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Studying the Effectiveness of Solar Thermal Collectors Using Nanofluid

Rone*

Abstract

Energy plays a crucial role in the technological growth that humanity is now experiencing. However, new avenues for energy generation and consumption have also been made possible by this advancement in science and technology. Another major factor driving up energy needs is an increase in population density. Carbon footprints are being left on the environment by fossil fuels, which are running out more quickly. Dependence on renewable energy sources, which are limitless, environmentally benign, and widely accessible in nature, is unavoidable in this situation. Effective use of solar energy is a feasible substitute for all other renewable energy sources in order to satisfy the rising demand for energy, especially for applications requiring low temperatures. Although using solar energy for a variety of household purposes is not new, it is now experiencing issues with decreased effective energy conversion. The apparatus that collects incoming solar energy and transforms it into a usable form is called a solar collector. The most notable devices among the several types of collectors for converting incoming radiation into working fluid thermal energy are solar flat plate collectors (SFPC). There are two main strategies for increasing the thermal efficiency of collectors: altering the working fluid's characteristics or modifying the shape and operating settings. The current work focuses on improving the thermophysical and optical properties of the working fluid by suspending nanoparticles as a method for efficiently converting solar radiation into useful heat energy, because various geometrical and operating parameters and modifications are more or less saturated. Thermophysical characteristics and their impact on SFPC's thermal performance are evaluated using empirical correlations found in the public domain, and the results of experiments are compared. A significant discrepancy between the analytical and experimental results is seen. Therefore, a careful analysis of each parameter's impact on collector efficiency is conducted. Every working fluid's viscosity and thermal conductivity are evaluated experimentally and compared to the current correlations.

Keywords: Solar flat plate collector, solar device, solar air heaters, solar energy

INTRODUCTION

Energy is becoming an integral part of human life. Escalation of technology and an acceleration in population growth rate are accelerating the energy demands at an exponential rate. The past few decades are clear evidence of potential growth in various fields like automobile, electronics, power generation, etc., where energy becomes an intrinsic requisite.

***Author for Correspondence**
Rone
E-mail: rone.somadder@eitfaridabad.co.in

Assistant Professor, Department of Mechanical Engineering, Echelon Institute of Technology, Faridabad, Haryana, India

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However, this causes an energy crunch. Thus, energy generation technologies are seeking an innovative and cutting-edge method. The prevalent fossil sources are non-renewable in nature and have finite availability. However, these non-renewable energy sources are reaching the verge of being out and eventually leaving carbon footprints on the environment either directly or indirectly [1]. The dependence on these depleting energy sources and consequent greenhouse gas emissions can be effectively reduced by the use of different renewable energy sources. Therefore, the sustainable development of renewable energy utilization is an effective and unsurpassed approach to meeting future energy needs with minimum environmental vulnerability. In the recent past, people from different communities, like expert researchers and scientific communities, to the common man, and governments, are well aware of the need for benign renewable energy (Figure 1). Among all renewable energy sources, solar energy is a widespread and viable alternative with its clean, abundant, inexhaustible, and eco-friendly nature [2–7].

SOLAR ENERGY POTENTIAL IN INDIA

India is gifted with immense solar energy potential. India receives about 5,000 trillion kWh per year of solar energy over its terrestrial area. Average solar radiation of 4–7 kWh/m^2/day is received in most parts of India. If a very small portion of total incident solar radiation is captured, that can meet the entire power requirements of the country (Figure 2). The estimated energy output from all the energy reserves in India can easily be met by one full year's solar energy collection [8–10].

LITERATURE REVIEW

Solar radiation with the solar collector: By keeping this in mind, a comprehensive review of literature concerning SFPC and its thermal efficiency/performance has been presented. The entire literature is split into 10 different phases. The first stage focused on how different geometrical and operational characteristics affected the SFPC's performance. The foregoing sections focus on synthesis, preparation of the nanofluid, and its stability. While the fifth section concentrated on the preparation of nanofluids and their thermophysical properties, whereas subsequent section consolidates the refinement of thermophysical properties of hybrid nanofluids [11–13]. The seventh section describes the influence of ethylene glycol on solar collector performance. In the eighth section, a brief literature review is presented on the performance of forced circulation/active solar thermal collectors using different nanofluids. In most of the real-time domestic applications, solar collectors are run on natural circulation mode only; hence, the thermal performance of solar collectors under natural circulation/passive mode is presented in the foregoing section [14]. The thermodynamics second law analysis and entropy generation due to heat transfer and flow friction on solar collectors is discussed in the 10th section. Comparative studies on solar thermal collectors operated on different absorption configurations and operating modes are presented in the subsequent section. The consequent sections accomplish the concluding remarks from the literature review, followed by the gaps identified from the literature [15–17].

Literature Addressing the Geometry

Though a reasonable amount of work is carried out on geometrical and operating conditions' optimization of SFPCs, considerable milestones in this area are presented in the current section. The existing solar flat plate collector design was later modified to develop an improved model, which remains the most widely used configuration to this day.

Ackermann *et al*. investigated the effect of internal fins in SFPC and noticed a marginal improvement in collector performance [18]. A notable thing that they mentioned is, the collector performance can be further improved either by reducing the fin pitch or by using higher thermal conductive materials for the fin material.

Hellstrom *et al*. examined the influence of geometrical changes of the absorber plate on the performance of SFPC [19]. They also studied the effect of thermal and optical properties of collector materials on collector performance. They reported that, thermal efficiency of SFPC can be improved by 12.1% by introducing a honeycomb structure on the absorber plate. They also suggested that the collector efficiency can be further improved by using a highly thermal conductive material for the honeycomb structure and also using optically polished glass, which would act as transparent to short waves and opaque to long waves. Hence, a potent greenhouse effect is created.

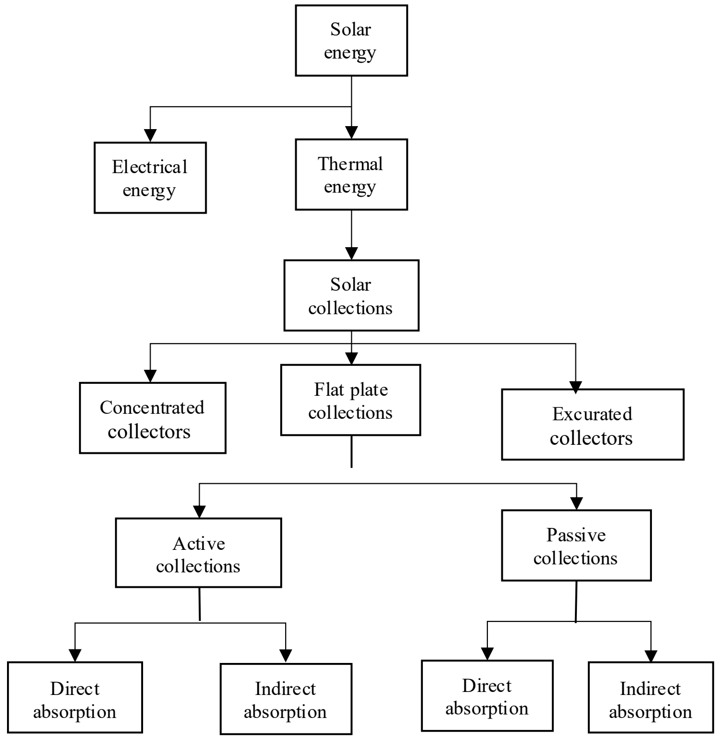

Figure 1. Classification of solar collectors for current research.

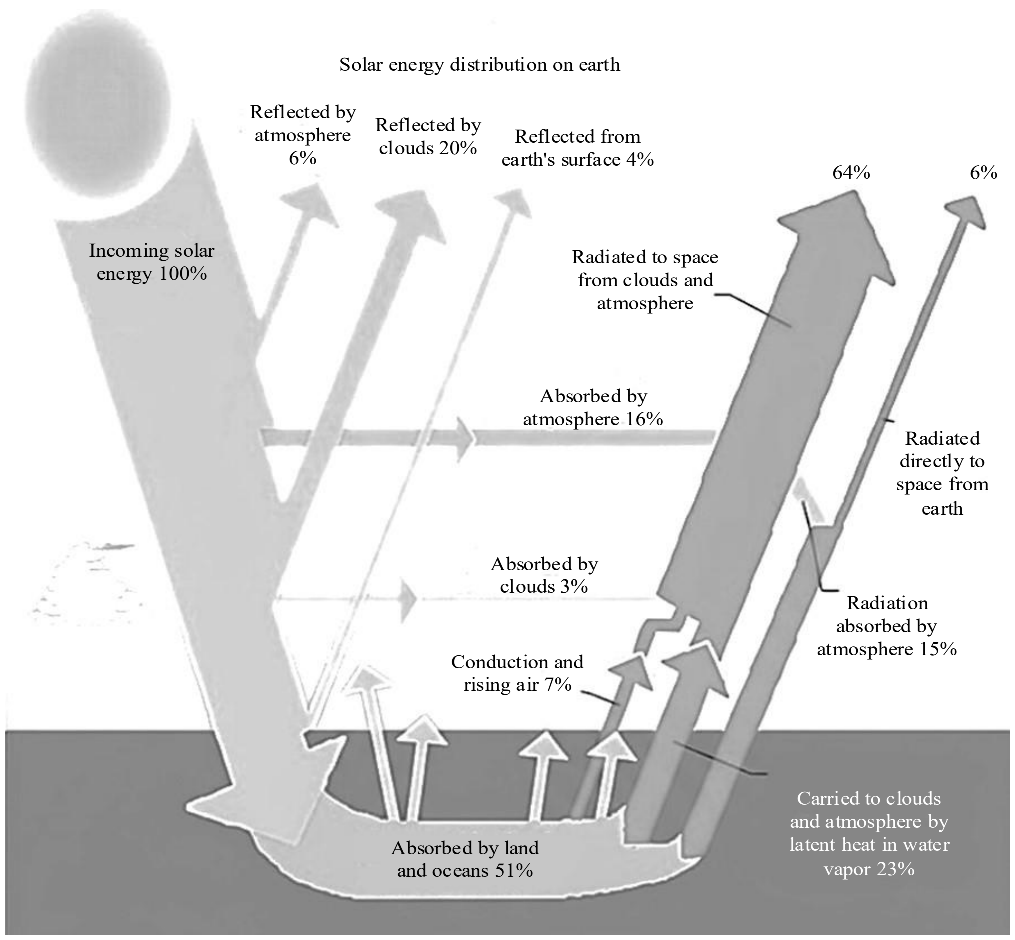

Figure 2. Solar energy distribution on Earth.

OBJECTIVES OF THE RESEARCH WORK

In the current research, analytical and experimental investigations are carried out to evaluate the thermal efficiency of SFPC operated at different absorption (indirect and direct) modes and operating modes (forced and natural convection). A comparative study is conducted among different modes with different working fluids.

1. Selection and preparation of different nanofluids. The nanoparticles and base fluids for preliminary studies are chosen from open literature.
2. Thermodynamic analysis is conducted on different working fluids and identified the preliminary nanoparticles.
3. Developed two experimental tests rigs that are capable of conducting the experiments for all modes of operations with minor peripheral changes and attachments. The test setups are capable of producing repeatable and reliable results.
4. To choose the appropriate nanoparticle, pilot experimental trials are conducted with different working fluids, and considerable deviation is noticed between analytical and experimental results.
5. Critically analyzed the reasons for the deviation, and presumed that fluid transport and thermal transport properties are considerable parameters for this deviation.
6. Experiments are conducted in two absorbing configurations of indirect and direct absorption and operating modes of forced and natural circulation.
7. Analyzed the effect of nanoparticles on the thermal efficiency of the solar collector and noticed a considerable enhancement in collector efficiency. Comparative studies are conducted by considering all possible errors while conducting experiments.

Thus, the viscosity and thermal conductivity of nanofluids are experimentally measured and compared with the analytical solutions. It is noticed that the thermal conductivity of nanofluids has relatively less deviation from the experimental outcomes, whereas a substantial deviation is noticed in dynamic viscosity, and hence, a new correlation is proposed, and all other calculations are conducted with the developed correlation.

MATERIALS AND METHODS

All of the nanoparticles (Al_2O_3, Cu, CuO, SiO_2, and TiO_2) in diameters ranging from 30 to 50 nm are acquired for the current study from SISCO Research Laboratory Pvt. Ltd. in India. It is expected that the particle size matches the supplier's quotation. When preparing nanofluids and doing tests to compare collector performance, distilled water is used as the base fluid. Both mono and hybrid nanofluids are produced using a two-step process. An ultrasonicator (provided by Electrostatic Industries, India) is used to disperse the nanoparticles in the base fluid in order to break up the clumped particles and create a stable, uniform suspension. The sonicator generated 180 W of ultrasonic waves while the fluid was continuously sonicated for 2 h. As a surfactant, CTAB improves the stability of nanoparticle dispersion in the base fluid. When creating a stable nanofluid, agglomeration is managed using both sonication and surfactant.

CuO/water—The particle concentrations that are appropriate for solar applications: 0.125, 0.5, 0.5, and 1%, are used to create all of the nanofluids. It has been observed that all of the nanofluids exhibit no visible settling for at least 36 h. To perform studies, a 50%:50% hybrid nanofluid (Cu-CuO) is generated.

MEASUREMENT ANALYSIS

The two most important thermophysical characteristics that control a nanofluid's flow behavior and heat transmission are thermal conductivity and viscosity. The trade-off between a nanofluid's dynamic viscosity and thermal conductivity is required for many technical applications. The favorable characteristics for improved thermal performance of an SFPC include enhanced heat transport capabilities and minimum viscosity increase. Water and all other nanofluids have their viscosity and thermal conductivity determined experimentally.

Figure 3. Using an ultrasonic sonicator to create nanofluids (i) Al_2O_3/water nanofluids.

The particle concentrations used in the experiments range from 0.125 to 1%. Conductivity of heat (W/mK) Assessment of Viscosity: Using the Rheolab QC rotating rheometer (Anton Paar supplier, India), the dynamic viscosity of water, mono nanofluids, and hybrid nanofluids at various particle concentrations and temperatures is evaluated (Figure 3).

The apparatus is equipped with a Peltier temperature-controlled thermostatic bath with a computer interface to control and measure the rheological behavior of the nanofluid at different temperatures. The apparatus can measure the viscosity over a range of 1 to 109 mPa.S and over a temperature range of –20 to 180°C. The computer interface facilitates recording the measured data and varying the temperature of the working fluid. For the reliability of measurements, viscosity of distilled water is experimentally measured and compared with the standard data taken from REFPROP tables. The experimental readings have close approximations with standard data with less than 2% deviation, over the considered range of temperatures. The nanofluid is placed between the concentric cylinders of the rheometer. The outer cylinder is rotated by external means, while the inner cylinder remains stationary. When the outer cylinder rotates, the torque is transmitted to the inner stationary member through a thin liquid film of nanofluid formed between the cylinders. Based on the speed of rotation and thickness of fluid film (gap between cylinders), one can measure the viscosity of fluid from its Newtonian behavior.

RESULTS AND DISCUSSION

Among several thermophysical properties of nanofluid, density, specific heat, viscosity, and thermal conductivity are the basic governing properties that influence the collector efficiency. However, along with these properties, the thermal expansion coefficient also plays a vital role in thermosyphon mode operating collectors, whereas optical properties play a pivotal role in direct absorption collectors.

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Analytical studies are carried out on solar collectors to study the influence of thermophysical and optical properties of the working fluid on instantaneous efficiency. Experimental studies are also conducted to make comparative studies. A substantial variation in instantaneous efficiency of SFPC is noticed between analytical and experimental results. Experimental measurements of the thermal conductivity and viscosity of nanofluids are made in order to determine the probable cause of this variance. The current empirical correlations are used to determine the thermal conductivity of nanofluids, and the results are compared to the experimental findings. Since the empirical and measured readings were found to differ by less than 5%, a new correlation was created.

CONCLUSION

When it comes to viscosity, the findings from the current empirical correlations differ significantly from those from experiments. For instance, at 1.0% particle concentration of CuO/water nanofluid, an 18.58% divergence is observed. As a result, a novel correlation is created to accurately calculate the viscosity of a nanofluid, and additional analysis is conducted utilizing the correlation.

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