Research Article

Combined Experimental and CFD Investigation of the Parabolic Shaped Solar Collector Utilizing Nanofluid (CuO-H₂O and SiO₂-H₂O) as a Working Fluid

Ketan Ajay and Lal Kundan

Mechanical Engineering Department, Thapar University, Patiala 147001, India

Correspondence should be addressed to Ketan Ajay; ketan.bhardwaj88@gmail.com

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Nanoscience application plays a major role in heat transfer related problems. A nanofluid is basically a suspension of fine sized nanomaterials in base fluids like water, Therminol VP-1, ethylene glycol, and other heat transfer fluids. This paper evaluates the possible application of nanofluid in parabolic shaped concentrating solar collector using both experimental and CFD analysis. Different types of nanomaterials used are SiO₂ and CuO of 20 nm average size. Nanofluids of SiO₂-H₂O (DI) and CuO-H₂O (DI) of 0.01% volume concentration are used. Flow rates of 40 LPH and 80 LPH are used. ANSYS FLUENT 14.5 is used for carrying out CFD investigation. 3D temperature distribution of absorber tube is obtained using numerical investigation and the result is compared with the experimental one. Improvement in efficiency of collector of about 6.68% and 7.64% is obtained using 0.01% vol. conc. SiO₂-H₂O (DI) nanofluid and 0.01% vol. conc. CuO-H₂O (DI) nanofluid, respectively, as compared to H₂O (DI) at 40 LPH while at 80 LPH improvement in efficiency of collector of about 7.15% and 8.42% is obtained using 0.01% vol. conc. SiO₂-H₂O (DI) nanofluid and 0.01% vol. conc. CuO-H₂O (DI) nanofluid, respectively, as compared to H₂O (DI). Both experimental and CFD temperature results are in good agreement.

1. Introduction

1.1. Solar Energy. Owing to the increasing rate of development and modernization, great threat has been posed to conventional resources like coal, oil, and so forth as their reserves have marginally become scarce [1]. To overcome such problem, different means of powering our life have been sorted which are basically everlasting and above all are eco-friendly. One of the means which fulfill such desired need is solar energy [2]. Solar energy is the immense and splendid gift bestowed upon us by God. It has been estimated that Earth receives about 1.8×10^{11} MW amount of energy a year [3]. Various different devices have been developed from time to time to harness this energy like flat plate collector, parabolic concentrating solar collector, heliostats, and so forth [4]. Efficiency of such collector is dependent upon numerous factors like intensity of solar radiation, absorber material, design and concentration ratio of solar collector, and nature

and thermophysical properties of the working fluid [5]. Solar collector is basically a heat exchanger where solar energy is transferred to the working fluid flowing in the absorber tube [6]. Applicability of solar collector depends upon the output received from solar collector [7]. Flat plate collector is mainly used for domestic heating purpose while parabolic shaped concentrating solar collector is used for producing steam, which in turn is helpful in producing power [8].

1.2. Nanotechnology in Working Fluid. In order to achieve better heat transfer rate and to have efficient heat exchangers, this can be done by changing the nature and properties of working fluids or by incorporating nanofluid rather than normal working fluid [9]. Suspension of fine sized nanomaterials in base fluids is called nanofluid [10]. Nanomaterials of different materials like gold, silver, copper, aluminum, or carbon nanotubes or their corresponding oxides are used in base fluids like water, ethylene glycol, and so forth [11].

FIGURE 1: Schematic flow diagram of an experimental study.

Nanofluid possess enhanced thermal conductivity and better heat transfer coefficient as compared with base fluid [12]. Nanofluid is basically prepared by two means: (1) two-step method and (2) one-step method [13]. Some of the advantages of using nanofluid in solar collector as working fluid are as follows: (a) nanofluid absorbs energy directly, so there is no intermediate heat transfer [14]; (b) absorptivity value is high in solar range, while in infrared range the nanofluid's emissivity is low [15]; (c) due to enhanced thermophysical properties, system efficiency is enhanced [16]. Taylor et al. [17] have experimentally found that by using nanofluid of Al_2O_3 - H_2O (0.01% vol. conc.) system performance is enhanced by around 10.12%. Khullar and Tyagi [18] have conducted finite difference technique to evaluate the efficiency of parabolic shaped solar collector having 0.05% vol. conc. of Al_2O_3 - H_2O nanofluid and have concluded that the system performance is enhanced by around 6.7% as compared with conventional working fluid. Chaji et al. [19] carried out experimental analysis to study the effect of Al_2O_3 nanofluid in heat transfer enhancement and have found out that system performance is enhanced when water is replaced by alumina nanofluid.

2. Experimental Methodology

Detailed schematic diagram showing various components involved in the study is shown in Figure 1. Specifications of the parabolic solar collector are shown in Table 1. The three different working fluids used are water, nanofluid of 0.01% CuO - H_2O , and nanofluid of 0.01% SiO_2 - H_2O (DI), where working fluid is made to flow at flow rates of 40 LPH and 80 LPH. Main components of the parabolic solar collector are absorber tube (HCE), reflector, and storage tank with associated pumping arrangement and insulating piping arrangement. Reflector is mainly made of mirror strips placed all over the parabolic shaped structure which is shown in Figure 2.

Absorber tube is insulated with the help of glass cover so as to avoid the radiation losses. Manual tracking arrangement is used to track the solar collector. Experiment is mainly conducted from 9.30 a.m. to 2.30 p.m.

2.1. Working Procedure. Working fluid (7 liters) from the insulated storage tank is made to pass through absorber tube

TABLE 1: Specifications of parabolic shaped concentrating solar collector.

Parameter	Value
Collector length, L	1.20 m
Collector breadth, W	0.915 m
End plate thickness	2 mm
Aperture area, $A_{\text{aper.}}$	1.0188 m^3
Rim angle	90 degrees
Focal length	0.30 m
Receiver inside diameter (D_i)	0.027 m
Receiver outside diameter (D_o)	0.028 m
Receiver length	1000 nm
Glass envelope inside diameter (D_{ci})	0064 nm
Glass envelope outside diameter (D_{co})	0.066 nm
Insulation on pipes	Aluminum foil, Superlon
Concentration ratio, C_r	9.66

FIGURE 2: Parabolic reflector and absorber tube along with glass cover.

which is made of copper tube and is black coated. Flow is regulated via flow control valve. Flow rates of 40 LPH and 80 LPH are used. Working fluid after receiving both incoming solar radiation and concentrated solar radiation which are concentrated in absorber tube with the help of reflector is made to enter into a storage tank from where again flow is circulated with the help of pump placed inside the storage tank. Temperature of both inlet and outlet fluid is measured with the help of thermometer placed at both inlet and outlet of the absorber tube. Solar power meter is used to measure the solar flux, while wind velocity is measured through anemometer. Recording of inlet and outlet temperature, solar flux, and wind velocity is measured from 9.30 a.m. till 2.30 p.m. with an interval of 30 min. Solar collector is tracked throughout the day with the help of manual tracking arrangement incorporated in the system.

2.2. Nanofluid Preparation. Nanofluid of 0.01% vol. conc. SiO_2 - H_2O (DI) and 0.01% vol. conc. CuO - H_2O (DI) is prepared by dispersing the known weight of nanomaterials of both SiO_2 and CuO nanomaterials, respectively, in a known volume of H_2O (DI) so as to have a volume concentration of 0.01%. Table 2 shows the amount of nanoparticles required for the formation of nanofluid (for 1 liter). Mixture so

TABLE 2: Amount of nanoparticles required for the preparation of nanofluid (1 liter).

Sample	Amount of nanoparticles required (grams)
SiO ₂ -H ₂ O (DI) (0.01% vol. conc.)	0.265
CuO-H ₂ O (DI) (0.01% vol. conc.)	0.632

FIGURE 3: Ultrasonic water bath.

FIGURE 4: Prepared sample of 0.01% vol. conc. SiO₂-H₂O (DI) nanofluid.

prepared is then stirred in a magnetic stirrer for around 30 minutes.

Then, the stirred mixture is then placed into a sonicator tank of ultrasonicator, where sonication of nanofluid is done for around 2 hours as shown in Figure 3, where ultrasonic rays are made to traverse through the fluid where nanoparticles are broken down, from where fine dispersed nanofluid is prepared which is then ready to be used in the system. Figures 4 and 5 show the prepared sample of 0.01% vol. conc. SiO₂-H₂O and 0.01% vol. conc. CuO-H₂O, respectively. For better stability of a nanofluid, CTAB (hexadecyltrimethylammonium bromide) as surfactant is used [20, 21]. Moreover, pump is also placed within the storage tank in order to avoid the settling of the nanoparticles [22].

FIGURE 5: Prepared sample of 0.01% vol. conc. CuO-H₂O (DI) nanofluid.

2.3. Governing Equations Used for Evaluating the Various Thermophysical Properties of the Nanofluid

(1) Density of nanofluid [20] is expressed by

$$\rho_{nf} = f_v \rho_{np} + (1 - f_v) \rho_{bf}, \quad (1)$$

where ρ_{np} , ρ_{nf} , and ρ_{bf} are the density of nanoparticle (kg/m^3), density of nanofluid (kg/m^3), and density of base fluid (kg/m^3), respectively, and f_v is the volume concentration of nanofluid.

(2) Specific heat of nanofluid [20] is expressed by

$$C_{nf} = \frac{f_v \rho_{nf} C_{np} + (1 - f_v) \rho_{bf} C_{bf}}{\rho_{nf}}, \quad (2)$$

where C_{nf} , C_{np} , and C_{bf} are the specific heat of the nanofluid, nanoparticle, and base fluid, respectively, in $\text{J/kg}\cdot\text{K}$.

(3) Thermal conductivity of nanofluid [20] is expressed by

$$K_{nf} = \left[\frac{K_{np} + 2K_{bf} + 2f_v (K_{np} - K_{bf})}{K_{np} + 2K_{bf} - f_v (K_{np} - K_{bf})} \right] K_{bf}, \quad (3)$$

where K_{nf} , K_{bf} , and K_{np} are the thermal conductivity of the nanofluid, base fluid, and nanoparticle, respectively, in $\text{J/kg}\cdot\text{K}$.

(4) Dynamic viscosity of nanofluid [20] is expressed by

$$\mu_{nf} = \frac{\mu_{bf}}{(1 - f_v)^{2.5}}, \quad (4)$$

where μ_{nf} and μ_{bf} are the dynamic viscosity of the nanofluid and base fluid, respectively.

TABLE 3: Various thermophysical properties of different materials associated with HCE.

Thermophysical properties	Water	SiO ₂ -water based nanofluid (0.01% vol. conc.)	CuO-water based nanofluid (0.01% vol. conc.)	Glass
Density (kg/m ³)	1000	1014	1054	2200
Specific heat (J/kg·K)	4187	4106	3.965	910
Thermal conductivity (W/m·K)	0.667	0.6723	0.6870	1.75
Viscosity (m ² /s)	0.415e – 6	0.411e – 6	0.396e – 6	—

FIGURE 6: Geometric model of HCE (absorber tube).

3. Computational Fluid Dynamics (CFD) Methodology

ANSYS FLUENT 14.5 is used for simulating the absorber tube (HCE) of parabolic shaped concentrating solar collector, where nanofluid is made to flow. Nanofluid is simulated using one-phase modelling techniques [23], while solar load cell and solar ray tracing are used for modelling the solar fluxes. Various different steps adopted for conducting CFD simulation are shown below.

3.1. Domain Description and Meshing. Firstly, the 3-dimensional geometry of heat collector element is created which is shown in Figure 6. Geometry is so created which includes HCE along with glass tube. HCE tube is made to split into two parts, namely, upper and lower part.

Upper part is mainly incident by incoming solar radiation while lower part is incident by reflected and concentrated solar radiation with the help of mirror reflector. Annular fluid zone for vacuum is also included. Three-dimensional geometry is made to orient along z-axis where south direction is indicated along positive Z while east direction is denoted by positive X. Tetrahedral mesh is done over a fluid domain of absorber tube. Figure 7 shows the meshed geometry of absorber tube.

3.2. Material Model. In ANSYS FLENT 14.5, material model is applied. In material model, various thermophysical properties of the material are specified. Table 3 shows the thermophysical properties of the various materials involved with absorber tube.

FIGURE 7: Meshed model of HCE (absorber tube).

TABLE 4: Various boundary conditions applied over HCE.

Inlet	Mass flow rate
Outlet	Out flow
Wall (upper)	Solar radiation as calculated by solar load cell and no slip condition
Wall (lower)	Heat flux (concentrated by mirror reflector)

3.3. Boundary Conditions. Boundary conditions are applied for carrying out numerical simulation. For numerical simulation of nanofluid based solar collector, the following boundary conditions are imposed which are depicted in Table 4.

3.4. Solar Load Model. Solar load model is applied for numerical simulation, where typical inputs include day and time of the experiment and longitude and latitude of location. By substituting the input values, CFD solar load cell will calculate the direct and solar radiation. S2S (surface-to-surface) radiation model is applied for modeling the radiation mode of heat transfer between diffuse surfaces involved in the system.

3.5. Numerical Methodology. The following governing equations are applied for carrying out numerical simulation.

(a) Continuity equation is given as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0. \quad (5)$$

(b) Momentum equation is given as follows:

$$\rho \frac{Du}{Dt} = \frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u \vec{V}). \quad (6)$$

TABLE 5: Details of grids used in mesh-independence test for water as working fluid at 40 LPH.

Grid size	Outlet temperature (K)
152880	323.12
267860	323.55
365770	324.71
403450	324.72

TABLE 6: Details of grids used in mesh-independence test for 0.01% SiO₂-H₂O as working fluid at 40 LPH.

Grid size	Outlet temperature (K)
152880	323.72
287890	324.15
398760	326.31
445340	326.36

TABLE 7: Details of grids used in mesh-independence test for 0.01% CuO-H₂O as working fluid at 40 LPH.

Grid size	Outlet temperature (K)
152880	323.52
295660	324.28
356790	325.94
406750	325.96

TABLE 8: Details of grids used in mesh-independence tests for H₂O as working fluid at 80 LPH.

Grid size	Outlet temperature (K)
152880	323.87
215660	324.38
334560	325.21
367890	325.22

(c) Energy equation is given as follows:

$$\rho \frac{De}{Dt} = \frac{\partial(\rho e)}{\partial t} + \nabla \cdot (\rho e \vec{V}). \quad (7)$$

The first-order upwind differencing scheme is implemented for the momentum and energy equations. Residual target of 10^{-4} is used for monitoring convergence criterion except for the energy equation, for which a target of 10^{-7} is used.

3.6. Grid Independence Test. Mesh sensitivity analysis is carried out for each condition of a working fluid. Tables 5–10 illustrate the same.

4. Results

4.1. Governing Equation for Efficiency Calculation. The following different governing equations are used for evaluating the parabolic solar collector's efficiency with different working fluids at different mass flow rates.

TABLE 9: Details of grids used in mesh-independence test for 0.01% SiO₂-H₂O as working fluid at 80 LPH.

Grid size	Outlet temperature (K)
152880	326.17
235660	326.28
364560	327.74
437890	327.77

TABLE 10: Details of grids used in mesh-independence test for 0.01% CuO-H₂O as working fluid at 80 LPH.

Grid size	Outlet temperature (K)
152880	325.11
265670	326.28
384990	326.84
429810	326.85

(1) Absorbed flux is represented by

$$S = G_T R_b (\alpha \tau) \beta Y. \quad (8)$$

(2) Convective heat transfer coefficient is represented by

$$h_f = N_u \times \frac{k}{D_i}, \quad (9)$$

where $N_u = 0.023 \times \text{Re}^{0.8} \times \text{Pr}^{0.4}$,

$$\begin{aligned} \text{Pr} &= \frac{(\mu \times C_p)}{k}, \\ \text{Re} &= \frac{(\rho \times V \times D_i)}{\mu}, \\ V &= \frac{(4\dot{m})}{(\pi \times D_i^2 \times \rho)}. \end{aligned} \quad (10)$$

(3) Useful heat gain is represented by

$$q_u = \dot{m} C_p (T_{\text{out}} - T_{\text{in}}). \quad (11)$$

(4) Instantaneous efficiency, η_i , is represented by

$$\eta_i = \frac{\dot{m} C_p (T_{\text{out}} - T_{\text{in}})}{G_T R_b W L}. \quad (12)$$

(5) Thermal efficiency, η_t , is represented by

$$\eta_t = \frac{\dot{m} C_p (T_{\text{out}} - T_{\text{in}})}{G_T A_{\text{aper}} t}. \quad (13)$$

(6) Overall efficiency, η_o , is represented by

$$\eta_o = \frac{\dot{m} C_p (T_{\text{out}} - T_{\text{in}})}{G_{\text{avg}} A_{\text{aper}}}, \quad (14)$$

FIGURE 8: Temperature contours with water as a working fluid in HCE at 40 LPH.

FIGURE 9: Temperature contour with $\text{SiO}_2\text{-H}_2\text{O}$ (DI) as a working fluid in HCE at 40 LPH.

FIGURE 10: Temperature contour with $\text{CuO-H}_2\text{O}$ (DI) as a working fluid in HCE at 40 LPH.

where G_T is global solar intensity in W/m^2 , R_b is bond resistance, α is absorptivity of the absorber tube, τ is glass cover transmissivity for solar radiation, β is specular reflectivity, Y is intercept factor, N_u is Nusselt number, K is thermal conductivity in $\text{W/m}\cdot\text{K}$, D_i is inner diameter of absorber tube in m, Pr is Prandtl number, μ is dynamic viscosity in $\text{Pa}\cdot\text{s}$, C_p is specific heat in $\text{J/kg}\cdot\text{K}$, ρ is density in kg/m^3 , Re is Reynolds number, V is average velocity in m/s , $\dot{m}$ is mass flow rate in kg/sec , W is width of the solar collector in m, L is the length of the absorber tube in m, A_{aper} is the aperture area of the solar collector in m^2 , t is the time duration, and G_{avg} is the average value of solar radiation in W/m^2 .

4.2. CFD Temperature Contours. Figures 8–13 show the temperature contour with water, 0.01% vol. conc. $\text{SiO}_2\text{-H}_2\text{O}$ (DI) nanofluid, and 0.01% vol. conc. $\text{CuO-H}_2\text{O}$ nanofluid as working fluid at flow rates of 40 LPH and 80 LPH, respectively. All the temperature contours are for a simulation conducted from 12 to 12.30 p.m. It has been seen that maximum temperature rise is seen when $\text{CuO-H}_2\text{O}$ (DI) nanofluid is used as compared to water and $\text{SiO}_2\text{-H}_2\text{O}$ (DI) nanofluid. Also

FIGURE 11: Temperature contour with H_2O (DI) as a working fluid in HCE at 80 LPH.

FIGURE 12: Temperature contour with $\text{SiO}_2\text{-H}_2\text{O}$ as a working fluid in HCE at 80 LPH.

FIGURE 13: Temperature contour with $\text{CuO-H}_2\text{O}$ as a working fluid in HCE at 80 LPH.

higher value of temperature gain is seen when a particular working fluid is made to flow at 80 LPH as compared to flow rate of 40 LPH.

4.3. Variation of Temperature Rise with Time of Day

4.3.1. Water as a Working Fluid. Variations of temperature rise, both experimentally calculated and simulated values with time of day, when water is made to flow within the HCE (absorber tube) at 40 LPH and 80 LPH, are shown in Figures 14 and 15, respectively. It is seen that maximum temperature rise (both experimental and simulated values at each flow rate) increases as the time progressed and after that it remains the same, but after 12 at noon, drop

FIGURE 14: Variation of temperature rise with time of day for water as a working fluid at 40 LPH.

FIGURE 15: Variation of temperature rise with time of day for water as a working fluid at 80 LPH.

in the temperature rise takes place which is mainly due to increased radiation heat transfer, as the fluid gained sufficient energy. Maximum temperature rise of 3.7°C and 4.4°C is seen at 11-11.30 a.m. for flow rates of 40 LPH and 80 LPH, respectively. Also, when working fluid flow rate is increased from 40 LPH to 80 LPH, a higher value of temperature gain is seen. Moreover, both experimentally calculated and simulated values of temperature rise are in close agreement with a maximum difference of 7%.

4.3.2. 0.01% Vol. Conc. $\text{SiO}_2\text{-H}_2\text{O}$ (DI) Nanofluid as a Working Fluid. Variation of both experimental and simulated values of temperature rise with time duration for 0.01% vol. conc. $\text{SiO}_2\text{-H}_2\text{O}$ (DI) nanofluid as working fluid at 40 LPH and 80 LPH is shown in Figures 16 and 17, respectively. It is seen that the simulated value of temperature rise is greater than the

FIGURE 16: Variation of temperature rise with time of day for 0.01% vol. conc. $\text{SiO}_2\text{-H}_2\text{O}$ (DI) nanofluid as a working fluid at 40 LPH.

FIGURE 17: Variation of temperature rise with time of day for 0.01% vol. conc. $\text{SiO}_2\text{-H}_2\text{O}$ (DI) nanofluid as a working fluid at 80 LPH.

experimental value of temperature rise at all time durations, and maximum value of temperature rise of 5.3°C and 6.7°C is seen for a flow duration of 40 LPH and 80 LPH. Also, drop in the value of temperature rise is reported with increasing time duration, which is mainly due to associated heat transfer which takes place due to increased temperature rise of the working fluid. Also, both experimental and simulated values of temperature rise are in close agreement with a difference of 11%.

4.3.3. 0.01% Vol. Conc. $\text{CuO-H}_2\text{O}$ (DI) Nanofluid as a Working Fluid. Variations of both experimental temperature rise and simulated value of temperature rise when $\text{CuO-H}_2\text{O}$ (DI) nanofluid of 0.01% vol. conc. is used as a working fluid at 40 LPH and 80 LPH are shown in Figures 18 and 19, respectively.

It is seen that both experimental and simulated values of temperature rise are in close agreement with a difference of

FIGURE 18: Variation of temperature rise with time of day for 0.01% vol. conc. CuO-H₂O (DI) nanofluid as a working fluid at 40 LPH.

FIGURE 19: Variation of temperature rise with time of day for 0.01% vol. conc. CuO-H₂O (DI) nanofluid as a working fluid at 80 LPH.

10%. Maximum values of 5.7°C and 7.8°C are seen at time interval of 10.30–11 a.m. After 12 at noon, drop in the value of temperature rise is seen from both experimental and CFD simulated results.

4.4. Variation of Instantaneous Efficiency with Time of Day for All Working Fluids. Figures 20 and 21 show the comparison of different working fluids (water, 0.01% vol. conc. SiO₂-H₂O (DI) nanofluid, and 0.01% vol. conc. CuO-H₂O (DI) nanofluid) on the parabolic solar collector's instantaneous efficiency (experimental and simulated) for each time interval at 40 LPH, respectively, while for 80 LPH it is shown in Figures 22 and 23. From both experimental and simulated analysis, it is seen that maximum value of instantaneous efficiency is with 0.01% vol. conc. CuO-H₂O (DI) as compared to other different working fluids at a particular flow rate. From

FIGURE 20: Variation of experimental instantaneous efficiency with time of day for all working fluids at 40 LPH.

FIGURE 21: Variation of simulated instantaneous efficiency with time of day for all working fluids at 40 LPH.

FIGURE 22: Variation of experimental instantaneous efficiency with time of day for all working fluids at 80 LPH.

FIGURE 23: Variation of simulated instantaneous efficiency with time of day for all working fluids at 80 LPH.

FIGURE 24: Variation of experimental thermal efficiency with time of day for all working fluids at 40 LPH.

experimental and simulated results, maximum instantaneous efficiency of 29.1% and 27.4% is seen, respectively, for 0.01% vol. conc. CuO-H₂O (DI) nanofluid at 80 LPH. Higher value in instantaneous efficiency is seen for a particular working fluid when mass flow rate is changed from 40 LPH to 80 LPH, though, at low flow rate, fluid residence time is high due to which fluid absorbs the maximum amount of solar energy, but on the other hand, fluid also loses energy due to radiation heat transfer as this mode of heat transfer scales with fourth power of the temperature of working fluid. Also, from both experimental and simulated values of instantaneous efficiency, it is seen that maximum value of instantaneous efficiency (both experimental and simulated) is seen at initial time duration with all working fluids, but afterwards drop in the values of instantaneous efficiency takes place, which is mainly due to increased radiation heat transfer due to increased temperature of the working fluid.

4.5. Variation of Thermal Efficiency with Time of Day for All Working Fluids. Figures 24 and 25 show the comparison of different working fluids (water, 0.01% vol. conc. SiO₂-H₂O

FIGURE 25: Variation of simulated thermal efficiency with time of day for all working fluids at 40 LPH.

FIGURE 26: Variation of experimental thermal efficiency with time of day for all working fluids at 80 LPH.

(DI) nanofluid, and 0.01% vol. conc. CuO-H₂O (DI) nanofluid) on the parabolic solar collector's thermal efficiency for each time interval at flow rate of 40 LPH while for flow rate of 80 LPH it is depicted in Figures 26 and 27. From both experimental and simulated analysis, it is seen that maximum value of thermal efficiency is with 0.01% vol. conc. CuO-H₂O (DI) as compared to other different working fluids for a particular working fluid.

From experimental and simulated results, maximum thermal efficiency of 13.8% and 17.2% is seen, respectively, for 0.01% vol. conc. CuO-H₂O (DI) nanofluid at flow rate of 80 LPH. Also, from both experimental and simulated values of thermal efficiency, it is seen that maximum value of thermal efficiency (both experimental and simulated) is seen at initial time duration with all working fluids, but afterwards drop in the values of thermal efficiency takes place, which is mainly due to increased radiation heat transfer due to increased temperature of the working fluid. Also, higher value of thermal efficiency is seen when flow rate is varied from 40 LPH to 80 LPH for a particular working fluid; this is mainly due to more heat loss occurring at a lower flow rate.

FIGURE 27: Variation of simulated thermal efficiency with time of day for all working fluids at 80 LPH.

5. Conclusions

Nanofluid due to its better thermophysical properties as compared to its base fluid tends to improve the performance of a solar collector which can be seen from both experimental and CFD simulated results. It has been seen that there is an improvement in both thermal and instantaneous efficiency of the parabolic solar collector, when nanofluid is used as a working fluid as compared to water. Improvement of about 7.64% and 6.68% in the efficiency of the parabolic solar collector is seen, when 0.01% vol. conc. CuO-H₂O (DI) and 0.01% vol. conc. SiO₂-H₂O (DI) nanofluid are used as compared to water, respectively, at 40 LPH while at 80 LPH improvement of about 8.42% and 7.15% is seen when 0.01% vol. conc. CuO-H₂O (DI) and 0.01% vol. conc. SiO₂-H₂O (DI) are used as compared to water. Also, higher values of both instantaneous efficiency and thermal efficiency are seen at initial time duration for all working fluids, but after that drop in the value is seen with all working fluids which is mainly due to increased heat transfer losses. Also performance of solar collector is improved when flow rate is increased from 40 LPH to 80 LPH. Moreover, there is close agreement between both experimental and CFD simulated results, as maximum difference of 11% is reported.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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