A Simulation Based Study on the Effect of Metallic and Non-metallic Nano-particles on the Performance of Parabolic Trough Concentrator

Un estudio basado en simulación sobre el efecto de nanopartículas metálicas y no metálicas en el rendimiento del concentrador cilindroparabólico

Um estudo baseado em simulação sobre o efeito de nanopartículas metálicas e não metálicas no desempenho do concentrador de calha parabólica

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Recibido: 19/08/2023 Aceptado: 15/11/2023

Summary. - This research investigates the simulation-based performance of metallic and non-metallic nanoparticles, along with water-based heat transfer fluids, used in parabolic trough concentrator. Its main goal is to analyze the performance enhancement of the concentrator, divided into two phases. The first phase focuses on validating the experimental setup using computational fluid dynamics through ANSYS software. The same validated simulation model is then utilized to assess the performance of solar parabolic trough concentrator with different metallic and non-metallic, plus water-based nanofluids.

The study utilizes water alone, along with copper, gold, and silver, and two non-metallic nanoparticles, alumina oxide, and copper oxide, in varying volumetric concentrations from 1% to 3%. The simulation analysis, conducted at a speed of 0.12 m/s, reveals that the highest average temperature increase is observed in the case of alumina + water-based nanofluid at 3% volumetric concentration, with a maximum average heat transfer of 351.89 watts. Additionally, the silver + water-based nanofluid demonstrates the highest average value of the coefficient of convective heat transfer at 88055.5 W/(m2 K). The gold + water-based nanofluid shows a higher average value of the Reynolds Number at 4352.268, while the maximum Nusselt number is observed with alumina oxide + water-based nanofluid, measuring 1.7698.

Keywords: Parabolic trough concentrator, Metallic nanoparticles, Non-metallic nanoparticles, Water-based nanofluids, Heat transfer enhancement.

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Memoria Investigaciones en Ingeniería, núm. 25 (2023). pp. 172-196
https://doi.org/10.36561/ING.25.10
ISSN 2301-1092 • ISSN (en línea) 2301-1106

Resumen. - *Esta investigación investiga el rendimiento basado en simulación de nanopartículas metálicas y no metálicas, junto con fluidos de transferencia de calor a base de agua, utilizados en concentradores cilindroparabólicos. Su principal objetivo es analizar la mejora del rendimiento del concentrador, dividido en dos fases. La primera fase se centra en validar la configuración experimental utilizando dinámica de fluidos computacional a través del software ANSYS. Luego se utiliza el mismo modelo de simulación validado para evaluar el rendimiento del concentrador cilindroparabólico solar con diferentes nanofluidos metálicos y no metálicos, además de a base de agua.*

El estudio utiliza agua sola, junto con cobre, oro y plata, y dos nanopartículas no metálicas, óxido de alúmina y óxido de cobre, en concentraciones volumétricas variables del 1% al 3%. El análisis de simulación, realizado a una velocidad de 0,12 m/s, revela que el mayor aumento de temperatura promedio se observa en el caso de alúmina + nanofluido a base de agua al 3% de concentración volumétrica, con una transferencia de calor promedio máxima de 351,89 vatios. Además, el nanofluido a base de plata + agua demuestra el valor promedio más alto del coeficiente de transferencia de calor por convección con 88055,5 W/(m2 K). El nanofluido de oro + agua muestra un valor promedio más alto del número de Reynolds con 4352,268, mientras que el número de Nusselt máximo se observa con óxido de alúmina + nanofluido de agua, que mide 1,7698.

Palabras clave: *Concentrador cilindroparabólico, Nanopartículas metálicas, Nanopartículas no metálicas, Nanofluidos a base de agua, Mejora de la transferencia de calor.*

Resumo. - *Esta pesquisa investiga o desempenho baseado em simulação de nanopartículas metálicas e não metálicas, juntamente com fluidos de transferência de calor à base de água, utilizados em concentradores de calha parabólica. Seu principal objetivo é analisar a melhoria de desempenho do concentrador, dividido em duas fases. A primeira fase concentra-se na validação da configuração experimental utilizando dinâmica de fluidos computacional através do software ANSYS. O mesmo modelo de simulação validado é então utilizado para avaliar o desempenho do concentrador solar parabólico com diferentes nanofluidos metálicos e não metálicos, além de nanofluidos à base de água.*

O estudo utiliza apenas água, juntamente com cobre, ouro e prata, e duas nanopartículas não metálicas, óxido de alumina e óxido de cobre, em concentrações volumétricas variadas de 1% a 3%. A análise de simulação, realizada a uma velocidade de 0,12 m/s, revela que o maior aumento médio de temperatura é observado no caso do nanofluido à base de alumina + água na concentração volumétrica de 3%, com transferência de calor média máxima de 351,89 watts. Além disso, o nanofluido à base de prata + água demonstra o maior valor médio do coeficiente de transferência de calor convectivo em 88.055,5 W/(m2 K). O nanofluido à base de ouro + água apresenta um valor médio mais elevado do Número de Reynolds em 4352,268, enquanto o número máximo de Nusselt é observado com óxido de alumina + nanofluido à base de água, medindo 1,7698.

Palavras-chave: *Concentrador de calha parabólica, Nanopartículas metálicas, Nanopartículas não metálicas, Nanofluidos à base de água, Melhorador de transferência de calor.*

1. Introduction. – Pakistan has always greatly relied on fossil fuels which defines it as an energy importer country. But the cost of oil importation with recent hikes in the prices of fossils fuels alongside an increasing demand for continuous power supply is weighing heavily not only on the foreign exchange reserves of the country but also on its delicate electricity grid. Pakistan is struggling hard to fill the voids created by energy shortfalls directly or indirectly in almost all economic sectors of the country. Renewable energy, which is already available in abundant volume, have got considerable attention to refill the energy gapes. According to Owusu et al. (2016) [1] renewable energy can be categorized into six distinct resources namely modern biomass, hydropower, solar wind, wave, geothermal and tide energy.

Solar energy can beat other renewable energy resources because the energy consumed by Earth from the Sun in an hour can exceed the total amount of energy a human acquires in one year. Further, as mentioned by Lewis et al. (2006) [2] there are two major methods of use of solar energy, solar photovoltaic, which converts Sunlight directly into electricity, and solar thermal concentrators which concentrate the light from the sun to produce heat and then employ it to operate heat engines.

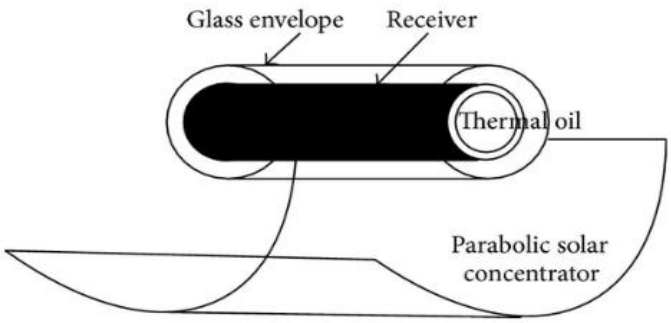

Figure I. Parabolic Trough Concentrator.

Linear parabolic concentrator, as shown in Figure. 1, heats up the pumped heat transfer fluid in the absorber by focusing sunlight on it (Dupeyrat, Patrick & Ménézo, Christophe & Fortuin, Stefan, 2014). In order to minimize heat loss and avert corroding, a vacuum space is maintained between the absorber and the envelop using a glass envelop of good light transmittance and heat-durability. This heat loss can be further reduced if there is a vacuum between the receiver and glass envelope. Moreover, an enhanced optical performance of glass envelope should increase the luminousness which alongside the anticorrosion property of glass envelope is the most important in creating vacuum, which cannot be created if the glass is corroded, or the performance of luminousness is bad. Uzair and Naveed (2021) [3] presents a method for evaluating the intercept factor (γ) of a beam-down parabolic trough collector.

In recent years the parabolic trough concentrators have received a noticeable attention. The focus of attention remained on their thermal performance. Many of the latest methods and different approaches have been used to make a significant change in their thermal performance. In this journey, Sandeep and Arunachala (2017) [4] suggested some methods to tackle the issue of enhancement in performance of PTC with the help of nanofluids. In the same manner, Govindaraj et al. (2017) [5] deployed some other nanofluids for the same cause. A nanofluid, as the name suggests, is a fluid with nano-sized solid particles (usually metal oxides), having dimensions less than 100 nm, suspended and dispersed in a base fluid. These particles can enhance both the thermal properties such as the thermal conductivity and specific heat capacity as well as fluid properties like density and viscosity, all of which have effective impact on heat transfer. The study pertaining to the different properties of newly developed heat transfer fluid called nano-fluid is yet developing. According to Gupta et al. (2017) [6] the size of nanoparticle as well as the type of nanoparticle, used for developing a nanofluid for its application as heat transfer fluid, has noticeable effect on the thermophysical properties of nanofluid. Further, the parameters like concentration and base fluid also do affect the cited properties of nanofluid.

With the focus to enhance the performance of solar parabolic trough concentrator experimental as well simulation-based approaches were used by different researchers. In experimental side, Bharti et al. (2019) [7] proposed experimental performance analysis design aspects for parabolic and triangular secondary reflector. They observed that there was a maximum temperature rise of 10.9, 9.6, and 7.4°C in case of parabolic trough collector with parabolic SR, with triangular SR, and without a SR. Further, Ekiciler et al (2021) [8] in their research work used three different hybrid nanoparticles with Syltherm 800 as base fluid and claimed an increase of 15% in efficiency of parabolic trough concentrator when Ag-MgO was used with 04% volumetric concentration. Again, an Experimental analysis was conducted in which Al2O3 with water was used in PTC and the results revealed that the thermal efficiency was increased up to 04% and at the same time receiver heat loss were decreased from 0.82% to 2.72%. Also, the receiver water temperature was increased to 15% (Patil & hekhawat, 2022) [9]. In the same year, Al-Oran et al. (2022) [10] in their research work focused to enhance LS-2 parabolic trough model and compared the improvement effects that achieved using various mono and hybrid nanofluids. In their research it was concluded that Al2O3 and CuO hybrid nanofluids gave more efficiency than Al2O3 and CeO2 hybrid nanofluids. Moreover, they also mentioned that Al2O3 and CuO hybrid nanofluids showed 1.09% and 1.03% maximum increment of the thermal and exergy efficiency, respectively.

On other side, Benabderrahmane et al. (2016) [11] used computational fluid dynamics over different shapes of fins. The shape used were of longitudinal and triangular type. They revealed that the shape has significant impact on Nusselt number upto 1.8 times as compared to normal circular shape piped. They further revealed that the efficiency was also improved with friction factor increment to 1.85 times to base fluid. Furthermore, in the reign of simulation field Kaloudis et al. (2016) [12] developed a two-phase model to study the properties of nanofluid. In that model Al2O3 + syltherm based heat transfer fluid was used. They increased volumetric concentration of Al2O3 to get 10% enhancement in thermal efficiency of PTC. Moreover, a detailed computational fluid dynamics-based approach was also used containing nanoparticle + water based nanofluid. They used various volumetric concentration to analyze the behavior of heat transfer fluid also in phase of turbulent flow. Ghasemi et al. (2016) [13] concluded that CuO+ water based nanofluid improved efficiency to 35% of PTC. In continuation, a simulation-based approach was also used to make a comparison in the output performance of solar parabolic trough collector. Bellos et al. (2018) [14] used pressured water with oil as heat transfer fluid, first. Further, the same results were compared with Al2O3 + oil based nanofluid. They obtained an enhancement of approximately 6%, in thermal performance with pressurized water and approximately 4%, with nano-fluid. Uzair et al. (2018) [15] presented a probabilistic modeling approach correlating Heat Transfer Fluid (HTF) temperature at the exit of a linear Parabolic Trough Collector (PTC), with a validated analytical heat transfer model based on twenty-six factors, achieving a high coefficient of determination (R^2) of 98.4%, and proposed a simplified correlation with nine significant factors, with potential applications in various solar-related systems such as power generation, heating, cooling, refrigeration, and desalination.

Recently, Al-Oran et al (2020) [16] in his research used nanofluid CeO2/H2O and distilled water as working fluids to investigate the performance of two identical parabolic trough collector (PTC) systems, at different volumetric concentrations. That maximum thermal efficiency for CeO2

https://doi.org/10.36561/ING.25.10
ISSN 2301-1092 • ISSN (en línea) 2301-1106

nanofluid achieved at 0.1% volumetric concentration as 18.03%. And the thermal efficiency was 17.15%, 16.11% and 14.40% for volumetric concentration of 0.06%, 0.03% and 0.01%, respectively and it was 11.71% for water. In the journey of increasing the thermal efficiency of PTC Abed et al. (2021) [17] adopted a different numerical approach. In that research work the use of swirl inserts with and without SiO nanofluid was adopted with base fluid as Terminol VP1. The results showed that at concentration of 06% swirl insert energy efficiency was improved up to 15%. Recently, Ajbar et al. (2023) [18] explored the use of eight hybrid nanofluids to enhance the thermal efficiency of a parabolic trough solar collector (PTSC), and the developed model demonstrated close agreement with experimental results, showing an average error of 1.92% and 2.34% for outlet temperature and thermal efficiency; the simulation results revealed a maximum improvement of 2.8% in PTSC thermal efficiency using hybrid nanofluids and an average improvement of 1.6% compared to Syltherm 800, indicating the potential of these nanofluids to enhance PTSC performance through increased heat transfer coefficients and Nusselt numbers. In another study, Shyam et al. (2023) [19] used a solar parabolic trough collector with optimized secondary optics which was numerically analyzed using ANSYS FLUENT 15.0, revealing that the proposed model outperforms the standard LS-3 collector with a maximum available and overall thermal efficiency of 92.6% and 84.2%, respectively, along with a maximum heat transfer coefficient of 1481 W/m2K and exergy efficiency of 52.8%. The investigation, conducted over a range of Reynolds numbers and inlet temperatures, demonstrated the improved thermal performance of the proposed model compared to the standard LS-3 collector.

This research work embodies the validation of research work by Tagle et al. (2018) [20]. The simulation work was performed by ANSYS CFD software where same parameters of alumina plus water based nanofluid were used as were quoted in the selected research article with some assumptions to validate the results. After validation of results, the different volumetric concentration ranging from 1% to 3% with an increment of 0.5% of various metallic and nonmetallic nanofluid were used to compare their performances with each other and also with water as heat transfer fluid.

2. Methodology. –

2.1. Overview of selected research paper for validation. – An experimental setup is shown in figure no. 02 which was used by Tagle et al. (2018) [21]. The setup shown is composed of parabolic trough concentrator, pump, heat exchanger and tank. The parabolic trough concentrator shown in figure no. 03 was designed by a Mexican company, as per opted paper, with the characteristics as shown in table no .01.

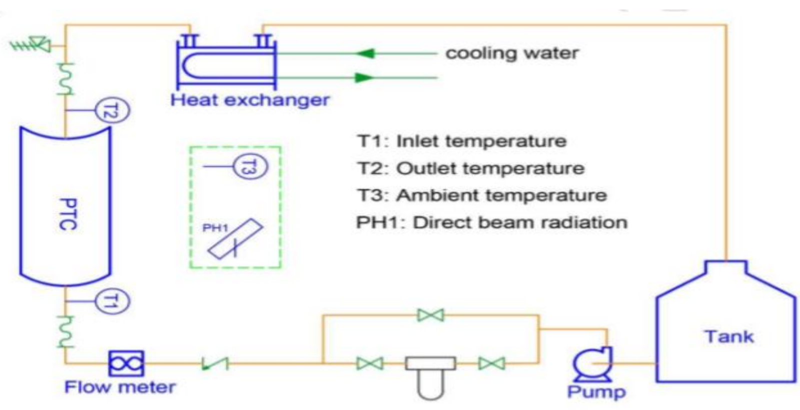

Figure II. Experimental Setup.

The parameters used in their experimental setup includes the intensity of direct beam, mass flow, ambient temperature, inlet temperature and outlet temperature. The velocity used in their experiments was 0.12m/s.

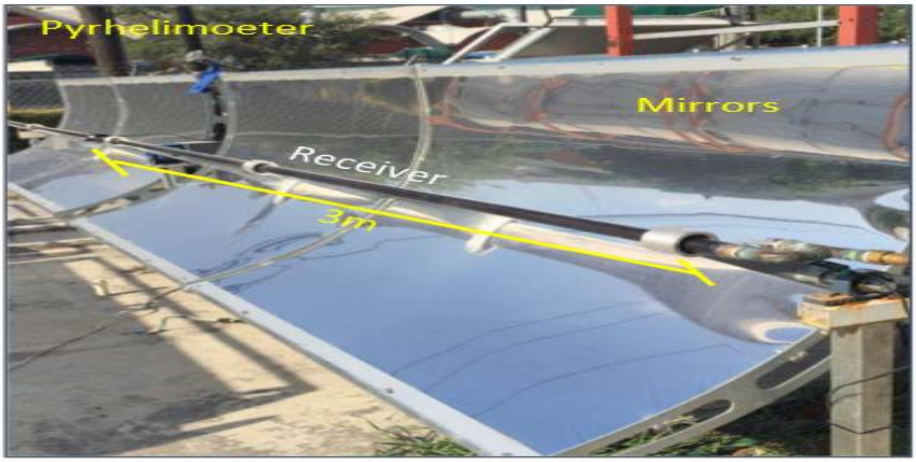

Figure II. Parabolic Trough Concentrator.

General	Aperture (m)	1.1
	Length (m)	3
	Focal Distance (m)	0.34
	Γ	0.84
Mirror	Material	Anodized aluminum sheets
	P	0.86
Receiver	Cover glass	Borosilicate, Ø44mm x 2mm thickness
	T	0.97
	Anti-reflective coating	No
	Evacuated	No
	Tube	AISI 304 1" Sch 40
	Selective coating	Yes

Table I. Characteristics of Power Trough 110

As per the selected paper they fixed angle of incident as 10o. In their setup the heat transfer fluid used in parabolic trough collector was the combination of Al2O3 and water with volumetric concentration of 1% of alumina nanoparticles. The nano-fluid used by them was synthesized in two steps method. First the 10 nm particles were combined to distilled water and after that were dispersed using an ultrasonic bath and processor. Following were the variables which were compared in between experiments and simulations by them.

Difference of the temperature at inlet and exit	ΔT1i-1o
Temperature at the exit	Tout
Average of the temperature of the fluid and ambient air	ΔTave-a
Receiver Thermal Efficiency	η

2.2. Calculation of nano-fluid properties. – A receiver tube is shown in figure no. 04 which receives the heat flux on its surface. A glass is surrounding the receiver tube and inside of the absorber tube a heat transfer fluid flow.

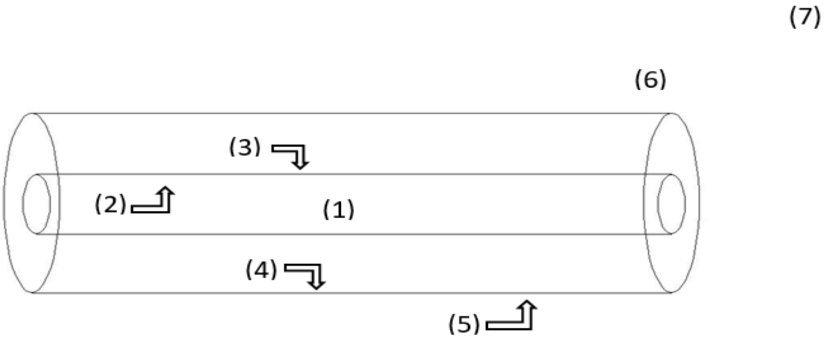

Figure IV. Receiver Tube.

(1) HTF
(2) Inner surface of the absorber tube
(3) Outer surface of the absorber tube
(4) Inner surface of the glass envelop
(5) Outer surface of the glass envelop
(6) Ambient
(7) Sky

The heat transfer properties of the base fluid enhance with the addition of nanoparticles in the base fluids. The improvement in the working properties of nanofluids, obtained by combination of base fluid and nanoparticles, depends upon the volumetric concentration of nanoparticles used. That volumetric concentration used is denoted by Ø in %. Normally, the amount of volumetric concentration varies from 1% to 3% and may be more depending upon the type of nanoparticle used. The different properties of nano-fluild can be obtained by following equations (Khanafer, 2011).
The density of nanofluid can be found by following equation;

$$\rho_{n_f} = \rho_{bf} \cdot (1 - \emptyset) + \rho_{nP} \cdot \emptyset \quad (1)$$

The heat capacity is given by next equation as;

$$C_{P \cdot nf} = \frac{\emptyset \cdot \ (\rho C_P)_P \ + \ (1-\emptyset) \ (\rho \cdot C_P)_f}{\rho_{nf}} \quad (2)$$

In order to calculate the thermal conductivity of the nano-fluid following equation can be used;

$$k_{nf} = \frac{k_{n\rho} + 2 \cdot k_{bf} - 2 \cdot \emptyset \cdot \left(k_{bf} \ - \ k_{nP}\right)}{\frac{k_{nP}}{k_{bf}} + 2 + \frac{k_{bf} - k_{nP}}{k_{bf}}} \quad (3)$$

https://doi.org/10.36561/ING.25.10
ISSN 2301-1092 • ISSN (en línea) 2301-1106

The viscosity of the nano-fluids can also be calculated by;

$$\mu_{nf} = \mu_{fb} \cdot (1 + 2.5 \cdot \emptyset + 6.5 \cdot \emptyset^2) \qquad (4)$$

The transfer of heat amount can be calculated by;

$$Q = h \cdot A_{abi} \cdot (T_{ab} - T_{HTF}) \qquad (5)$$

The other parameters can also be obtained by following equations

$$h = \frac{k \cdot N_u}{D} \qquad (6)$$

$$N_u = \frac{\left(\frac{f}{8}\right)(R_e - 1000)\ P_r}{1 + 12.7 \cdot \left(\frac{f}{8}\right)^{\frac{1}{2}}\ \left(P_r^{2/3} - 1\right)} \qquad (7)$$

$$f = (0.79 \cdot ln\ \ R_e - 1.76)^{-2} \qquad (8)$$

$$R_e = \frac{\rho \cdot v \cdot D}{\mu} \qquad (9)$$

$$P_r = \frac{\mu\ \cdot\ C_P}{k} \qquad (10)$$

2.2. Validation through Ansys CFD. – To solve the enigma of heat transfer and fluid dynamics a simulation-based application, known as ANSYS computational fluid dynamics was used. The results of research paper being validated are mentioned in table no. 02, whereas the results obtained through ANSYS CFD model are listed in table no. 03. The obtained results showed that the CFD simulation-based results were approximately close to experimental based results with an average error of 0.032625%.

Experimental conditions			Experimental results			
I (W/m2)	T_a (C^0)	T_{in} (C^0)	T_{out} (C^0)	$\Delta T_{1i\text{-}1o}$ (C^0)	$\Delta T_{1ave\text{-}a}$ (C^0)	η (%)
839.2	43	56.3	57.2	0.9	13.7	57.6
810.3	31.1	54.1	55	0.9	23.4	58.6
818.6	30.7	54.8	55.7	0.9	24.6	57.9
743.1	30.4	56.4	57.2	0.8	26.4	55.4
831.7	31.3	59.1	59.9	0.9	28.2	55.7
841.2	30.5	63	63.8	0.9	32.9	53.6
855.8	39.2	57.6	58.5	0.9	18.9	54.2
905.3	38.2	39.2	40.3	1.1	1.4	61.1

Table II. Experimental based.

Simulation results			
T_{in}	T_{out}	ΔT_{1i-1o}	Error
C°	C°	C°	%
56.3	57.3	1.0	0.17
54.1	55.07	0.97	0.13
54.8	55.67	0.87	-0.05
56.4	57.19	0.79	-0.017
59.1	60.0	0.9	0.166
63.0	63.9	0.9	0.156
57.6	58.517	0.91	0.029
39.2	40.17	0.97	-0.323

Table III. Simulation based results.

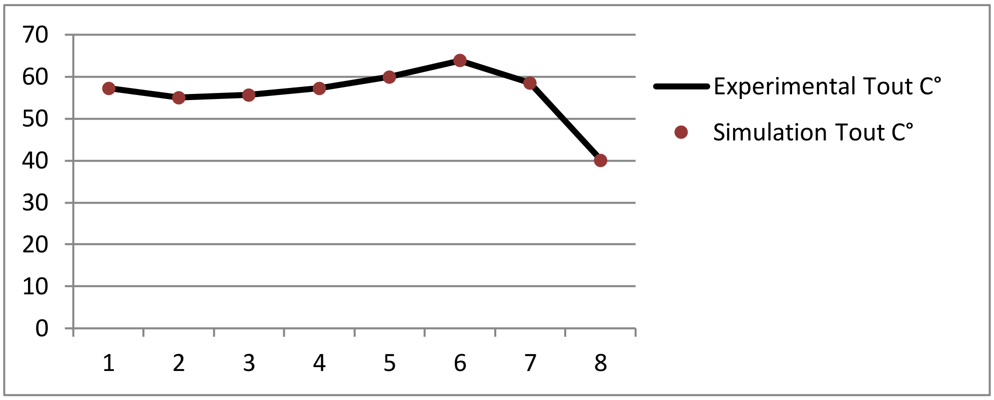

Figure V. Comparison of Experimental vs. Simulation based results.

The cited validation was performed in six steps. The first step was the creation of geometry of the pipe in which heat transfer fluid will flow. For that purpose ANSYS Design Modeler was used to create a geometry of the pipe. The dimensions of the pipe used as receiver are taken as under;

Diameter of Pipe	Inner Dia	0.0254 (m)
	Outer Dia	0.0274 (m)
Thickness		0.002 (m)
Length of Pipe		3.00 (m)

Table IV. Dimensions of tube.

Then, the next step was to perform meshing of the geometry design. In this step the geometry was divided into number of small sized nodes and elements as shown in Figure VI.

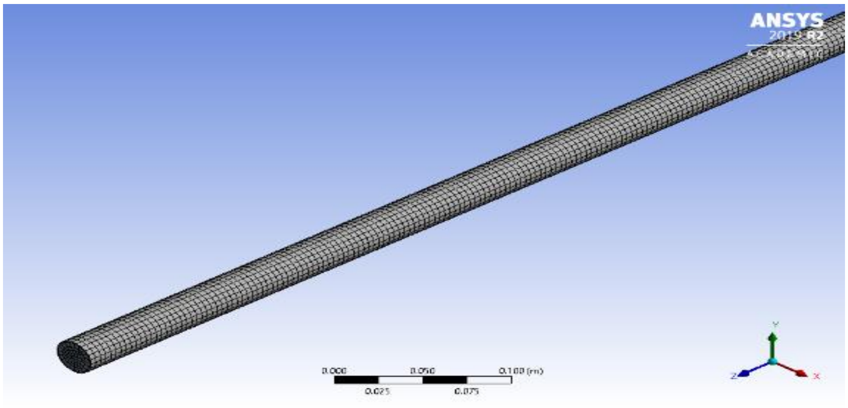

Figure VI. Meshing of 3D Pipe.

The number of elements and nodes have direct influence on the mesh refinement. As, the number of elements and nodes increases then it improves the refinement of mesh and reduces the error which improves the accuracy and influences the speed of simulation. So, after the geometry meshing was performed to get maximum number of elements as mentioned below;

Nodes	88434
Elements	70481

Table V. Meshed statistics.

Then, grid independence test was performed. Grid independence test was performed to check whether there is a significant change or not in output results by changing number of elements and nodes in a mesh. The following table shows the results of grid independence test performed by altering the number of divisions in a mesh from 30 divisions to 85 divisions with an increase of 5 five divisions each time. The results showed that there was a change of 0.16% in the heat transfer results. Further, the mesh refinement alters the results of convective heat transfer coefficient up to 0.00397%. Moreover, the change in output temperature with changing number of divisions was about 0.003%.

Sr. No.	Number of Divisions	Mesh Nodes	Mesh Elements	Heat-transfer [W]	Heat-transfer-Coefficient [W m^-2 K^-1]	Nusselt-number	exit-temperature [K]
1	30	82768	52398	216.78312	9432.6472	1.759332	336.89992
2	35	88434	70481	216.89099	9432.9438	1.759586	336.90191
3	40	97628	63818	216.96181	9432.9891	1.759636	336.90218
4	45	130928	89378	217.00709	9432.9933	1.759654	336.90252
5	50	112528	67258	217.04137	9432.9897	1.759799	336.90261
6	55	131053	82058	217.06616	9433.0044	1.759857	336.90274
7	60	127348	74658	217.08569	9433.0018	1.760198	336.90279
8	65	172549	116098	217.09938	9433.0056	1.760204	336.90281
9	70	142308	82128	217.11176	9433.0198	1.760116	336.90283

Table VI. Grid Independence test results.

In the next step CFD simulation was created. In this step the model, type of fluid, its properties and different boundary conditions of nano-fluid were provided with velocity as 0.12m/s. The properties of nano fluid calculated from the equation no. 1, 2, 3 and 4 at volumetric concentration of 1% are listed below;

	Density (Kg/m3)	Sp: Heat (J/Kg.k)	Thermal Conductivity (w/m.k)	Viscosity (Kg/m.s)
Properties of Nano particle Al_2O_3	3950	875	30	
Properties of H_2O	998	4180	0.6	0.001003
$Al_2O_3 + H_2O$ @ 1% volumetric concentration	1027.52	4021.11	10.596	0.001029

Table VII. Properties of base fluid & nano fluid.

After providing boundary conditions the residual was set to 1e-06 to get accurate results. Then, solution initialization step was done by selecting the option of compute from inlet. After that selected the option of run the calculation by setting number of iteration to 1000. The model selection plays very important role for the outcome of the temperature at exit. Selection of model depends upon the Reynolds no. of the fluid being used. Since the Reynolds no. of the nano-fluid at 1% volumetric concentration is about 3044.504, which is greater than laminar flow and the fluid is in transition state, so the suitable model for such case was selected as K-omega SST model. Since, the flow was turbulent so in order to avoid the complexity following assumptions were taken during simulation process.

- Flux is constant throughout the surface of pipe tube.
- There is no slip between the fluid and wall of pipe tube.
- Nano fluid flowing through the pipe is of single phase.

Further, after setting up the iteration to 1000 results were obtained, as listed in table no. 3, when the solution was converged. Furthermore, figure no. 07 shows the contours of pipe tube from which heat transfer fluid passes.

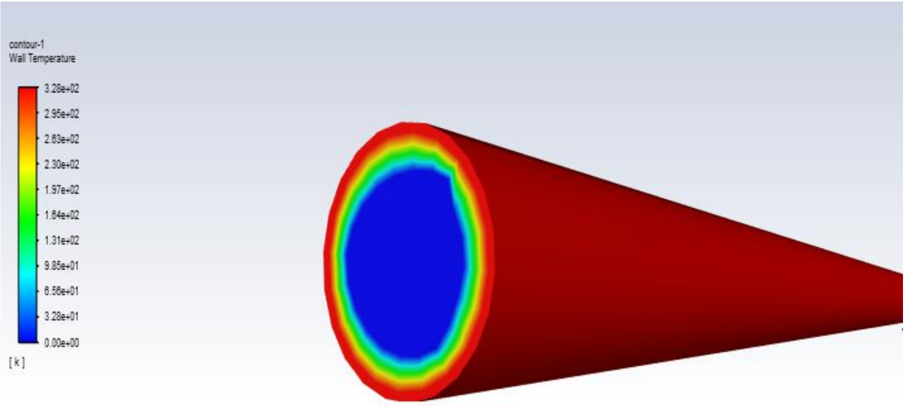

Figure VII. Contours of Wall Temperature.

Furthermore, after the validation of the opted research paper the proposed CFD based model was further enhanced by adding the option of solar load calculator to reduce error. Table no. 08 and 09 shows the required parameters and different flux and initial temperature values to use solar load calculator in CFD simulation. Moreover, this validated and updated model was then used to analyze the effects of metallic and non-metallic particle-based nano-fluids over PV trough concentrator performance at various volumetric concentration ranging from 1% to 3% volumetric concentration.

Location	NED UET Karachi
Latitude	24.9318°
Longitude	67.1126°
GMT	+5

Table VIII. Location coordinates.

Flux	T_1
830.8	51.3
790.6	49.1
795.9	49.8
840.3	50.4
880.7	54.1
910.2	55.2

Table IX. Flux and initial temperature.

3. Results obtained. -

3.1. Water as heat transfer fluid. - In this model following results, as listed in table no. 10, were observed when water was made to flow as HTF with mentioned properties as in table no. 11. The results indicated that the maximum increase in output temperature was 0.7 ºC.

H_2O					
Flux	T_1 (C^0)	T_2 (C^0)	ΔT	% Increase	Q (w/m^2)
830.8	51.3	52	0.7	1.364522417	119.7706
790.6	49.1	49.769	0.669	1.362525458	115.6451
795.9	49.8	50.478	0.678	1.361445783	116.8429
840.3	50.4	51.997	0.597	1.18452381	106.0635
880.7	54.1	54.792	0.692	1.279112754	118.706
910.2	55.2	55.9	0.7	1.268115942	119.7706
	Average Increase in Temp	0.67266667			
	Average % Increase in Temp	1.303374361			
	Average Q	116.1331			

Table X. Results of H_2O as HTF.

H_2O	
Reynolds Number	3033.413
Nusselt Number	30.125
Friction Factor	0.14963362
Prandtl Number	1.05564
Convective Heat Transfer (h) W/(m^2 K)	946.36914

Table XI. Properties of H_2O as HTF.

The Figure VIII given below shows the increase in output temperature and the table shows the different properties of water.

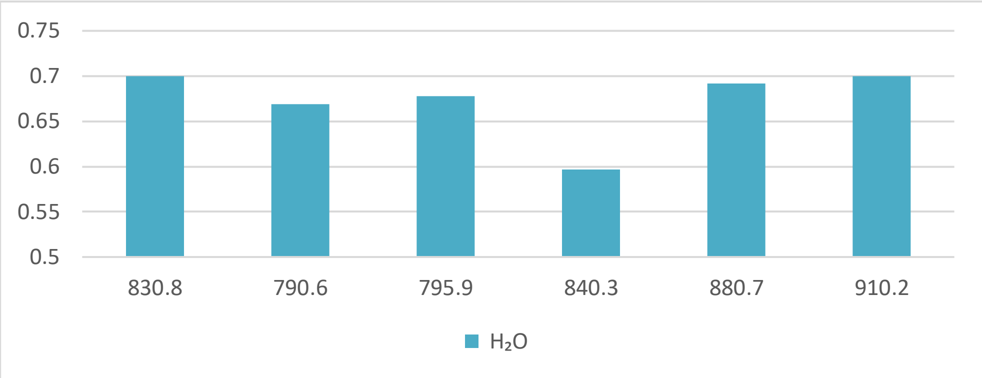

Figure VIII. Increase in the Exit Temperature of H_2O.

3.2. Metallic nano-particles as heat transfer fluid. - In this set up following three metallic nanoparticles were used with water to create metallic nano-fluid at various volumetric percentages ranging from 1% with 0.5% increment to 3%.

- Copper (Cu)
- Gold (Au)
- Silver (Ag)

3.3. Copper + Water nano-fluid. - In family of metallic nano-fluid when the copper-water based nanofluid was opted as working fluid to pass through receiver pipe at different volumetric concentration as 1%, 1.5%, 2%, 2.5% and 3% then the following properties and results were obtained, as shown in table no. 12 and 13 respectively,

Properties	1%	1.5%	2.00%	2.50%	3.00%
Density (Kg/m^3)	1077.98	1117.897	1157.796	1197.695	1237.594
Specific Heat (J/Kg.k)	3865.43	3724.1	3592.511	3469.686	3354.78
Thermal Conductivity (w/m.k)	132.18	133.47	134.76	136.05	137.34
Viscosity (kg/m.s)	0.001028726	0.00104207	0.0010557	0.001069762	0.001084

Table XII. Properties of Cu + H_2O as HTF.

Volumetric Concentration	Average Increase in T_{out}(°C)	Re	Nu	f	Pr	h	Q
1%	0.843667	3193.934	0.1685	0.1604	0.169	81616	216
1.50%	0.8445	3269.79	0.1408	0.1630	0.163	81734	216
2%	0.845	3342.77	0.1395	0.16725	0.122	82519	216
2.50%	0.845833	3412.511	0.1381	0.17150	0.121	83304	216
3%	0.846333	3479.877	0.1369	0.13690	0.119	84090	216

Table XIII. Results of Cu + H_2O as HTF.

The Figure IX given below shows the comparative increase in output temperature. The copper + water based nano fluid shows highest increase of 0.875Co in output temperature at flux with value as 910.2 at volumetric concentration of 3%.

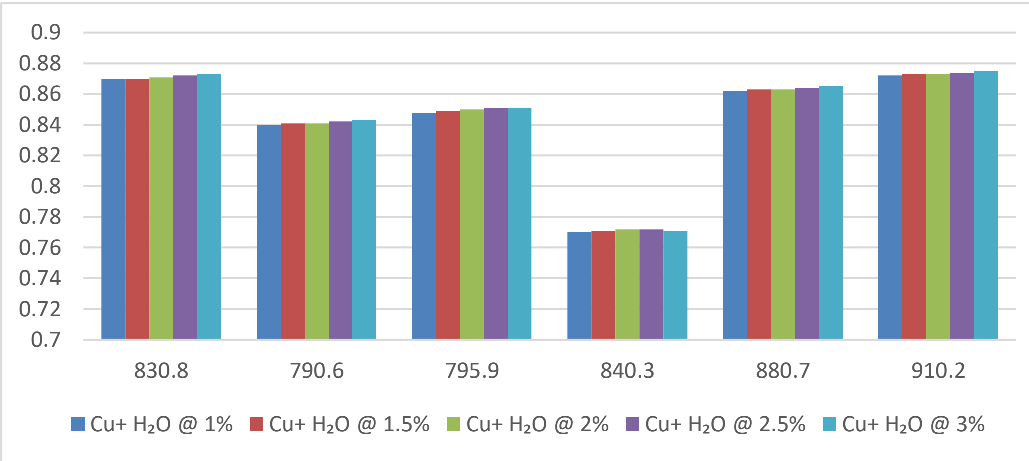

Figure IX. Increase in the Exit Temperature of Cu + H_2O.

3.4. Gold-water based nano-fluid. - Similarly, when the gold-water based ano fluid was used as heat transfer fluid through the pipe at different volumetric concentration as 1%, 1.5%, 2%, 2.5% and 3% then the following properties & result were obtained;

Properties	1%	1.5%	2.00%	2.50%	3.00%
Density (Kg/m^3)	1181.418	1273.027	1364.636	1456.245	1547.854
Specific Heat (J/Kg.k)	3519.336	3259.53	3034.615	2837.99	2664.641
Thermal Conductivity (w/m.k)	101.629	102.614	103.6	104.5955	105.5859
Viscosity (kg/m.s)	0.00102	0.00104	0.00105	0.00106	0.00108

Table XIV. Properties of Au + H_2O as HTF.

Volumetric Concentration	Average Increase in T_{out} (ºC)	Re	Nu	f	Pr	h	Q
1%	0.8465	3500.409	0.1849	0.167	0.155	62340	216
1.50%	0.847667	3723.505	0.1832	0.175	0.153	62926	217
2%	0.849333	3939.768	0.1814	0.184	0.151	63516	217
2.50%	0.850833	4149.187	0.1797	0.192	0.149	64114	220
3%	0.852	4352.268	0.1780	0.201	0.147	6479	220

Table XV. Increase in the Exit Temperature of Au + H_2O.

The result in figure no. 10 shows that there was maximum increase of 0.89Co in output temperature of gold + water-based nano-fluid at flux value of 880.7 with volumetric concentration of 3.0%.

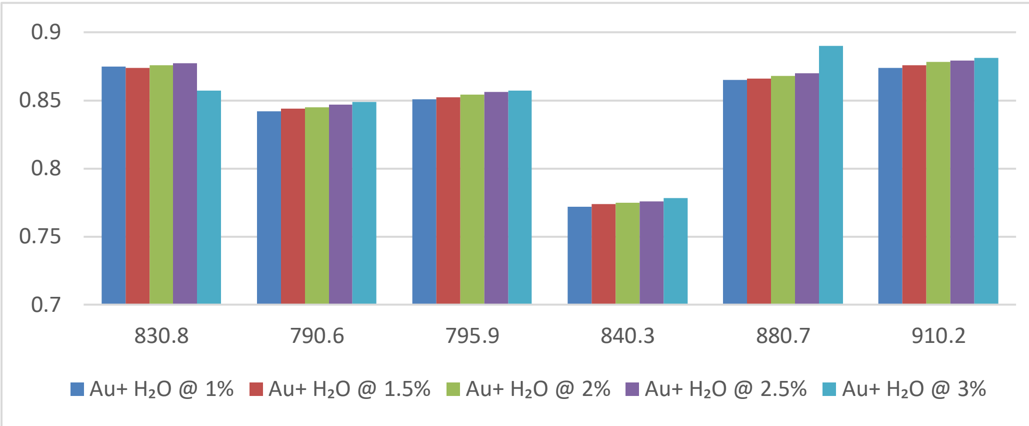

Figure X. Increase in the Exit Temperature of Au + H_2O.

3.5. Silver-water based nano-fluid. - Further, when the silver-water based nano-fluid was used as heat transfer fluid through the pipe at different volumetric concentration as 1%, 1.5%, 2%, 2.5% and 3% then the following result were obtained;

Properties	1%	1.5%	2.00%	2.50%	3.00%
Density (Kg/m^3)	1093.218	1140.727	1188.236	1235.745	1283
Specific Heat (J/Kg.k)	3803.2539	3637.5419	3485.012	3344.3436	3214
Thermal Conductivity (w/m.k)	138.2539	139.787	141.1386	142.49	144
Viscosity (kg/m.s)	0.00102	0.00104	0.00105	0.00106	0.00108

Table XVI. Properties of Ag + H2O as HTF.

Fig. 10 – Increase in the Exit Temperature of Au + H_2O

Vol. Concen.	Ave. Inc. in T_{out} (°C)	Re	Nu	f	Pr	h	Q
1%	0.845333	3239	0.135	0.16	0.12	84764	216
1.50%	0.8465	3336	0.134	0.17	0.12	85586	216
2%	0.848667	3430	0.133	0.17	0.12	86409	216
2.50%	0.850333	3520	0.131	0.17	0.12	87232	220
3%	0.851833	3607	0.13	0.18	0.11	88055	220

Table XVII. Results of Ag + H_2O as HTF.

The following chart clearly shows that silver + water based nano fluid has highest increase of 0.88Co in output temperature at flux value of 910.2 with volumetric concentration of 3%.

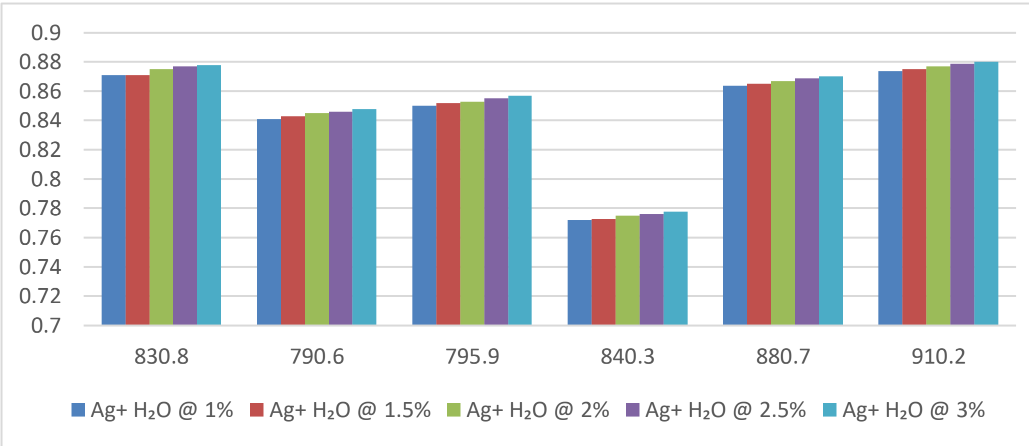

Figure XI. Increase in Exit Temperature of Ag + H_2O.

3.6. Non-metallic nano-particles as heat transfer fluid. - After metallic nanoparticles two different non-metallic nanoparticles were used with water to create water based non-metallic nano-fluids with volumetric concentration ranging from 1% to 3%.

- Alumina Oxide (Al_2O_3)
- Copper Oxide (CuO)

3.7. Alumina-water based nano-fluid. - When the alumina-water based Nano fluid was used as heat transfer fluid through the pipe at different volumetric concentration as 1%, 1.5%, 2%, 2.5% and 3% then the following properties & result were obtained;

Properties	1%	1.5%	2.00%	2.50%	3.00%
Density (Kg/m3)	1027.52	1042.477	1057.236	1071.995	1086
Specific Heat (J/Kg.k)	4055.677	3994.044	3934.89	3877.365	3821
Thermal Conductivity (w/m.k)	10.596	10.694	10.792	10.89	10.988
Viscosity (kg/m.s)	0.00102	0.00104	0.00105	0.00105	0.0011

Table XVIII. Properties of Al_2O_3 + H_2O as HTF.

Vol. Concent.	Average Increase in T_{out} (°C)	Re	Nu	f	Pr	h	Q
1%	0.872667	3044	1.769	0.154	0.675	9421	280
1.50%	0.874	3049	1.75	0.156	0.672	9498	301
2%	0.874	3052	1.737	0.158	0.670	9575	330
2.50%	0.874333	3090	1.72	0.16	0.66	9658	332
3%	0.875	3055	1.73	0.16	0.66	9727	351

Table XIX. Results of Al_2O_3 + H_2O as HTF.

The chart given below shows the comparative increase in output temperature at different flux values. From this chart it is clearly visible that there is maximum increase of 0.904Co in exit temperature at flux value of 910.2 with volumetric concentration of 2.5% & 3%.

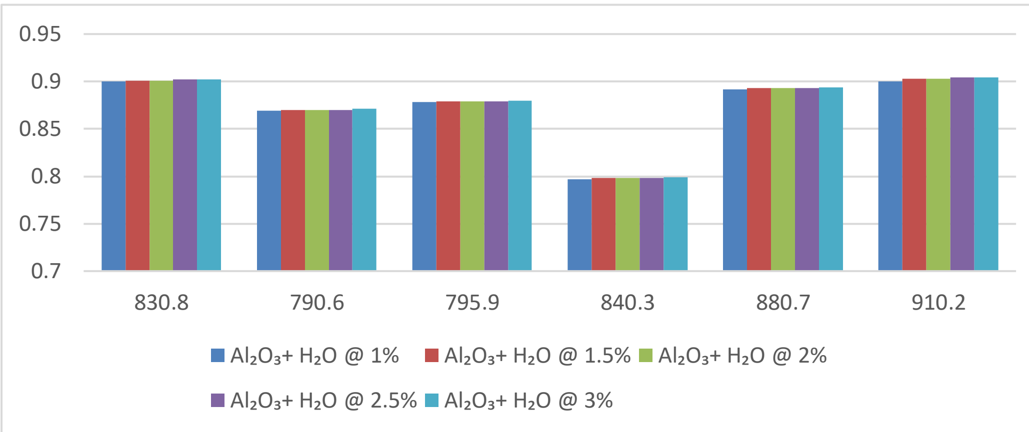

Figure XII. Increase in Exit Temperature of Alumina Oxide + H_2O.

3.8. Copper-oxide-water based nano-fluid. - Furthermore, when the Copper Oxide -water based nano fluid was used as heat transfer fluid through the pipe at different volumetric concentration as 1%, 1.5%, 2%, 2.5% and 3% then the following properties & result were obtained as:

Properties	1%	1.5%	2.00%	2.50%	3.00%
Density (Kg/m^3)	1051.31	1077.877	1104.436	1130.995	1157.554
Specific Heat (J/Kg.k)	3965.5	3865.2094	3769.77	3678.812	3592.02
Thermal Conductivity (w/m.k)	26.372	26.624	26.87733	27.13	27.382666
Viscosity (kg/m.s)	0.0010	0.001	0.001	0.0010	0.0011

Table XX. Properties of CuO + H_2O as HTF.

Vol. Concent.	Average Increase in T_{out} (°C)	Re	Nu	f	Pr	h	Q
1%	0.853333333	3114	0.711	0.156	0.429	20976	218.9
1.50%	0.864	3153	0.704	0.159	0.423	21106	220
2%	0.855166667	3191	0.69	0.16	0.422	21305	219
2.50%	0.854666667	3228	0.68	0.16	0.416	21658	219
3%	0.854833333	3255	0.68	0.169	0.464	21616	219.6

Table XXI. Results of CuO + H_2O as HTF.

The bar chart given below shows that copper oxide + water-based Nano fluid shows maximum increase of 0.893Co in output temperature with volumetric concentration of 3% at flux value of 910.2

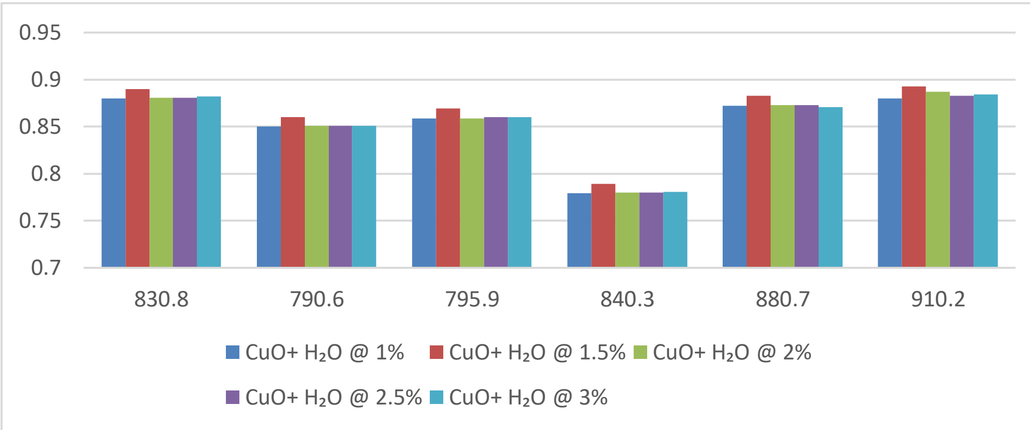

Figure XIII. Increase in Exit Temperature of CuO+H_2O.

4. Comparison in different properties. -

4.1. Average increase in temperature. - The following bar chart presents the comparison in average increase in temperature among metallic and nonmetallic nano fluids at different volumetric concentrations. It reveals that alumina + water based nano fluid possesses larger value of average increase in temperature at 3% volumetric concentration with average Reynolds number of 3058.459, lesser than other nano-fluids, and with highest value of average Nusselt number 1.7068 (higher than other nano-fluids).

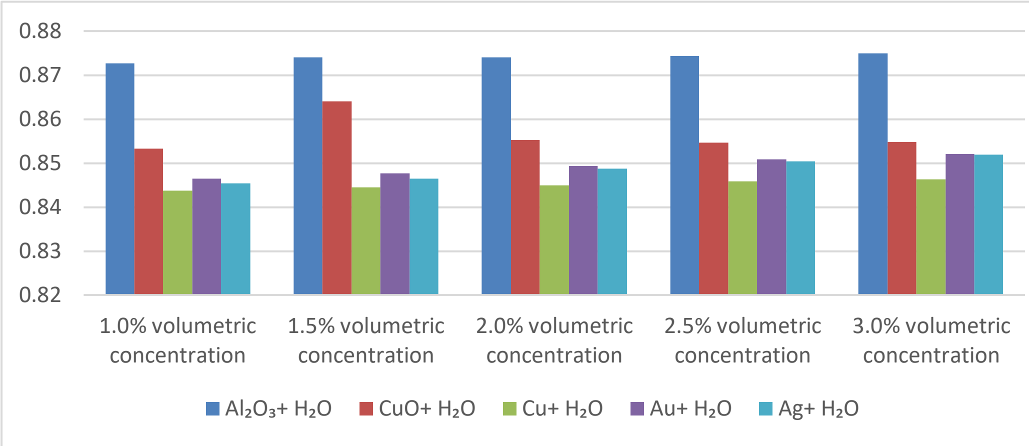

Figure XIV. Comparison in Average Temperature increase.

Whereas copper + water-based Nano fluid possesses the lowest value of average increase in temperature at 1% volumetric concentration.

4.2. Heat Transfer. - The figure no. 15 presents the comparison in average rate of heat transfer in five nano-fluids at various volumetric concentration from 1% to 3% with an increment of 0.5. The chart shows that there is maximum heat transfer in alumina oxide + water-based Nano-fluid at 3% volumetric concentration with value of 351.89 watt. The highest heat transfer is due to higher value of Nusselt number in comparison to other nano-fluids.

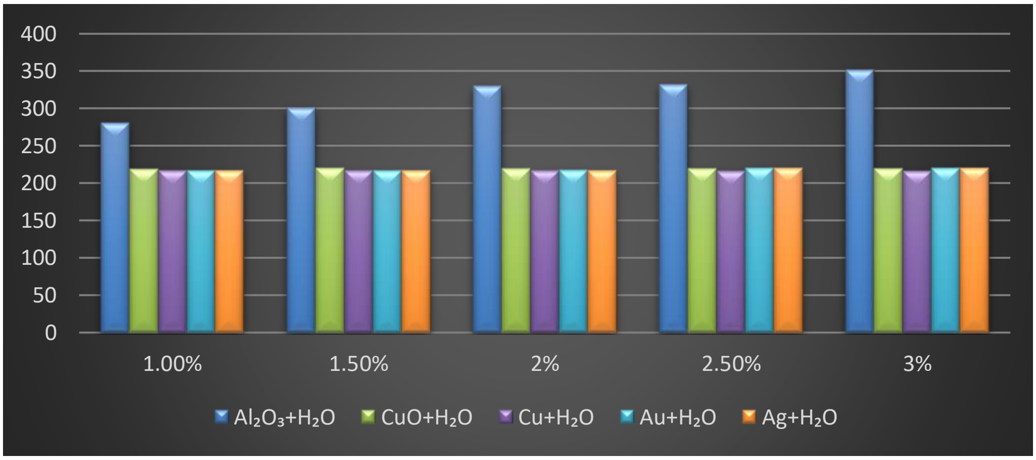

Figure XV. Comparison in Heat Transfer.

4.3. Convective heat transfer coefficient. - Further, the following bar chart in Figure XVI represents the comparison of coefficient of convective heat transfer among five different Nano-fluids. The following bar charts shows that silver + water-based Nano-fluid possesses the higher value of 88055.5 W/(m2 K) at 3% volumetric concentration, because of the higher value of thermal conductivity as 143.84133 W/m K, whereas the alumina + water-based Nano fluid possesses the lowest value of coefficient of convective heat transfer at 1% volumetric concentration.

https://doi.org/10.36561/ING.25.10
ISSN 2301-1092 • ISSN (en línea) 2301-1106

Furthermore, it also highlights the increase in convective heat transfer of metallic Nano-fluids with increasing volumetric concentration.

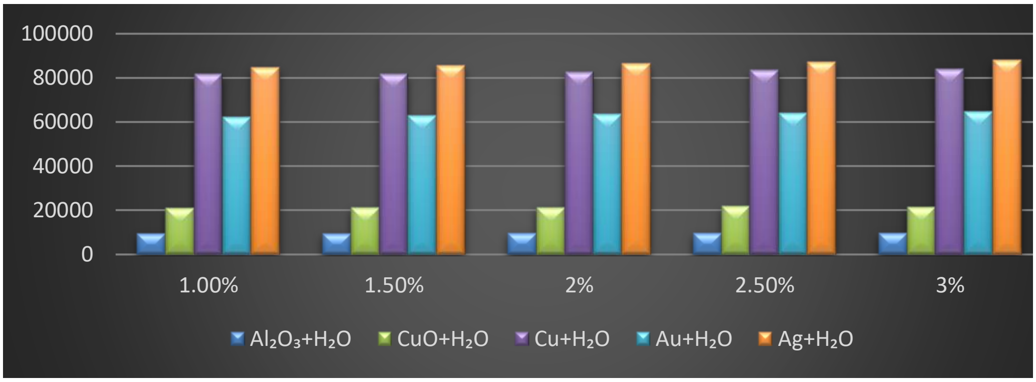

Figure XVI. Comparison in Coefficient of Convective Heat.

4.4. Reynolds number. - Reynolds Number is also an important property of a flowing fluid which decides the nature of flow. The following bar chart provides a brief comparison among different metallic and non-metallic Nano fluids. It can be seen from the Figure XVII that gold + water-based Nano fluid possesses higher value of Reynolds Number which is due to high density of gold nanoparticle. Whereas alumina + water-based nano-fluid possesses the lowest value at 1% volumetric concentration.

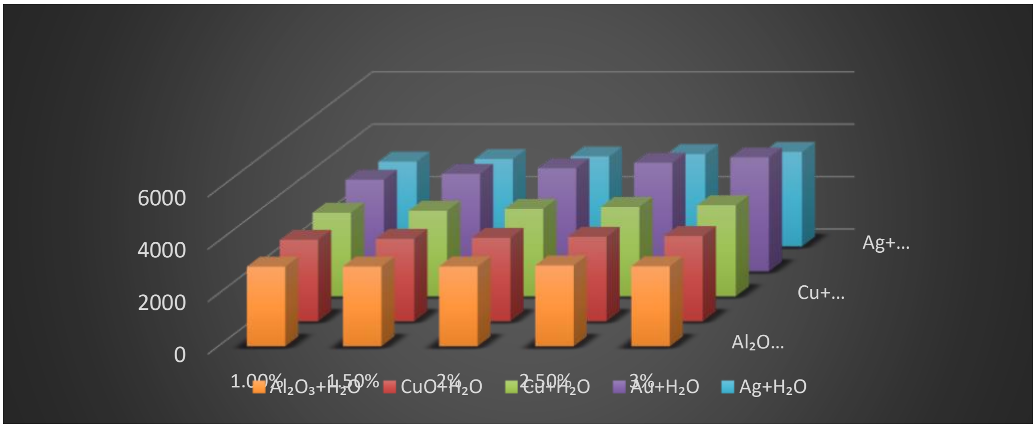

Figure XVII. Comparison in Reynolds Number.

4.5. Nusselt Number. - The ratio of convective heat transfer to conduction heat transfer is called Nusselt number. It is a dimensionless number. For assessment of heat transfer and fluid flow Nusselt number is also an important parameter. The following bar chart shows comparison of Nusselt number between metallic and non-metallic Nano fluids. It can be seen, from the bar chart, that alumina + water based nano fluid possesses higher value of Nusselt number as compared to others. Since, the Nusselt number depends upon the Prandtl number and further the Prandtl number depends upon the specific heat therefore the Nusselt number is higher because of higher value of specific heat in case of alumina + water based nano fluid.

https://doi.org/10.36561/ING.25.10
ISSN 2301-1092 • ISSN (en línea) 2301-1106

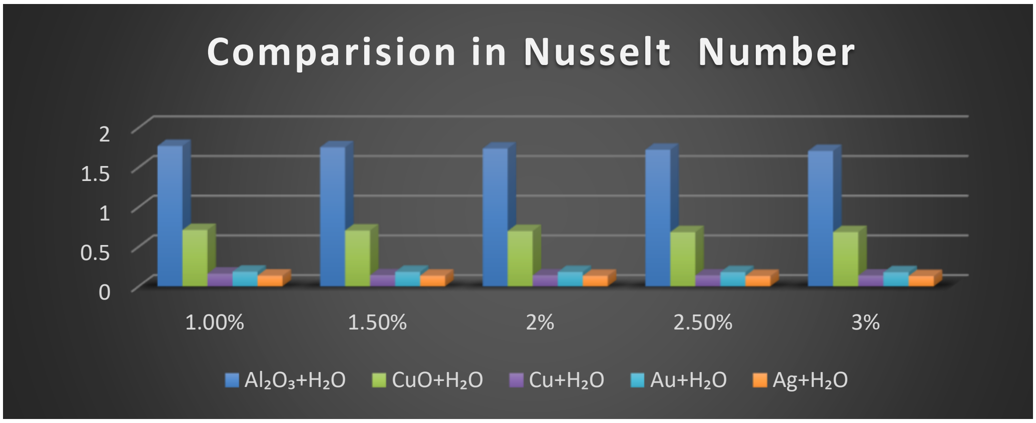

Figure XVIII. Comparison in Nusselt Number.

5. Conclusion. - A validated CFD model was used to investigate the effect of different Nanoparticles on the performance enhancement of parabolic trough system. When water was used as working fluid through PTC the software reported an average increase of 0.672C0 in the output temperature value of the working fluid with 116.1331W/m2 average heat transfer rate. While, other metallic and nonmetallic water-based Nano fluid, when used as heat transfer fluid, showed following behavior.

- In case of increase in the exit temperature of nano fluid the maximum average increase in output temperature, which is 0.875 K, is reported in alumina + water based nano fluid at 3% volumetric concentration. Whereas the maximum increase in output temperature is 0.904 K and reported at flux value of 910.2 W/m2 in alumina + water-based Nano fluid at 2.5 % and 3% volumetric concentration.
- The maximum average heat transfer is reported as 351.89 watt in aluminum oxide + water based nanofluid at 3% volumetric concentration.
- Further, the results show that there is a maximum average value of coefficient of convective heat transfer as 88055.5 W/(m2 K) in case of silver + water-based nano-fluid at 3% volumetric concentration.
- Moreover, it is also observed that gold + water-based Nano fluid possesses higher average value of Reynolds Number which is 4352.268.
- Furthermore, it is also observed that in all five metallic and nonmetallic water based nano fluids alumina + water-based Nano fluid possesses higher average value of Nusselt number which is 1.7698.

6. Nomenclature. –

A	Receiver Tube Area (m^2)
C_p	Specific heat (W/Kg.K)
D	Outer dia of glass envelop(m)
f	Factor of Friction
H	air coefficient convective heat transfer (W/m2.K)
k	Thermal conductivity (W/m.K)
N_u	Nusselt Number
P_r	Prandtl number
Qconv	Heat transfer rate, (W/m)
R_e	Reynolds Number
Tab,i	Receiver Temperature (K)
T_{HTF}	Working Fluid temperature (K)
V	Velocity (m/s)
ρ	Density (kg/m3)

% Error	Relative error of a measurement (%)
η	Collector thermal efficiency

I	Solar irradiation
W	width of collector (m)
L	length of collector (m)
K	Incident angle modifier
T^*	Reduced temperature (m^2K/W)
Ω_o	Peak thermal efficiency
α	Coefficient of thermal losses (W/m^2K)

Greek symbols

υ	Kinematic viscosity

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Nota contribución de los autores:

1. Concepción y diseño del estudio
2. Adquisición de datos
3. Análisis de datos
4. Discusión de los resultados
5. Redacción del manuscrito
6. Aprobación de la versión final del manuscrito

MAA ha contribuido en: 1, 2, 3, 4, 5 y 6.

MU ha contribuido en: 1, 2, 3, 4, 5 y 6.

Nota de aceptación: Este artículo fue aprobado por los editores de la revista Dr. Rafael Sotelo y Mag. Ing. Fernando A. Hernández Gobertti.