Experimental Evaluation on The Efficiency of Evacuated Tube Solar Collector Using Al2O3/Deionized Water Nanofluids

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Most heat transfer devices nowadays are based on the use of nanofluids since these particles are scientifically proven to outperform traditional fluids and are more effective and efficient in thermal transfer. This study considers the deionized water-based Aluminium oxide nanofluid and evaluates its stability. The study also compares the thermal efficiency of evacuated tube solar collector (ETSC) when using Al2O3 /DI nanofluids against the efficiency observed when using base fluid (DI) at different volume fractions in the range of 0.1% - 0.3%. In the next stage, thermal efficiency test was conducted on the solar collector with a range of flow rates including 1.5, 3, and 4 L/min. The use of Al2O3 nanoparticles in the collector during the experiment revealed a maximum rise of 39.6% in the fluid’s temperature difference. These nanoparticles also yielded 33% maximum heat gain when the collector was subjected to 950 W/m2 of solar irradiance. The nanofluids depict a 1.17 to 1.23 greater heat removal factor in comparison to water provided the flow rate is the same for both fluids. The outcomes showed that the use of Al2O3 /DI nanofluid in the ETSC yields 26.3% greater thermal efficiency in comparison to base fluid. Hence, the study suggested better overall performance of the collector in the presence of Al2O3 nanofluid.

Keywords: Solar energy, Evacuated tube solar collector, Nanofluid, Efficiency ,Al2O3 nanoparticles.

1. Introduction

The advancement in technology has resulted in more efficient utilization of energy. Over the years, industrialization made it possible to make more efficient use of energy. Sustainability and efficient use of energy resources are among the key priorities of the present business world since long-term industrial growth cannot be achieved without sustainability. Businesses are constantly on the lookout for alternative energy sources(Elsheikh et al., 2018; Farhana et al., 2019; Gorjian et al., 2020; Hussein, 2016). In this attempt, many businesses have utilized conventional energy resources to fulfill their energy requirements. However, the use of these resources is associated with various drawbacks including environmental destruction. Hence, it is recommended to utilize nonconventional energy resources to fulfill energy needs without any adverse environmental impact like environmental degradation and pollution. One of these renewable energy sources is solar energy from the sun which is available in abundant quantities. Hence, scientists and engineers have been working on exploiting this natural resource(Raj & Subudhi, 2018; Ramsden et al., 2018; Said et al., 2021; Wahab et al., 2019).

In the same vein, nanotechnology was used in various applications and devices to improve the energy efficiency of devices. Considering various forms of renewable energy currently available, the most prominent one is solar energy which is easily available in abundance. Solar energy can be best exploited with adequate technological expertise and the development of relevant supporting systems. Solar energy from the sun is first collected and then transformed into usable energy by making use of solar collectors and photovoltaic systems. Various types of solar collectors have been developed with the evacuated tube solar collector being the most widely used one due to its simple design, simple working, and effectiveness. The ETSC also does not require much maintenance. The ETSCs filled with traditional working fluid depict lower thermal conductivity and lower viscosity leading to lower thermal efficiency(Mahian et al., 2013, 2019; Motozawa et al., 2023). However, the thermal efficiency of ETSC can be increased by replacing base fluids with nanofluids. Nanofluids are attributed with high thermal conductivity and higher viscosity than conventional working fluid thus they have higher thermal efficiency. The rise in thermal performance of ETCs because of the use of nanofluids has been reported in many experimental studies. Choi (1995) was the first person to give the concept of 'Nanofluid'. Recently, many researchers have conducted studies to understand the conversion of energy into heat energy and heat exchange. After extensive research in this area, it was proved that the nanoparticle concentration in the working fluid is directly and positively associated with Thermal performance. The working fluid inside the ETSC provide an essential role in its efficiency.

The efficiency of evacuated solar collectors containing nanofluid has been determined in many studies to understand the difference observed in performance when replacing traditional base fluid with nanofluid. Mahbubul et al. (2018) reported a lower efficiency rate of 66%.Ozsoy & Corumlu (2018) suggested the use of Ag /H_2O nanofluid, which led to 40% increase efficiency for ETSC. Moreover, Sharafeldin et al. (2019) studied how metallic copper spherical nanoparticles (50 nm) influenced the efficiency of an ETSC. They conducted tests at three volume flow rates: 0.6 - 0.8 L/min. Their findings revealed that the energy rose ranging between 417 to 667 W, corresponding to a 34% decrease in the area of the ETSC. Cui et al. (2022) used a hybrid nanofluid of Fe_3O_4 and MWCNTs to study the energy efficiency of the ETSC. The findings showed that, in comparison to water and Fe_3O_4/water nanofluid, hybrid nanofluid increased efficiency by 28.3% and 14%, respectively. Kaya et al. (2018) conducted experiments to find the efficiency of an ETSC. They utilized a zinc oxide particle to the mixture comprising of equal parts (50%) of pure water and ethylene glycol. The ZnO nanoparticles were introduced into the working liquid at concentrations of 1 to 4% respectively. The increase in concentration of nanoparticles in the

ZnO nanofluid resulted in a increase in its conductivity. the maximum collector efficiency reached 62.87% at volume concentration of 3.0% when flow of 0.045 kg/s. This efficiency level represents a 26.42% improvement compared to using the work fluid is the pure water and pure ethylene glycol. Sabiha et al. (2015) work to collect solar energy and transform it into thermal energy by utilized water-based single-walled carbon nanotube (SWCNT) nanofluid as the working fluid in a heat pipe. The surfactant in this case was sodium dodecyl sulfate, and pure water was employed as the working liquid. The nanofluid was created with volume concentrations of 0.05 to 0.2%. Sonication was applied to disperse the SWCNT nanoparticles and prevent their agglomeration. The performance of the nanofluid was assessed at flow rates of 0.008, 0.017, and 0.025 kg/s, and compared with water. the maximum efficiency of 93.43% was achieved at a volume concentration of 0.2% when flow rate of 0.025kg/s. By raising the rate velocity and concentration of SWCNT, the collector efficiency rises. There is now an established empirical relationship between thermal conductivity and efficiency. According to Kakaç & Pramuanjaroenkij (2009), nanofluids increase forced convection heat transfer coefficient. Even the distribution of particles within the working liquid significantly enhances the traditional liquid thermal properties. The predictive model for thermal properties illustrates the promising capabilities of nanofluids in convection scenarios. In order to increase the efficiency of solar thermal collectors, nanofluids can be very important. When incoming radiation passes through the nanofluid, it is better dispersed and absorbed. In conventional collectors, the introduction of nanofluid reduces emissive heat loss and convection.

The researchers have extensively studied the domain of nanofluid use in solar devices. However, almost all studies considered some specific nanofluids overlooking numerous other nanofluids available. There is consensus among researchers regarding the positive impacts of fluid on solar collector thermal efficiency. The thermophysical properties of nanofluids like extraordinary thermal conductivity and high coefficient of heat transfer enable these fluids to enhance the thermal conductivity of the collector. However, the studies could not reach a consensus on other aspects of nanofluid use since all researchers analyzed nanofluids based on varying methods and techniques. Hence, the research must be conducted on unexplored nanofluid types and using reliable techniques to obtain useful information about nanofluids and their properties particularly the size of nanoparticles, their volume flow rate, and their solid volume fraction or concentration in the base fluid.

This study evaluates the fluid’s heat gain and temperature difference along with the thermal efficiency of the ETSC. The observations occurred during different solid volume fractions of Al_2O_3 nanoparticles in water-based working fluid. This study considered Al_2O_3 nanofluids which had never been studied before. Hence, the study is considered very useful. The study uncovers the potential of using this nanofluid in renewable energy applications. The study also indicated that solar radiation can be exploited more effectively by suspending Al_2O_3 nanoparticles in the traditional base fluid. Other factors that encouraged the researcher to use Al_2O_3 nanoparticles are their reasonable price and high thermal conductivity. The study also highlights the significance of generating energy through the use of nanoparticles. It can be concluded that this paper has scientific as well as practical implications.

2. Experimental Methodology

2.1. Preparation of Al_2O_3 Nanofluid

The current study considers solar collectors containing Al_2O_3/water nanofluid and deionized water as working fluids. The researcher obtained Al_2O_3 nanoparticles from US Research Nanomaterials. The particles were spherical and 99.5% pure. The particles measured 20 nm in diameter and had 3890 kg/m^3 density. The base liquid used in the work was deionized (DI) water. This base fluid was incorporated with the Al_2O_3 nanoparticles described above to prepare the nanofluid. Three separate nanofluids were prepared using different volume fractions of nanoparticles (0.1%, 0.2%, and 0.3%). In the second step, an ultrasonic homogenizer was used to apply ultrasonic vibration to the prepared nanofluid for fragmentation of its constituents; the process continued for nearly 90 min . Afterward, used a zeta potential analyzer to check the stability of the nanofluids prepared in the previous step. Figure 1 shows various steps involved in the nanofluid preparation. The outcomes showed that each of the nanofluids assessed in this study was adequately stable; thus confirming the reliability and accuracy of the methods used in this evaluation.

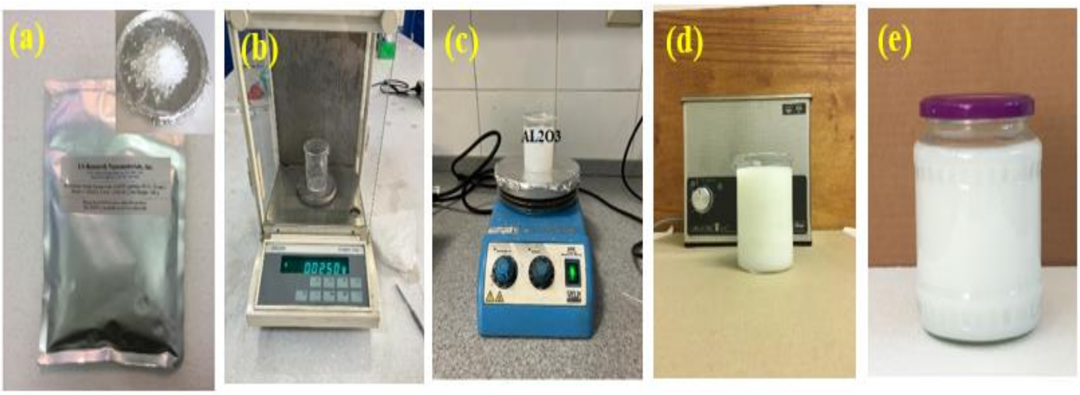

Fig.1. Steps for preparation of nanofluids: (a) Al_2O_3 nanoparticles, (b) weight scale, (c) magnetic stirrers, (d) ultrasonic processor, and (e) Al_2O_3/DI nanofluid.

2.2. Testing method

The main features of the evacuated tube solar collector have been depicted in Table 1. There are two stages in the solar system considered in this work . The first stage contains liquid of nanofluid. The nanofluid is pumped across the collector pipe with the help of a pumping machine. The working fluid (nanofluids) absorbed heat from the pipe. This heated fluid then enters the heat exchanger and passes to the second stage. The nanofluid remains in the storage where different instruments and methods are used to evaluate the fluid temperature. The outlet and inlet temperatures of the fluid are evaluated utilizing thermocouples (K-type). The Pyrometers are employed for evaluation of solar radiation while thermometers are used to take readings of the ambient temperature. This study adheres to the rules of the ASHRAE Standard while assessing the solar collector to determine its thermal efficiency. This standard guides the researchers in using the relevant techniques for precise evaluation of the solar collector’s performance. The ASHRAE Standard recommended performing outdoor testing for the thermal efficiency of the collector to ensure a minimum solar radiation of 790 w/m^2.

The standard also specified that the solar radiation must not show a variation of more than ±34 W/m^2 with period for collecting and analyzing data. The standard also suggested that the ambient temperature must not depict a variation greater than ±1.8 C during the period for collecting and analyzing data. The sunny days and times of peak solar irradiation were selected for conducting experiments. The solar radiation is the highest and most intense between 10 a.m. and 4 p.m. The readings are represented in graphical form. The graphs were plotted to show the association of collector efficiency with solar radiation and the association of efficiency with mass flow rate. The readings for efficiency were recorded at 3 different flow rates of 1.5, 3, and 4 L/min .The experiments were performed for many days in the climatic environment of Najaf city, in Iraq. The entire data collected was sorted to consider the most accurate and relevant data. Figure 2 show the diagram of the apparatus used in the experiment.

Table 1. Properties details of the FPSC.

Specification	Dimension/specification
Width	800 mm
Length	2030 mm
Height	140 mm
Latitude of location	32°
Absorption area	1.85 m^2
Weight	47 kg
Tilt angle	45°
Longitude of location	44°
Fluid capacity	0.8 L

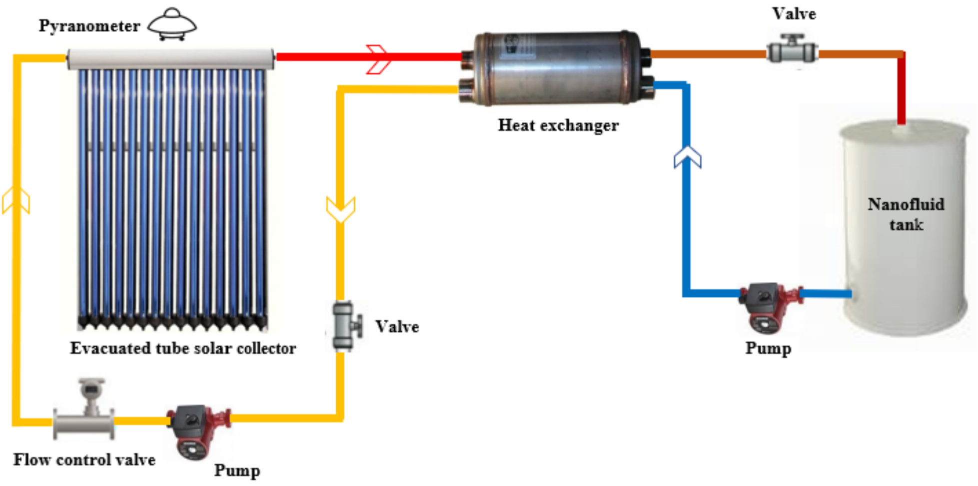

Fig. 2. Schematic of the experimental set-up.

2.3. Efficiency calculations

The density of the nanofluid and its specific heat can be calculated using Eqs. (1) and (2), respectively.

$$\rho_{nf} = \rho_{np}(\varphi) + \rho_{bf}(1 - \varphi) \qquad (1)$$

$$\left(\rho C_p\right)_{nf} = \left(\rho C_p\right)_{np}(\varphi) + (\rho C_{bf})_{bf}(1 - \varphi) \qquad (2)$$

The instantaneous efficiency calculated using Eq. (3).

$$\eta = \frac{Q_u}{A_c G_t} \qquad (3)$$

The formula (4) can be utilized to calculate the useful energy, commonly referred to as Qu.

$$Q_u = \dot{m} C_p (T_{fo} - T_{fi}) \qquad (4)$$

Also, the useful energy can be calculated by using Equation (5).

$$Q_u = A_c F_R [G_t(\tau\alpha) - U_L(T_{fi} - T_a)] \qquad (5)$$

Therefore, it can be determined the efficiency, as represented by Eq. (3), may be modified using one of the alternative various types presented in Eqs (6) - (8).

$$\eta = \frac{\dot{m} C_p (T_{fo} - T_{fi})}{G_t A_c} \qquad (6)$$

$$\eta = F_R \left[\tau\alpha - \frac{U_L(T_{fi} - T_a)}{G_t}\right] \qquad (7)$$

$$\eta = F_R(\tau\alpha) - F_R U_L \frac{(T_{fi} - T_a)}{G_t} \qquad (8)$$

Eq. (9) is used to compute the heat removal factor.

$$F_R = \frac{\dot{m} c_p \, [T_{fo} - T_{fi}]}{A_c \, [G_t(\tau\alpha) - U_L \, (T_{fi} - T_a)]} \qquad (9)$$

3. Results and discussion

3.1. Heat removable factor

The density, heat capacity and thermal conductivity and thermal conductivity of the working fluid in the ETSC are altered by the addition of nanoparticles. The heat removal factor (F_R) is dependent on the fluid’s thermophysical characteristics; thus, adding nanoparticles can be advantageous in this respect. The average surface temperature of the absorber can be substituted by the temperature of the liquid that enters the collector (Ti) by dividing the useful energy by the heat removal factor (F_R), which denotes the ratio between the real useful heat energy that the collector transfers and the maximum heat energy available. It is possible to transfer the latter when the inlet fluid and ambient temperature are the same; in such a situation, there is no heat loss to the environment. Nevertheless, the heat removal factor (F_R) is shown at the absorbed energy parameter [F_R ($\tau\alpha$)] in Eq. (8), as well as the removal energy parameter $F_R(U_L)$ in the identical equation. Therefore, the heat removal factor (F_R) has twin effects on the collector's efficiency. When it rises, this leads to the absorption of a greater amount of energy and an increase in the temperature of the outlet fluid. Additionally, increasing the temperature of the outlet fluid causes the temperature of the collector's absorber plate to rise; thus, an increase in the ambient temperature causes more heat to be lost. Accordingly, the collector's efficiency value is dependent on a balance being achieved with the heat removal factor value (F_R). The heat removal factor values for both water and the Al_2O_3/DI nanofluids are shown in Figure 3, the calculation of which was performed with Eq. (9). When the volume flow rate was 1.5 L/min, increases of 0.67 for water and 0.79, 0.82 and 0.83 for nanofluids were observed in the heat removal factor when the respective nanofluids had concentrations of 0. 1%, 0. 2%, and 0. 3%. When the volume flow rate was increased to 3 L/min, water recorded a heat removal factor of 0.692, whereas for nanofluids with concentrations of 0. 1%, 0. 2%, and 0. 3%, the values increased to 0.82, 0.84 and 0.86 respectively. The heat removal factor was determined to be 597aximized when the volume flow rate was 4 L/min with a value of 0.71 for water, and 0.86, 0.87 and 0.89 for the Al_2O_3/water nanofluid with concentrations of 0.1%, 0.2%, and 0.3%, respectively. It is found that the F_R increases to a maximum of 22.5% when the concentration of nanofluids is 0.3% at the corresponding flow rate of 4 L/ min. The reason for the increase in the heat removal factor is the increased thermal conductivity value for the working nanofluid as a result of the inclusion of nanoparticles of Al_2O_3. The increased thermal conductivity is a key factor that causes the working fluid's outlet temperature to rise. While nanofluids cause the heat capacity to be lowered, the increase in the fluids' outlet temperature leads to a rise in heat absorption. Clearly, the addition of nanoparticles of Al_2O_3 makes an important contribution to increasing the heat removal factor as well as the performance of the ETSC.

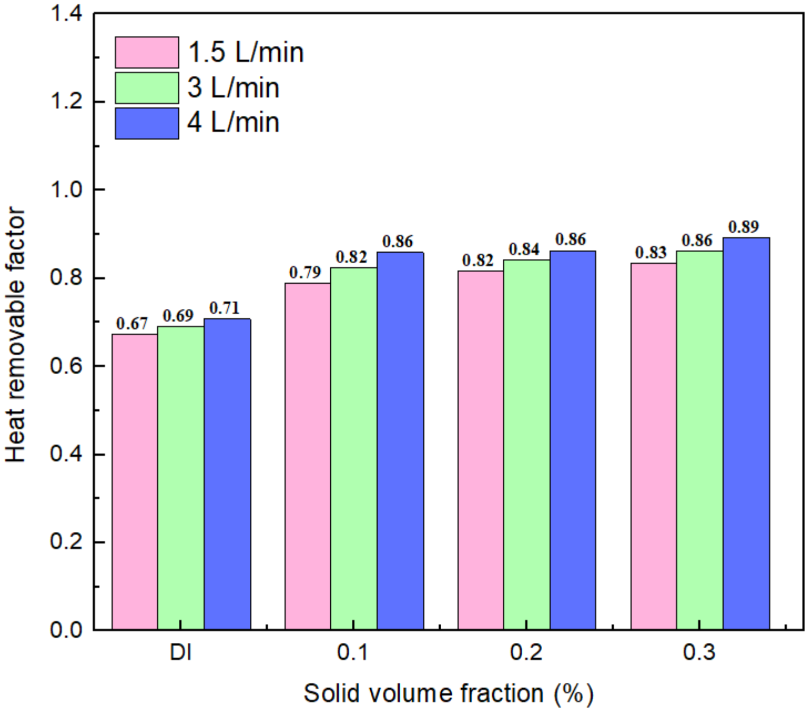

Fig .3. Heat removal factor for both DI and Al_2O_3 nanofluid.

3.2. Useful energy

The primary objective of this research is to increase the thermal energy provided by the ETSC by employing Al_2O_3 nanoparticles. The quantity of energy that can be accumulated by the ETSC is known as the useful heat gain, determined by volume flow rate, temperature difference, heat capacity, and density. Figure 4 shows the various values related to obtaining of useful energy at distinct flow rates for DI and distinct concentration of Al_2O_3 nanofluids. These values are obtained for the scenario where Ti = Ta and GT = 950 W/m^2 because the ETSC thermal efficiency is the highest according to ASHRAE when Ti = Ta, while GT = 950 W/m^2 signifies the mean solar radiation in all experiments. Figure 4 shows that water has useful heat gain values of 669, 759, and 892 W when the corresponding flow rates are 1.5, 3 and 4 L/min. When Al_2O_3 nanoparticles are used with a volume concentration of 0.1%, there is an increase in useful energy from 824 to 964 W at corresponding flow rates of 1.5 and 3 L/min, and to 1147 W when the flow rate is 4 L/min. It is also determined that when Al_2O_3 nanoparticles are at 0.2% volume concentration, the heat transfer increases to 896, 1195 and 1282 W at the corresponding of 1.5, 3 and 4 L/min flow rates. In the evacuated solar collector, useful heat gain has the highest values of 957, 1200, and 1366 W for the corresponding of 1.5, 3 and 4 L/min flow rates, when the volume concentration of nanoparticles is 0.3%. Nanofluids have higher useful heat gain values in comparison to water. The useful heat gain increases with an improve in the concentration of Al_2O_3 nanoparticles. Greater energy is absorbed in the highest flow of 4 L/min for water as well as nanofluids. It can be seen with the addition of nanofluids, there was an increase in the density of fluids; however, there was a reduces the heat capacity but augments the heat gain as a result of the aforementioned rise in the temperature difference.

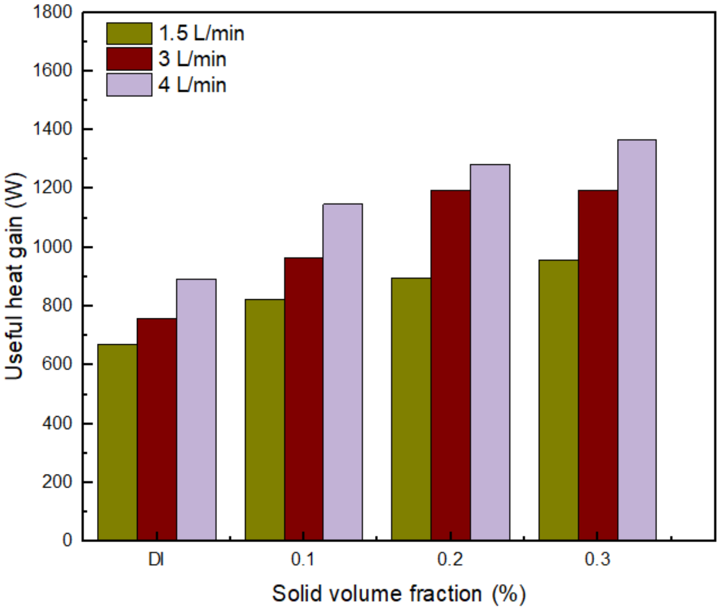

Fig.4. Useful energy for both DI and AL_2O_3 nanofluid.

3.3. The area reduction

The analysis essentially has the objective of determining the extent to which ETSC with working AL_2O_3 nanofluids can save material and energy. The working fluid forms a significant component of the solar system in any ETSC. The working fluid mainly absorbs and transfers a greater amount of heat from sunlight when moving across the pipes. There is a gradual increase in the temperature of the outlet water because of the circulation of the working fluid. It is possible to estimate the net useful heat gain and the collector efficiency after the experimental tests are carried out and readings are obtained. The conventional working fluid can then be compared with the suggested nanofluids. The basis of size reduction was the changes in the Performance of the ETSC with the use of Al_2O_3/water nanofluid. The input energy of the system in terms of the solar collector is the collector's surface area, which can be altered to offer the same outlet temperature with the use of standard working fluid. Therefore, the overall mass and the inherent energy of the system are directly affected by the decrease in collector area. The potential decrease in the sizes of solar collectors with the use of Al_2O_3/water is demonstrated in Figure 5. In comparison to the traditional evacuated tube solar collector that used water as the base liquid, the use of ETSC with Al_2O_3/DI as base liquid decreases the collector area by 18.7%, 25.29% and 30.06% for the corresponding solid volume fraction of 0.1%, 0.2% and 0.3% when the flow is 1.5 L/min. There is a decrease in the area of the collector by 21.2%, 30.4% and 34.65% for corresponding solid volume fraction of 0.1%, 0.2% and 0.3% when the flow is 3 L/min. When the flow is 4 L/min, the area of the collector experiences the highest decrease of 22.2%, 32.6%, and 36.4% for the corresponding Al_2O_3 nanoparticle concentrations of 0.1%, 0. 2%, and 0.3%, respectively. This is because nanofluids have greater thermal properties in comparison to those of conventional fluids.

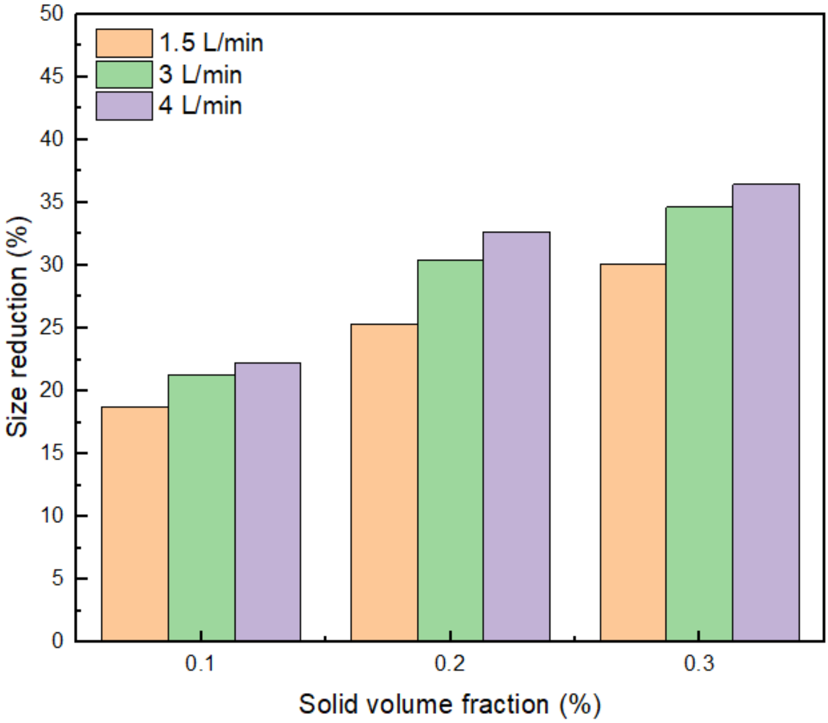

Fig.5. The reduction of area for AL_2O_3 nanofluids at different flow rates.

3.4.Temperature difference

Undoubtedly, the primary objective of this study is to increase the solar collector’s outlet temperature. This objective can be accomplished via the insertion of nanoparticles of AL_2O_3. It can be seen in Figure 6 that there is a decrease in temperature difference for DI from 6.4 to 5.5 when the flow increases 1.5 to 3 L/min. It further decreases to 5.2 when the flow becomes 4 L/min. When the volume fraction is 0.1%, there are greater values of temperature differences, i.e., 9.5, 8.8 and 8.2 for the corresponding flow of 1.5, 3 and 4 L/min. There is an increase in temperature difference to 11, 10 and 9 for the corresponding flow of 1.5, 3 and 4 L/min when the volume fraction increases to 0.2%. The highest temperature difference values are obtained for the volume fraction of 0.3%, which are 11.6, 10.5 and 9.5 for the flow of 1.5,3 and 4 L/min, respectively. When nanofluids are used, the temperature difference is comparatively higher than when water is used. In addition, there is a higher temperature difference when a higher concentration of the Al_2O_3 nanoparticles in base liquid is utilized. The lower flow also creates an increased temperature difference compared to the higher flow rate. When the concentration of Al_2O_3 nanofluids is 0.3% in comparison to DI, the highest increase in temperature difference when the flow of 1.5 L/min. This is because of the variation in the Al_2O_3 nanofluid's thermal conductivity in comparison to DI. There is an enhancement in the mainly heat transfer coefficient when the thermal conductivity increases. The cause of the rise in thermal conductivity is Brownian motion resulting from the nanoparticles colliding with molecules of water because of the use of a pump to move the fluids.

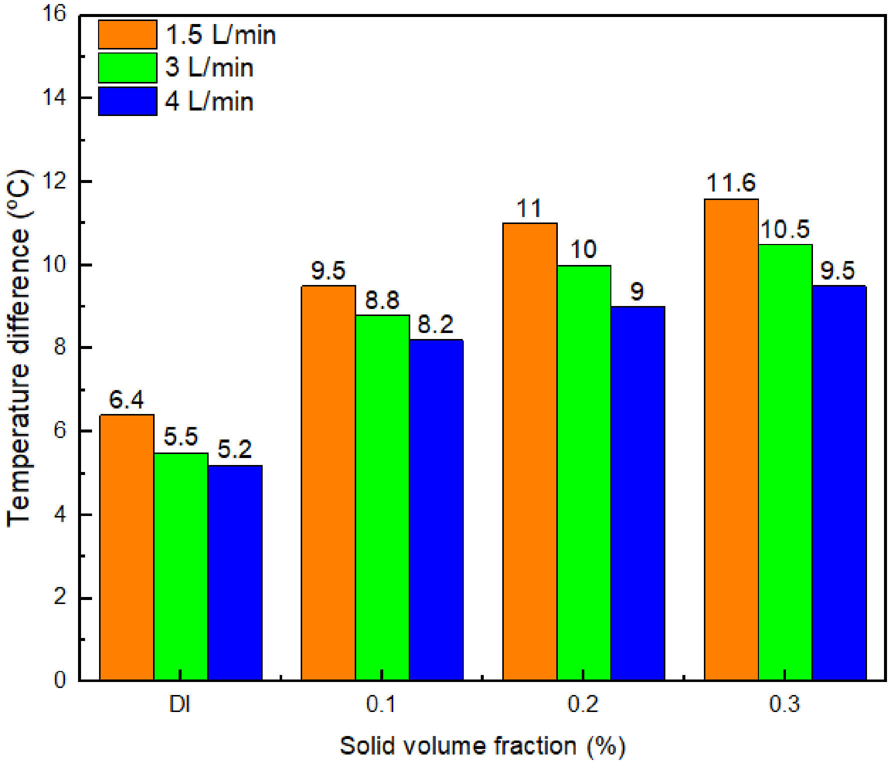

Fig.6. Temperature difference for both DI and AL_2O_3 nanofluid at different flow rates.

3.5.Thermal efficiency of ETSC collector

3.5.1. Effect of mass flow rate

The solar collector was evaluated to check its efficiency at different volume fractions of 0.1%, 0.2%, and 0.3% at various flow rates and the results are presented in Figure 7. Also, the thermal efficiency of the solar collector filled with water (operating fluid) was evaluated at various flow rates and tabulated in this figure .The outcomes revealed a rise in the thermal efficiency of the solar collector at higher flow rates. Nearly 16.66%, 22.2%, & 23.3% rise in thermal efficiency was noted accordingly for 0.1 %, 0.3 %, and 0.4 % of Al_2O_3 particle concentration in the working fluid when contrasted with the efficiency depicted by a solar collector in DI (deionized water) at 1.5 L/min flow rate. The highest rise in efficiency was observed when a flow of 4 L/min which amounted to 19.29 % (particle concentration of 0.1%), 23.44% (particle concentration of 0.2%) and 26.3% (particle concentration of 0.3%) higher than the efficiency evaluated with water as working fluid. The efficiency showed a significant rise at increased flow because of the lesser duration of fluid contact with a surface and consequently lower temperature under such conditions. The outcomes indicated a rise in the efficiency of the nanofluid-filled ETSC as the changed from 1.5 to 4 L/min of flow rate . As the flow rate declined, there was a reduction in the overall efficiency of the ETSC. This may be attributed to the fact that at a low flow rate, the fluid experiences a decline in its capability to eliminate heat from the manifold section and collector which in turn affects the thermal efficiency.

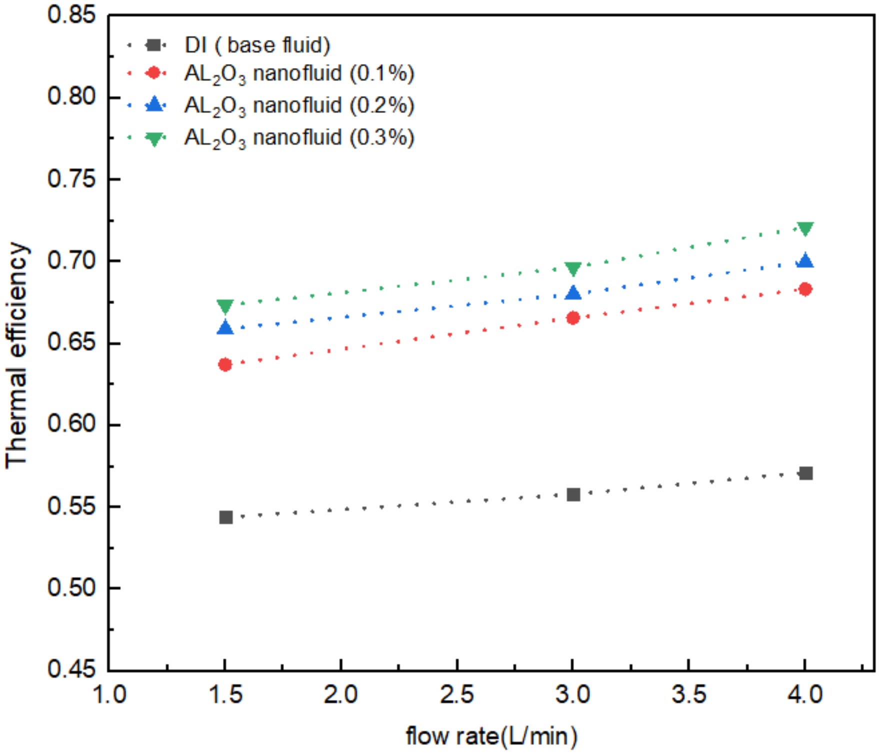

Fig. 7. Effect of AL_2O_3 nanofluid at different flow rates on thermal efficiency of ETSC.

3.5.2. Effect of solar irradiance

As the solar radiation became more intense, the solar collector became highly thermal efficient when the flow of 1.5 L/min (Figure 8) and 4 L/min (Figure 9). In both conditions, the collector exhibited the highest efficiency provided the solar irradiance was 950 W/m^2 and the volume fraction was 0.3 %. Initially, when the solar irradiance was below 650 W/m^2, the solar collector depicted average efficiency; however, the efficiency suddenly elevated as the solar irradiance reached the intensity in the value of 950 W/m^2. When the solar irradiance reached 950W/m^2 at the volume flow rate of 4 L/ min, there was a 23.5% increase in efficiency relative to the efficiency with water as a working fluid. The test noticed that the ETSC depicted the highest efficiency and greatest temperature difference at noon time because of exposure of the ETSC to the strongest radiation at that time. The efficiency of the ETSC started to decline gradually afternoon as the intensity of the rays started weakening.

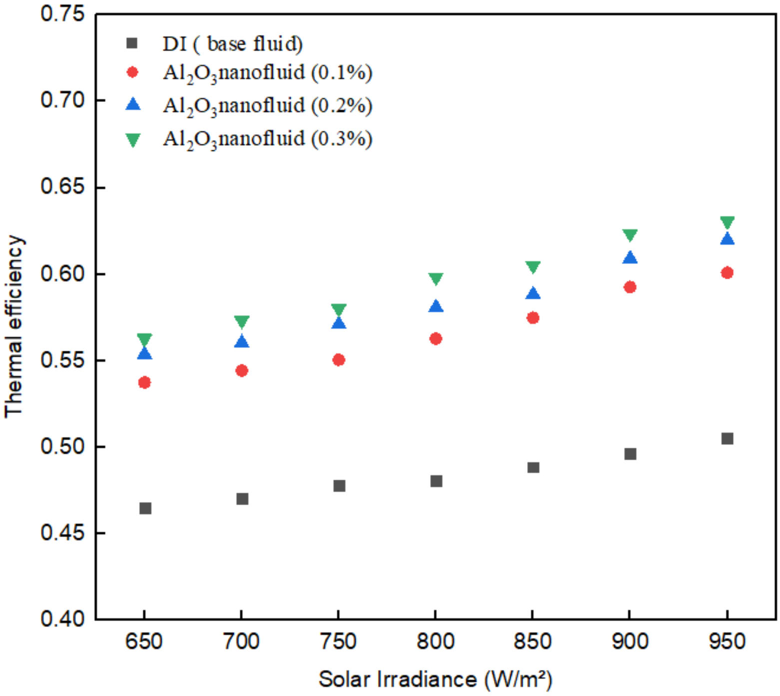

Fig.8. Effect of AL_2O_3 nanofluid at different flow rates on thermal efficiency of ETSC at flow rate 1.5 L/min .

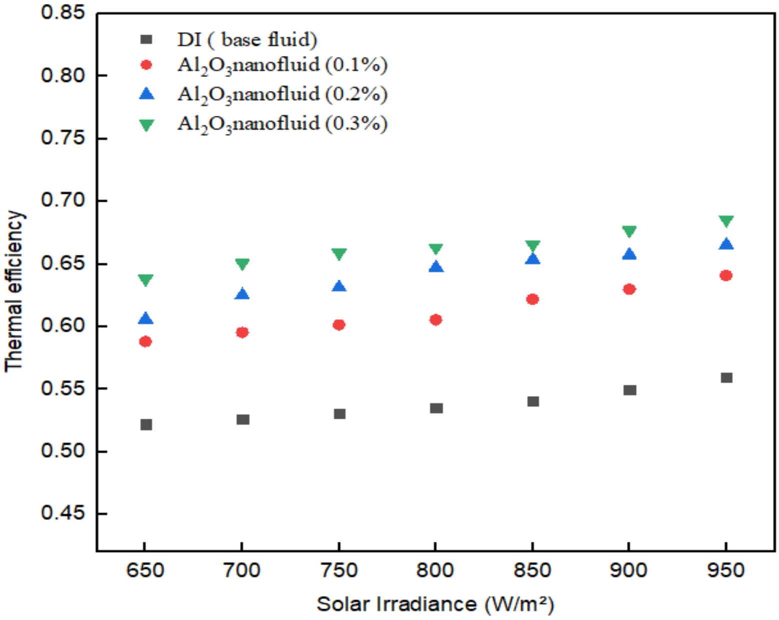

Fig.9. Effect of AL_2O_3 nanofluid at different flow rates on thermal efficiency of ETSC at flow rate 4 L/min.

4. Conclusions

This experimental study determines the enhancement in the thermal efficiency of ETSC at using Al_2O_3/DI based nanofluid. The collector efficiency was evaluated the collector's efficiency at different volume fractions of nanoparticles ranging from 0.1 to 0.3% at different flow of 1.5 - 4 L/min. The following are a few main points derived from the current research.

- The ETSC depicted higher efficiency with Al_2O_3 nanofluids compared to its thermal efficiency when utilizing DI.
- The ETSC's useful heat gain was enhanced by the nanoparticles of Al_2O_3.
- Solar irradiance had positive effects on the efficiency of collectors irrespective of the operating fluid inside but it increased more sharply in the case of using nanofluids. Importantly, when strong solar irradiance comes in contact with nanofluid with a higher concentration of Al_2O_3 nanoparticles, the efficiency increases significantly. This may be accredited to better convective heat transfer in such cases. the thermal efficiency of the water filled ETSC changed from 0.52 to 0.56 with changes in solar irradiance from 650 to 950 W/m^2 while the efficiency changed from 0.63 to 0.68 for the solar collector filled with 0.3 % nanofluid for the same change in solar irradiance.
- The thermal efficiency showed a rise of 20.2% at 1.5 L/min and a rise of 22.6% when the flow rate was 4 L/min .
- In comparison to water at the identical flow rate, the temperature difference increases peaked at 39.6% when the Al_2O_3 nanofluid concentration was 0.3% and the flow was 1.5 L/min.
- The maximum increment in heat removable factor was evaluated to be 22.5%.

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