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ANALYSING THE PERFORMANCE OF SOLAR THERMAL COLLECTORS BASED ON NANOFLUID

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Abstract - Mankind is living in the arena of evolution of technology in which energy is an integral part. However, this enrichment of science and technology has opened new pathways for energy consumption and generation as well. Raise of population density is another root cause for energy demands. Fossil fuels are depleting at faster rate and leaving carbon footprints on environment. In this scenario, it is inevitable to depends on renewable energy sources which are inexhaustible, eco-friendly and abundantly available in nature. Amid all renewable sources, effective utilization of solar energy is a viable alternative to meet the growing energy demands, particularly for low temperature applications. While consumption of solar energy for various domestic applications is not new, but it is suffering from lower effective energy conversion problem.Solar collectors are the device that absorbs the incident solar radiation and converts into useful form. Among different types of collectors, solar flat plate collectors (SFPC) are the noteworthy devices to convert the incident radiation into heat energy of working fluid. In view of enhancing the thermal efficiency of collectors, there are two major approaches as either changing the geometry and operating parameters or enhancing the properties of working fluid. Since, various geometrical and operating parameters and modifications are more or less saturated, present work is focused on enhancing the thermophysical and optical properties of working fluid by suspending nanoparticle as an approach for effective conversion of solar radiation into useful heat energy.Thermophysical properties and their influence on thermal performance of SFPC are estimated using the empirical correlations available in open literature and comparisons are made with the experimental outcomes. It is noticed that a substantial variation exists between the analytical and experimental outcomes. Thus, the influence of each parameter on collector efficiency is critically examined. Both thermal conductivity and viscosity of all working fluids are experimentally measured and compared with the existing correlations.

Key Words: Solar flat plate collector, solar device, solar air heaters, solar energy.

INTRODUCTION

Energy is becoming the integral part of human life. Escalation of technology and acclivity in population growth rate accelerating the energy demands at an exponential rate. Past few decades are clear evidence of potential growth in various fields like automobile, electronics, power generation, etc., where energy becomes an intrinsic requisite. However, this progress of technology is driving the mankind towards the energy crunch. Thus, energy generation technologies are seeking for an innovative and cutting edge method. The prevalent fossil sources are non-replenish in nature and have finite availability. However, these formal energy sources are reaching to the verge of obliterating out and eventually leaving carbon footprints on 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 meet the future energy needs with minimum environmental vulnerability. In the recent past, the people from different communities like expert researchers and scientific communities to common man and governments are well aware the need of benign renewable energy. Classification of various solar collectors are presented in Fig. 1.1. Amid all renewabl eenergy sources, solar energy is a 12 widespread and viable alternative with its clean, profuse, inexhaustible and eco-friendly nature.

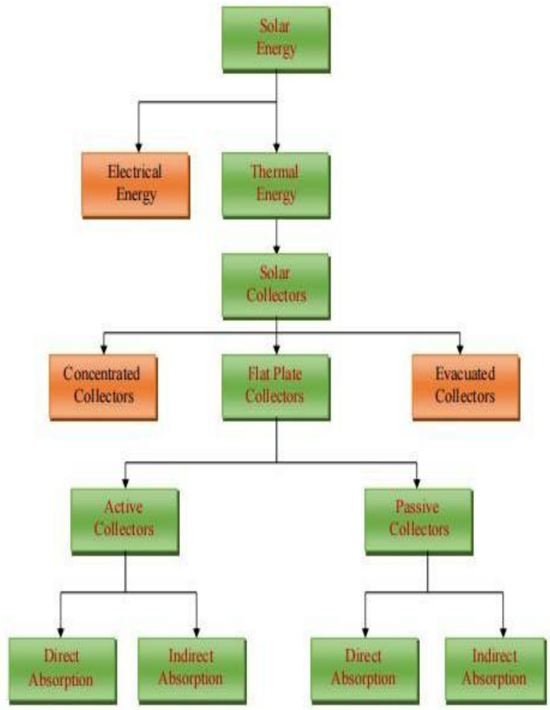

Fig. 1.1 Classification of solar collectors for the current research

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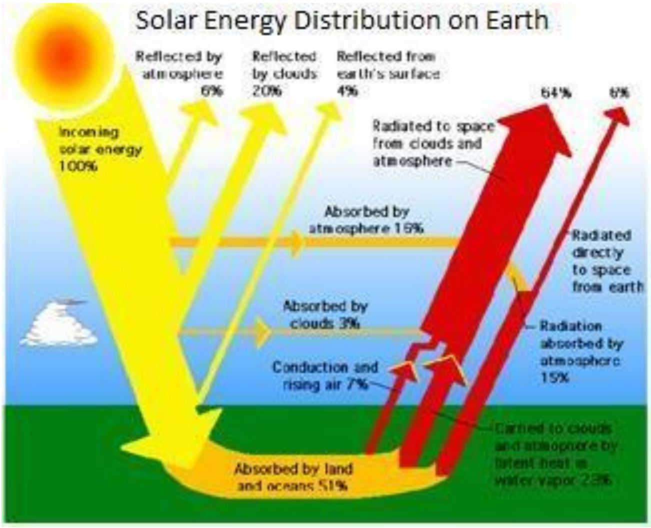
1.2 SOLAR ENERGY POTENTIAL IN INDIA

India is gifted with immense solar energy potential. India receives about 5,000 trillion kWh per year of solar energy over India's terrestrial area. Average solar radiation of 4-7 kWh/m2 /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. The estimated energy output from all the energy reserves in India can easily be met by one full year’s solar energy collection.



2. LITERATURE REVIEW

Solar radiation with the solar collector. By keeping this in mind a comprehensive review of literature concerning to SFPC and its therma lefficiency/performance has been presented. The entire literature is split into ten different phases. The first phase concentrated on the influence of various geometrical and operating parameters on performance of SFPC. While the foregoing sectionsfocuses on synthesis, preparation of nanofluid and their stability. While the fifth section concentrated on preparation of nanofluids and their thermophysical properties whereas consequent section is consolidates the refinement of thermophysical properties of hybrid nanofluids. In seventh section describes the influence of ethylene glycol on solar collector performance. In eighth section, a brief literature 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 foregoing section. Thermodynamic second law analysis and entropy generation due to heat transfer and flow friction on solar collectors is discussed in tenth section. Comparative studies on solar thermal collectors operated on different absorption configurations and operating modes are presented in the subsequent section. The consequent sections accomplishes the concluding 1112 remarks from the literature review flowed by the gaps identified from literature. Major objectives and scope of the present work is presented as separate section.

2.1. LITERATURE ADDRESSING THE GEOMETRY

Though the reasonable amount of work is carried out on geometrical and operating conditions optimization of SFPCs, considerable milestones in this area is presented in the current section. Hottel and Whillier [29] modified the existing SFPC by that time and developed a new model. it is the most commonly used geometry of flat plate collector till the date. Ackermann et al. [30] investigated the effect of internal fins in SFPC and noticed a marginal improvement in collector performance. A notable thing that they mentioned is, the collector performance can be further improved either by reducing the fin pitch or by using the higher thermal conductive materials for fin material. Hellstrom et al. [31] examined the influence of geometrical changes of absorber plate on performance of SFPC. 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 honeycomb structure on the absorber plate. They also suggested that, the collector efficiency can be further improved by using high thermal conductive material for honeycomb structure and also, using optically polished glass, which would act as transparent to short waves and opaque to long waves. Hence, potent green house effect is created.

2.2 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 (in-direct and direct) modes and operating modes (forced and natural convection). Comparative study is conducted among different modes with different working fluids.

1. Selection and preparation of different nanofluids. The nanoparticles and base fluids for the preliminary studies are chosen from the open literature.

2. Thermodynamic analysis is conducted on different working fluids and identified the preliminary nanoparticles.

3. Developed two experimental test rig that is capable for conducting the experiments for all modes of operations with minor peripheral changes and attachments. The test setups are capable to produce the repeatable and reliable results.

4. To choose the appropriate nanoparticle, pilot experimental trails are and conducted with different working fluids and considerable deviation is noticed between analytical and experimental results.

5. Critically analyse the reasons for the deviation, and presumed that fluid transport and thermal transport properties are considerable parameters for this deviation.

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Thus, viscosity and thermal conductivity of nanofluids are experimentally measured and compared with the analytical solutions. It is noticed that thermal conductivity of nanofluids has relatively less deviation from the experimental out comes 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.

6. Experiments are conducted in two absorbing configuration of indirect and direct absorption and operating modes of forced and natural circulation.

7. Analysed the effect of nanoparticles on the thermal efficiency of solar collector and noticed considerable enhancement in collector efficiency. Comparative studies are conducted by considering the all possible errors while conducting experiments.

2.3. MATERIALS AND METHOD

For the current research, all the nanoparticles (Al2O3, Cu, CuO, SiO2, and TiO2) of sizes 30- 50 nm are purchased from SISCO Research Laboratory Pvt. Ltd India. The size of particles is assumed to be same as quoted by the supplier. Distilled water is taken as the base fluid for nanofluid preparation as well as for conducting experiments for comparison of collector performance. Both mono and hybrid nanofluids are prepared by two step method. Nanoparticles are dispersed in the base fluid using ultra-sonicator (supplied by Electrostatic Industries, India) to brake the agglomerated particles and to obtain stable and homogeneous suspension. Fluid is 3940 subjected to continuous sonication for 2 hrs and the sonicator produced the ultrasonic waves at 180 W. CTAB is used as a surfactant to increase the dispersion stability of nanoparticles in base fluid. Both sonication and surfactant are used to control the agglomeration while preparing stable nanofluid.

Fig 3.1. Preparation of nanofluids by ultrasonic sonicator (i) Al2O3/water nanofluids

(ii) CuO/water (iii) Cu/water All the nanofluids are prepared at 0.125 % 0.25 %, 0.5 %, 0.75 % and 1 % particleconcentrations, which are the suitable particle concentration for solar applications. It is noticed that, all the nanofluids are stable for 36 h at least without any visual settlement. Hybrid nanofluid is prepared at 50%: 50% (Cu-CuO) to conduct experiments.

3.1 MEASURENT ANALYSIS

Among all the thermophysical properties, thermal conductivity and viscosity are two key properties, which govern the heat transfer and flow behaviour of a nanofluid. Many engineering applications demand the trade-off between dynamic viscosity and thermal conductivity of a nanofluid. Enhanced thermal transport properties along with minimal augment of viscosity are the favorable properties for better thermal performance of a SFPC. Both viscosity and thermal conductivity of water and all nanofluids are experimentally measured.

Experiments are conducted at different particle concentrations from 0.125% to 1%. Thermal conductivity (W/mK) Viscosity Measurement: Dynamic viscosity of water, mono nanofluid and hybrid nanofluids at different particle concentrations and temperatures are measured using Rheolab QC rotational rheometer (Anton Paar supplier, India). The apparatus is equipped with a peltier temperature controlled thermostatic bath with computer interface to control and measure the rheological behaviour of 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 oC to 180 oC. The computer interface facilitates to record the measured data and to vary the temperature of 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 rheometer. The

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outer cylinder is rotated by external means, while the inner cylinder remains stationary. When the outer cylinder rotates, the torque is transmitted to 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 behaviour.

4.1 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, thermal expansion coefficient also plays a vital role in thermosyphon mode operating collectors, whereas optical properties play a pivotal role in direct absorption collectors. Analytical studies are carried out on solar collector, to study the influence of thermophysical and optical properties of working fluid on instantaneous efficiency experimental studies are also conducted to made comparative studies. A substantially variation in instantaneous efficiency of SFPC is noticed between analytical and experimental results. In order to identify the potential reason for this variation, thermal conductivity and viscosity of nanofluids are experimentally measured. Thermal conductivity of nanofluids is estimated from the existing empirical correlations and results are compared with the experimental results. It is found to be less than 5 % variation between the empirical and measured readings and hence any new correlation was developed.

In case of viscosity, the results from the existing empirical correlations have a substantial deviation from experimental outcomes. For example, 18.58 % deviation is noticed at 1.0 % particle concentration of CuO/water nanofluid. Therefore, a new correlation is developed for precise calculation of viscosity of nanofluid and further analysis is carried out using the developed correlation

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