerical data. The results revealed that 3% efficiency increase can be achieved by using graphite nanoparticles of size 30nm, 5% efficiency increase can be achieved by using silver nanoparticles of size 20 to 40nm, where a 6% efficiency enhancement was observed when the particle size is halved.

Also light heat conversion characteristics of two different nanofluids (TiO2/water & CNT/water) were studied experimentally using vacuum tube solar collector in different weather patterns by He et.al [26]. The result shows excellent light heat conversion characteristics while using CNT/water nanofluids with 0.5% weight concentration. However, the temperature of CNT/water Nano fluid is observed to be greater, which shows the CNT/water Nano fluid is more suitable for vacuum tube solar collector application comparatively.

Recent investigation on flat plate solar collectors using MWCNT nanofluids studied by M.Faizal, et.al [27]. The study is focused on reducing the size of flat plate solar collector when MWCNT Nano fluid is used as working fluid. It is reported that 37% size reduction is possible by employing MWCNT as working fluid.

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III. SIMULATION METHODOLOGY

A. CFD Simulation method

The ANSYS 15.0 finite element program was used for analyzing Pipe flow. The equation of motion of Pipe is solved using FEV tool (ANSYS 15.0 – Fluid flow Fluent) as the equation of motion for a Pipe is difficult to visualize therefore some FEV tool is the only solution method for analyzing hydrodynamic characteristics. To find out the Reynolds number for different Nano fluid we are adopting Reynolds stress model for CFD simulation.

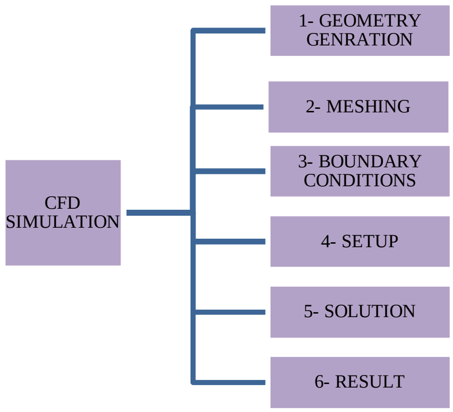

Figure: CFD Simulation Sequences**.**

The geometry and mesh was created by using ANSYS FLUENT 15.0 .The FLUENT is an integrated postprocessor for CFD analysis. The sequences of fluent steps are shown in Figure 4.1.

B. 4.4.1 Step 1 -Geometry generation

First of all in ANSYS 15.0 we choose Fluent in which we first draw the geometry with the help of ANSYS geometric tools. The key points were first created and then line and spline segments were formed. The lines were combined to create an area. Finally, this area was extruded and we modeled the square flat plate collector.

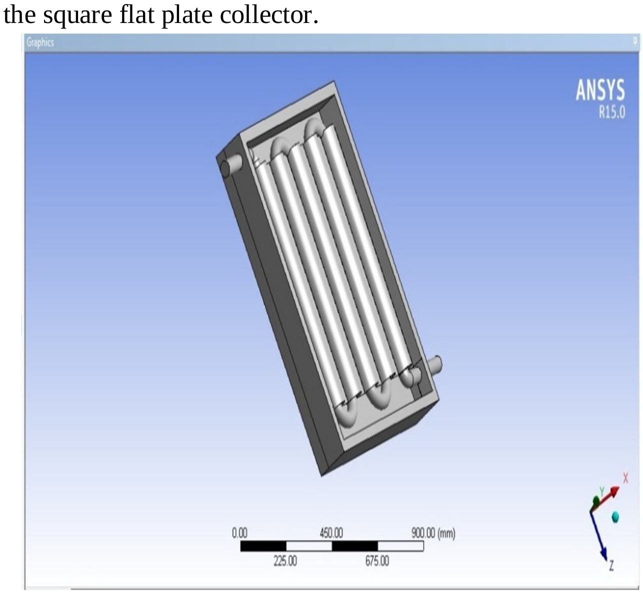

Figure CAD model of flat plate solar collector.

Figure shows the actual model of flat plate collector, since we are only dealing with the pipe flow and its temperature gain by solar radiation therefore only considering the pipe and pipe flow, therefore the geometry was taken for the simulation for different Nano fluid like SiO2 + Water as **Case 1**, AL2O3 + Water as **Case 2**, Ti2O + Water as **Case 3**& CuO + water as **Case 4** was shown below in figure below.

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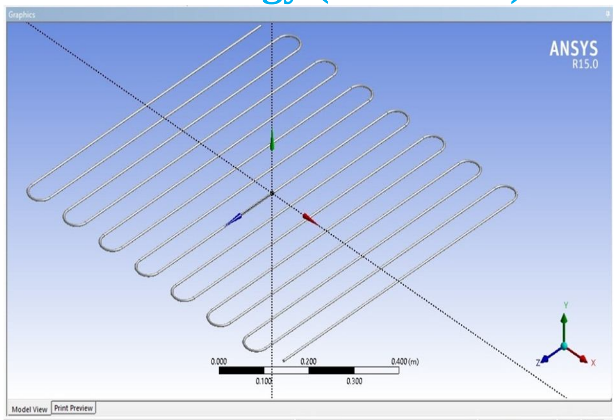

Figure: CAD model for 5.1 mm pipe diameter & for different Nano fluid.

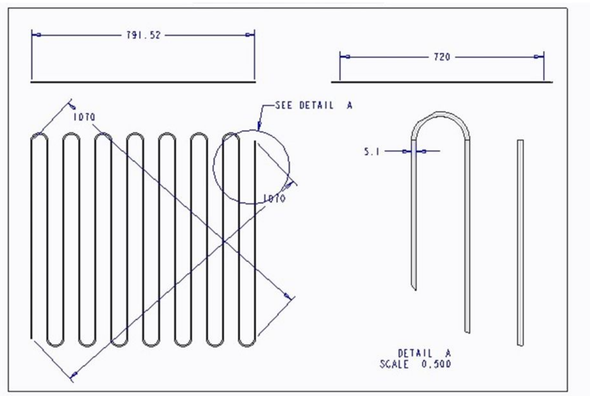

Figure: 2D diagram for 5.1 mm pipe diameter & for different Nano fluid

Figure shows the 2D diagram of geometry in which we take 5.1mm diameter of pipe for different Nano fluid like SiO2 + Water as **Case 1**, AL2O3 + Water as **Case 2**, Ti2O + Water as **Case 3**& CuO + water as **Case 4** and all other dimensions were referred from experimental diagram [55].

B. 4.4.2 Step 2 -Meshing

For this purpose, we switch to meshing where we choose the required meshing parameters.

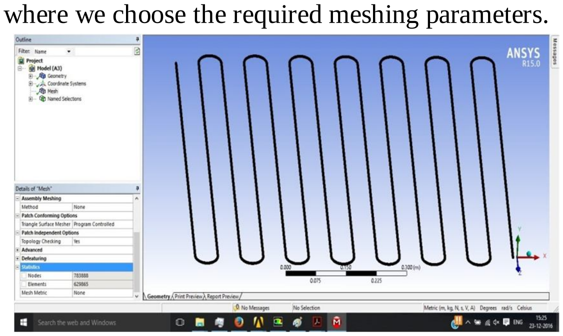

Figure: Mesh file for problem domain

Figure shows the mesh file for problem domain, in this case we have chosen meshing parameters as sizing parameters 1mm and created elements and nodes. There are 629865 element and 783888 nodes in the radial direction with a size ratio of 1 mm from the center to the wall.

C. 4.4.3 Step 3 -Boundary conditions

The physical boundary conditions for the geometry are defined as inlet, outlet and wall of the pipe. The continuum was the fluid. Then, the mesh file was well conducted into the ANSYS Fluent 15.0. The wall parameter of constant heat flux of 1.8 W/m-K and by referring M. Hasanuzzaman et al [56] the properties of different Nano fluid (AL2O3+ Water, Ti2O+ Water, and CuO+ water) was adopted and for SiO2 + Water Nano fluid the experimental data [55] was adopted for simulation.

D. 4.4.4 Step 4 -Setup for simulation

Now, we go to Setup of Fluent in which we check that whether energy equation is on, next we check the materials, which is SiO2 + Water termed as **Case 1**, AL2O3+ Water termed as **Case 2**, Ti2O+ Water termed as **Case 3**& CuO+ water termed as **Case 4** respectively and 2 % volume concentration for Nano fluid was adopted for maximum value of Reynolds number. By providing inlet velocity as 1 m/s and diameter of pipe 5.1 mm constant for different Nano fluid which is same as experimental. Now we select the best case (i.e. case 4) in which we get the enhanced heat transfer result for further investigation.

4.4.5 Step 5 – Solution

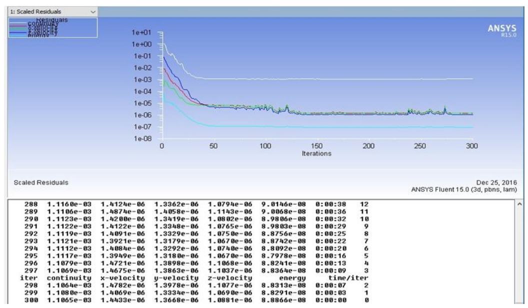

Figure: Solution converged for 5.1 mm pipe diameter & for different Nano fluid.

Figure shows the value of iteration for converged result for different Nano fluid. For that now, we will calculate or iterate the problem and for this problem we chose 300 iterations to converge the result and then we selected the graphs and plots window where we checked the contours of different graphs for different Nano fluid like SiO2 + Water as **Case 1**, AL2O3 + Water as **Case 2**, Ti2O + Water as **Case 3**& CuO + water as **Case 4.**

IV. RESULTS AND DISCUSSIONS

A. Validation with experimental data with present CFD simulation

Effect of the incident solar radiation on the collector efficiency when an experimental SiO2/water Nano fluid and water were used as coolants by referring experimental data [55] and influence of the same incident solar radiation on the Nano fluid (SiO2 + Water) by using CFD simulation i.e. present analysis in ANSYS 15.0 (Fluid flow FLUENT) are as follows.

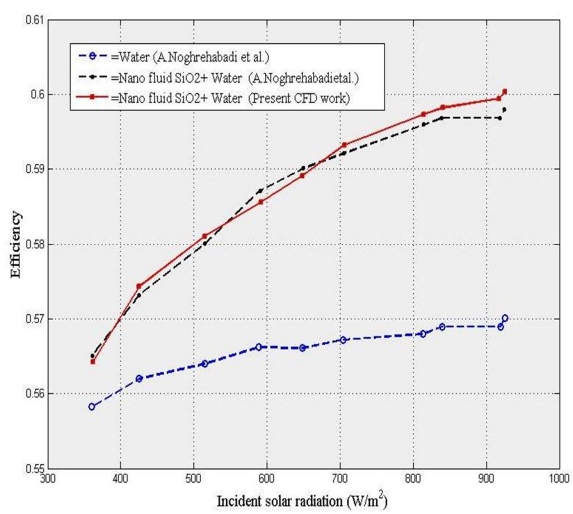

Figure: Validation with experimental data with present CFD simulation of Case-1.

Figure shows the graphical representation of experimental and CFD simulation of Case 1 by using MATLAB R2011a. In this simulation method the data were obtained by referring temperature contour of Case 1 and the efficiency is calculated by referring experimental governing equation [55] for 5.1 mm pipe diameter for SiO2 + water Nano fluid. For the water and SiO2/Water Nano fluid the data used were taken from the experiment result of A.Noghrehabadi et al. We compare the present CFD analysis and experimental data with the help of MATLAB (R 2011) simulation and plot the graph in between incident solar radiation and efficiency of flat plate collector in which we obtained efficiency for Case 1 which is 0.601 % and the experimental [55] efficiency of Nano fluid is 0.598 % and for water it is 0.57 % .

Hence we can clearly said that the result obtained from CFD simulation for 5.1 mm diameter for Sio2 + water Nano fluid (i.e. Case 1) is in good agreement with experimental results of A.Noghrehabadi et al. and we obtained the increase value of efficiency, which is directly proportional to heat transfer.

Table 2: Percentage Deviation in Efficiency of Present CFD analysis for Nano fluid (SiO2+ water) compare with Experimental data of Water by referring [55]

Experimental data of Water by referring [55]		Present CFD analysis for Nano fluid for (SiO2+ water) Case 1	% Deviation in Efficiency
Incident solar radiation	Efficiency	Efficiency	
361.148	0.56	0.56	1.058652
425.314	0.56	0.57	2.145095
514.952	0.56	0.58	2.934216
590.815	0.57	0.59	3.314828
649.406	0.57	0.59	3.907689
705.229	0.57	0.59	4.384011
814.118	0.57	0.60	4.916559
838.928	0.57	0.60	4.888503
918.147	0.57	0.60	5.085891
925.05	0.57	0.60	5.037032

From table 2 we obtained the value of 5% deviation in efficiency for Case 1 compare with Experimental data of Water by referring [55] and Present CFD analysis for (SiO2+ water) Nano fluid. (i.e. Case 1) which is in good agreement with A.Noghrehabadi et al.

Table 3: Percentage Deviation in Efficiency of Present CFD analysis for Nano fluid (SiO2+ water) compare with Experimental data of Nano fluid (SiO2 + water) by referring [55]

Experimental data of Nano fluid for (SiO2 + water) by referring [55].		Present CFD analysis with Nano fluid for (SiO2+ water) Case 1	% Deviation in Efficiency
Incident solar radiation	Efficiency	Efficiency	
361.15	0.57	0.56	-0.15
425.31	0.57	0.57	0.20
514.95	0.58	0.58	0.17
590.82	0.59	0.59	-0.25
649.41	0.59	0.59	-0.17
705.23	0.59	0.59	0.19
814.12	0.60	0.60	0.23
838.93	0.60	0.60	0.23
918.15	0.60	0.60	0.44
925.05	0.60	0.60	0.39

From table 3 we obtained the value of + 0.44 to – 0.15 % deviation in efficiency for Case 1 compare with Experimental data of Nano fluid by referring [55] and Present CFD analysis for (SiO2+ water) Nano fluid. (i.e. Case 1) , which is in good agreement with A.Noghrehabadi et al.

B. 5.2 Comparison between different Nano fluids with Reynolds number

It is found from the researches that the heat transfer increases with increasing Reynolds number of the flow. Now, we change the Nano fluid for model, like SiO2 + Water termed as Case 1, AL2O3+ Water termed as Case 2, Ti2O+ Water termed as Case 3& CuO+ water termed as Case 4 respectively by provide constant diameter of pipe 5.1 mm and Comparison between different Nano

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fluid with constant velocity of 1 m/s.

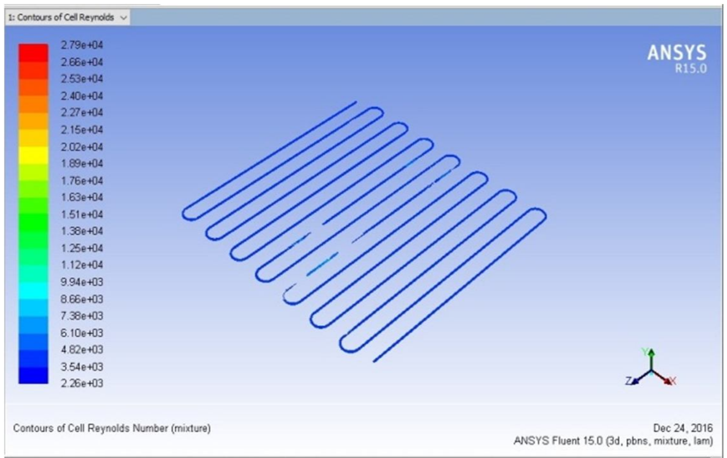

Figure: Contour of Reynolds number for (SiO2 + water) Nano fluid.

From figure, the value of Reynolds number is 27900 for 5.1 mm pipe diameter and for SiO2 + Water Nano fluid (i.e. Case 1). This is highest among all other Nano fluid.

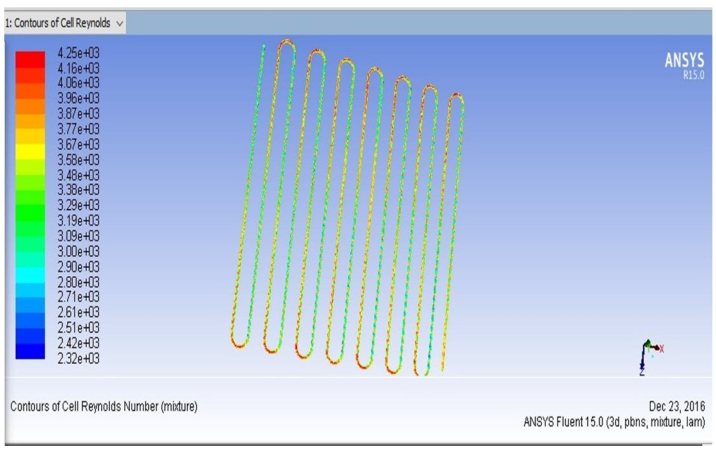

Figure : Contour of Reynolds number for (AL2O3+ water) Nano fluid**.**

From figure the value of Reynolds number is 4250 for 5.1 mm pipe diameter and forAL2O3 + Water Nano fluid (i.e. Case 2). This is highest among all other Nano fluid.

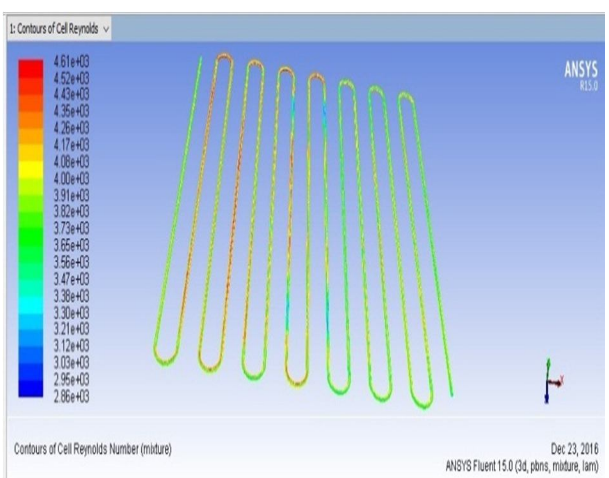

Figure: Contour of Reynolds number for (Ti2O + water) Nano fluid

From figure the value of Reynolds number is 4250 for 5.1 mm pipe diameter and forTi2O + Water Nano fluid (i.e. Case 3). This is highest among all other Nano fluid.

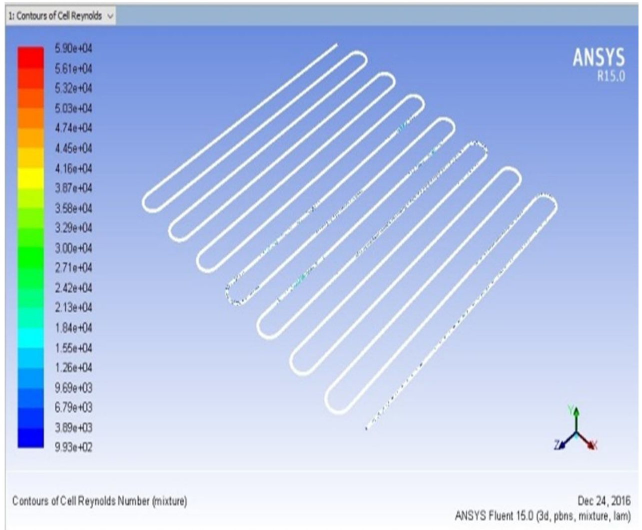

Figure: Contour of Reynolds number for (CuO + water) Nano fluid.

From figure the value of Reynolds number is 59000 for 5.1 mm pipe diameter and for CuO + Water Nano fluid (i.e. Case 4). This is highest among all other Nano fluid.

Table 4: Reynolds numbers for different Nano fluid

Nano fluid	Reynolds number
SiO2 + WATER CASE 1	27900
AL2O3 + WATER CASE 2	4250
Ti2O + WATER CASE 3	4610
CuO+ WATER CASE 4	59000

From table 4 we obtained the result, from the contour of Reynolds number for different Nano fluid and it was observed that the highest value for Reynolds number obtained with the CuO + Water Nano fluid i.e. Case 4 and hence we can say that the heat transfer will also increases with increasing Reynolds number of the flow.

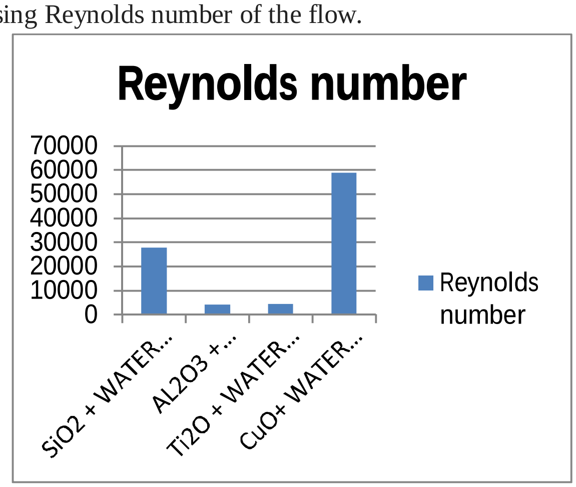

Figure: Bar chart for comparing different Nano fluid with Reynolds number.

From figure the value of Reynolds number is 59000 gained for CuO + Water Nano fluid. This is peak among all other Nano fluid. Now the value of Nusselt number and the value of heat transfer coefficient for CuO + Water Nano fluid i.e. Case 4 are to be obtained with the help of contour of Nusselt number and surface heat transfer coefficient which are as below.

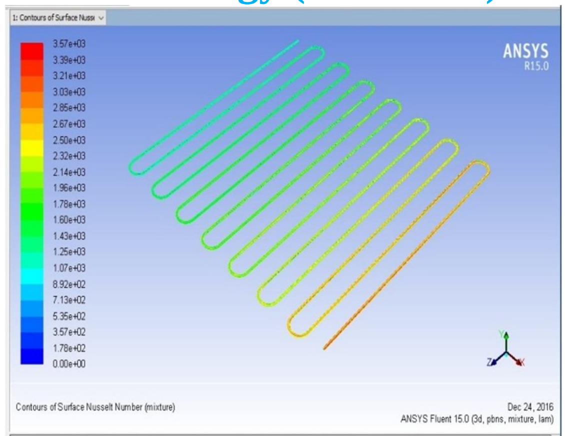

Figure: Contour of Surface Nusselt number for 5.1 mm pipe diameter & for (CuO + water) Nano fluid Case 4.

From figure the value of Nusselt number is 3570 for 5.1 mm pipe diameter and for CuO + Water Nano fluid. This is highest among all other Nano fluid.

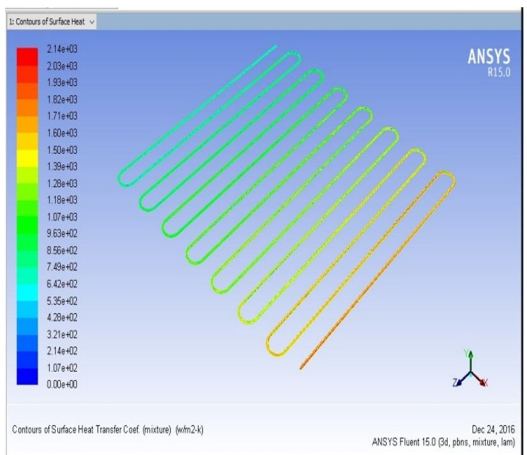

Figure: Contour of Surface heat transfer coefficient 5.1 mm pipe diameter & for (CuO + water) Nano fluid Case 4.

From figure the value of Surface heat transfer coefficient is 2140 w/m2-k for 5.1 mm pipe diameter and for CuO + Water Nano fluid Case 4. This is highest among all other Nano fluid.

V. CONCLUSION

This research presents overview about Nano fluid with solar collector applications, an existing emerging class of heat transfer fluid, in terms of barriers, future research and environmental challenges. Nano fluids are used to increase the performance of many thermal engineering systems.

By referring the experimental investigation [55], the main objective is to prepare a CFD model and using Nano fluid as flowing fluid, which investigate the efficiency of square flat plate solar collector and enhancement in heat transfer with the use of different Nano fluid as compare to water . Therefore we are adopting the simulation method to resolve the problem of Use of Nano fluid in the flat plate collector and to get the improved results by using computational fluid analysis in ANSYS 15.0 by FLUID FLOW FLUENT solver.

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