FABRICATION AND ANALYSIS OF FLAT PLATE SOLAR COLLECTOR USING AN ARTIFICIAL LIGHT SOURCE

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Abstract

Power generation is becoming more dependent on fossil fuels due to the rising demand for electricity caused by the expanding global economy. However, this is causing a shortage of non-renewable resources and contributing to global warming through brown energy. Using renewable energy sources like solar, wind, and hydropower can solve this problem. Specifically, solar energy is readily available and can be efficiently collected with flat-plate solar collectors. Solar thermal energy, in the form of heat, can be efficiently harnessed by a flat surface solar collector for a variety of heating applications and, in some cases, even power generation. This study aims to fabricate a flat solar collector with an artificial light source and find out how the collector performs at various flow rates. A black-painted curved tin sheet had been used as an absorber plate which enhances the contact area between the pipe and plate. A heat exchanger is installed to cool down the hot working fluid which is water in that case. The experiment is operated with different flow rates and various levels of intensity. The best performance of the collector has been observed at an optimal flow rate which is 1.6 l/min with high light intensity. Due to minor temperature differences in higher flow rate, the efficiency does not increase with flow rate. This solar collector can be produced economically for basic heating operations in homes and it can be easily mounted on the rooftops of homes and offices.

Keywords: light intensity, heat transfer, flow rates, efficiency

1.Introduction

Energy resources are finite, with electricity generation relying heavily on non-renewable fossil fuels such as coal, natural gas, and oil. The reliance on electricity has led to a steady and continuous rise in energy consumption over the years, mainly due to the increasing use of devices and modern industrial machinery [1]. According to the BP Statistical Review of World Energy, fossil fuels may be able to provide energy for up to 50 to 100 years[2]. Green energy is a solution of this alarming issue and green energy technology has been classified into three generations. The first generation includes technologies like biomass combustion, geothermal energy, and hydropower. The second generation comprises solar heating and wind power, while the third generation includes bio-refinery, biomass gasification, geothermal, and ocean/marine energy [3]. Solar energy has the potential to meet all of the world's electricity demands, and a solar power plant covering 64,516 square kilometers could do so [4]. Concentrating Solar Power (CSP) systems utilize a collector and receiver to store solar energy as heat. This heat is then transferred to a mechanical cycle to generate both mechanical and electrical energy [5]. One method of transforming solar radiation into usable heat is the flat plate solar collector, which works by using the warming effect. Using a computer model they created, Wang and Wu examined the temperature and working fluid patterns in solar collector arrays and warned against using U-shaped arrays in situations where there would be a lot of heat transfer [6]. According to Yadav's analysis, the forced circulation mode outperformed the thermosiphon modes by a small margin; however, due to the need for an extra energy source, this strategy was not cost-effective [7]. The efficiency of thermosyphon flat plate solar collectors was investigated by Hussein et al. under temporary conditions. In order to develop thermosyphon flat plate solar collectors and anticipate their transient thermal behaviour, the study proposed a simulation model. [8]. Benz and Beikircher showed that working fluid could be heated in the range between 100 and 150°C. During testing of the prototype collector at the outdoor facility, the efficiency surpassing 60% when exposed to steam temperatures of 100°C. Additionally, this research showed efficiencies of 45% when tested under steam temperatures of 150°C [9]. Ghamari and Worth proposed an optimum spacing of tubes in flat plate solar collectors. The study described the factors such as solar intensity, the thickness of the sheet, heat transfer coefficient between fluid and tube wall which were important for determining the

optimum space [10]. Balaram studied the efficiency of flat plate solar collectors by experimenting with several absorber plate geometries, including rectangular, trapezoidal, and other shapes. Rectangular plates exhibited a greater efficiency rate among the options, even though more energy had to pass through a rectangular profile with a local thickness change [11]. A technique for designing flat plate solar collectors that created lowest entropy was devised by Torres et al. The ideal mass flow rate, ideal temperature of the fluid leaving the absorber, and physical properties of the plate that might produce the least amount of entropy were all factors that were studied in that study [12]. Abdullah et al. looked at the outcomes of a study that tested several honeycomb layouts for use in solar collectors. While honeycomb has the potential to decrease top heat loss in solar collectors, it also has the potential to worsen optical efficiency if built incorrectly [13]. Research by Hellstorm et al. shown that the thermal and optical properties of the building material significantly influenced the efficiency of flat plate solar collectors. The experimental findings suggest that Teflon coatings and antireflection-treated glass may enhance the efficiency of solar collectors [14]. Riffat et al. evaluated a clip film solar collector, two flat plate heat pipe collectors, and a wavy fin collector to assess the performance of flat plate solar collectors. In the experiment, clip film solar collectors achieved a maximum efficiency of 86% [15]. Kalogirou proposed a technique using artificial neural networks to predict the performance of flat plate solar collectors.In the first phase of the design of these systems, the precision achieved by estimation was considered adequate [16]. Adnan et al. developed an innovative approach to assess the efficiency of flat plate solar collectors using an artificial neural network. The neural network, using a logistic sigmoid transfer function, yielded results with a maximum deviation of 2.56 and a minimum deviation of 0.002. [17]. One method that Himanshu et al. suggested for improving direct absorption solar collector performance was the use of nano-fluid. Using aluminium oxide as the main fluid, the study found a 10% improvement in efficiency while maintaining the same operating circumstances [18]. Using a variety of absorber plates, Mintsa et al. replicated the flat plate solar collector. More important than the length of the plate in determining efficiency was the air gap between it and the pipe, according to that study [19]. Researchers Bakari et al. measured how well various thicknesses of glass worked in flat plate solar collectors. That study found that the same geometric-shaped glass with a 4 mm thickness was 35.4% efficient, but with a 6 mm thickness, the efficiency dropped to 27.8%. [20]. Himangshu and Amin investigated a new technology for improving the performance of a solar collector using reflective mirrors which increased the performance by 10% [21]. Moss et al. showed that flat plate solar collectors could be used in rankine cycle for producing power but the efficiency was less than the photovoltaic systems. Organic rankine cycles coupled to a parabolic trough collector or flat plate solar collector would produce approximately 9% less power than a 15% efficiency photovoltaic panel under clear weather and 1000 W/m^2 irradiance [22]. Faizal et al. found that using SiO_2 could increase efficiency by 27% [23] whereas Moghadam et al. investigated the performance using CuO which improved the effectiveness by 17% [24].

2.Research Methodology

A flat plate solar collector has four essential components: glass, absorber plate, pipework, and insulation. The glass retains solar radiation inside the device, while the absorber plate converts this radiation into thermal energy. The pipeline is attached to the absorber plate, enabling heat transfer via a circulating fluid. This study focused on the construction of a flat-plate solar collector, including a collector, heat exchanger, pump, rotameter, thermocouple, and halogen light. The approach of this study is shown as a flowchart in Figure 3.1 below. The flat plate solar collector was designed to efficiently harness and use solar energy. The apparatus included several elements, including an absorber plate, tubing, insulation, glass, and a frame enclosure. A three-dimensional model of the proposed flat plate solar collector was first developed using SolidWorks software. Figure 3.2 illustrates the disassembled view of the flat plate solar collector, showcasing the proposed design and experimental setup. The collector's frame was made of wood. The equipment's absorber plate was made of tin sheet. The pipeline was fabricated using copper tubing to improve heat conductivity inside the pipe. Insulation was fabricated using cork sheets, and tempered glass was used for the upper part. A heat exchanger was used to reduce the temperature of the heated fluid from the collector. The cold fluid in motion absorbed heat from the hot working fluid, leading to its cooling. The designated heat exchanger had a straightforward design, including a rectangular enclosure that contained a U-shaped copper tube. This experiment used a 500-watt halogen lamp. A solarimeter was used to measure the light intensity of a halogen lamp. The experimental apparatus was established at the Mechanical workshop, CUET. Figure 3.3 depicts the flat plate solar collector used in this project. The collector was connected to an artificial light source, which served as the primary source of solar energy. The height of the halogen bulb may be adjusted, allowing for a variation in intensity levels. The diagram of the experimental setup is shown in the Fig 3.3 as follows.

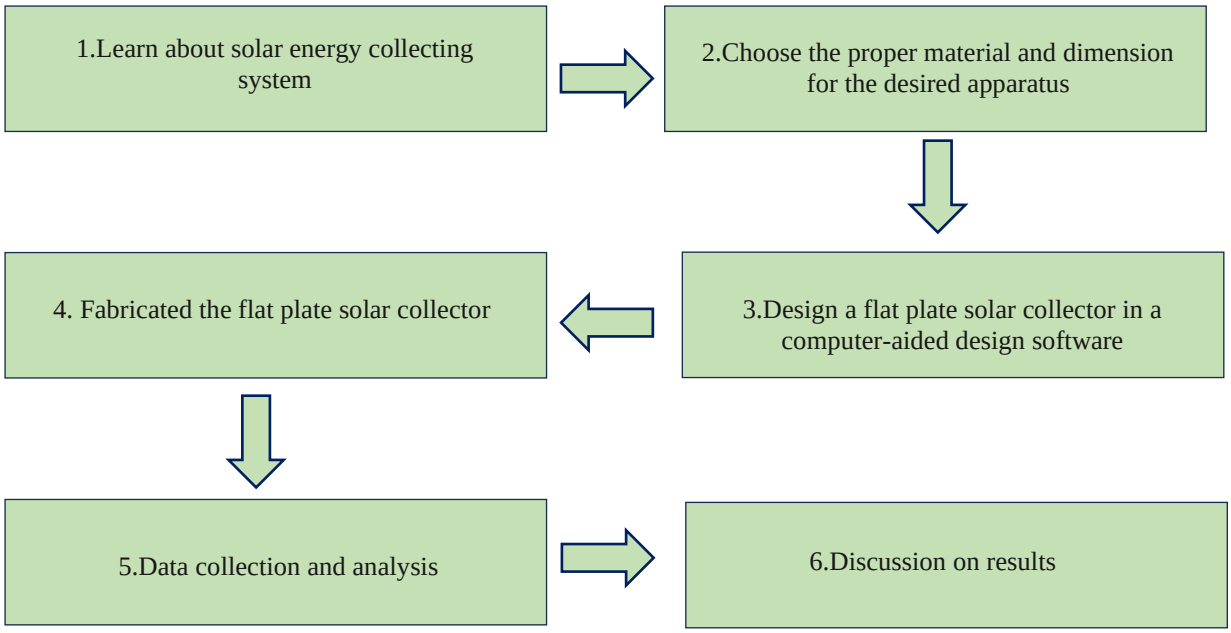


Fig 3.1: Flowchart on research outline.

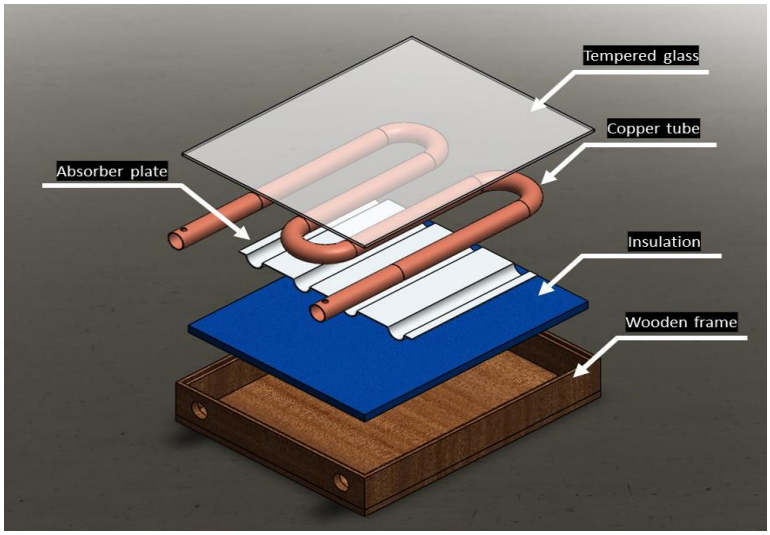


Fig 3.2: Three-dimensional view and experimental setup of the flat plate solar collector.

Investigating the effectiveness of a flat-plate solar collector is the primary goal of this study. After measuring all of the relevant parameters, the following formula have been used to compute the efficiency of the solar collector.

$$\eta = \frac{Qout}{Qin} = \frac{\dot{m}.c_p}{I.A}(T_O - T_i) \quad (1)$$

To analyze the result of the experiment, the necessary heat transfer parameters have to be determined. Nusselt number can provide more information about the mode of heat transfer of the system. The following formula has been used to find out the value of the Nusselt number.

$$\text{Nusselt number, Nu} = 3.66 + \frac{0.0668\times\frac{d}{L}\times Re\times Pr}{1+0.04\times(\frac{d}{L}\times Re\times \text{Pr})^{2/3}} \text{ [25]} \quad (2)$$

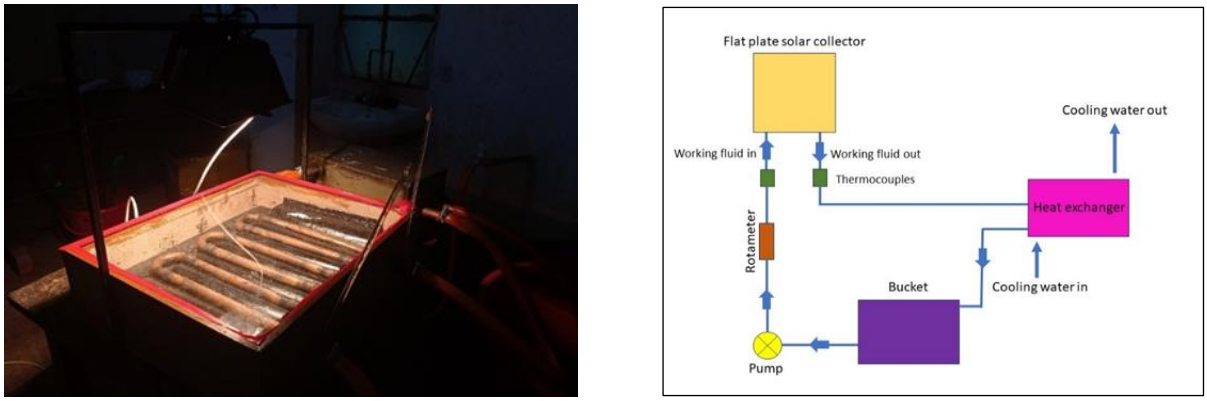


Fig 3.3: Illustration of the experimental setup.

3.Result and Discussion

All the data have been categorized into three groups based on intensity level: high intensity, medium intensity, and lower intensity. The flow rate had been altered during the experiment from 1 l/min to 2 l/min. In purpose to achieve steady conditions, the data sets of the 15 minutes of the experiment are considered for every flow rate and different levels of intensity. The viscosity of water has been calculated from the average temperature of the water. Similarly, thermal conductivity, density, and Prandtl numbers have been calculated for different levels of light intensity. Fig 4.1 shows the relationship between the convective heat transfer coefficient of the system and the Reynolds number. The graph illustrates that the convective coefficient linearly increases with the velocity of the fluid for any level of light intensity. The relationship is linear and has an upward trend.

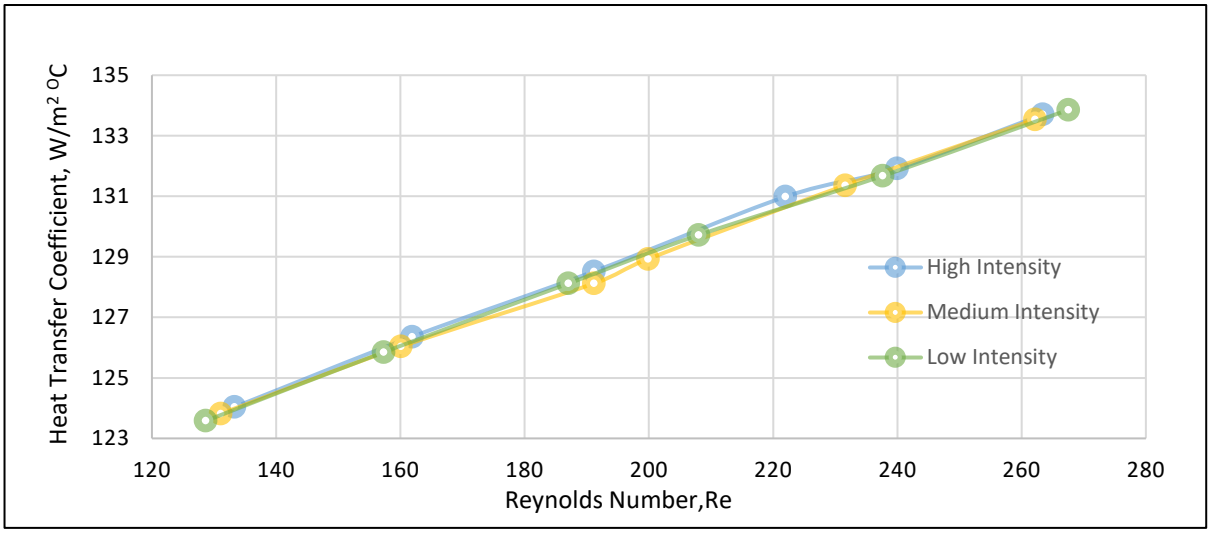


Fig 4.1: Graphical presentation of heat transfer coefficient with Reynolds number at various level of intensity.

An efficiency against flow rate graph has been developed and is shown in Fig 4.2 based on the acquisition of higher, medium, and lower intensity of light. For each intensity level, a trend line has been acquired. As heat transfer is proportional to the mass flow rate, the efficiency of the collector increases with the flow rate. However, the improving efficiency trend is limited to an optimal flow rate value. Despite this, after a certain flow rate, efficiency begins to decrease with flow rate. This is because of the minor temperature difference of the system in inlet and outlet section of fluid at a high flow rate. The graph indicates the flow rate should be at 1.6 liters per minute for maximum efficiency. Fig 4.3 illustrates the relationship between heat transfer through an absorbing plate and Reynolds number. For laminar flow, the rate of heat transfer increases with Reynolds number up to a value of 200 for any level of light intensity. Beyond that point, heat transfer begins to decrease with an increasing Reynolds number.

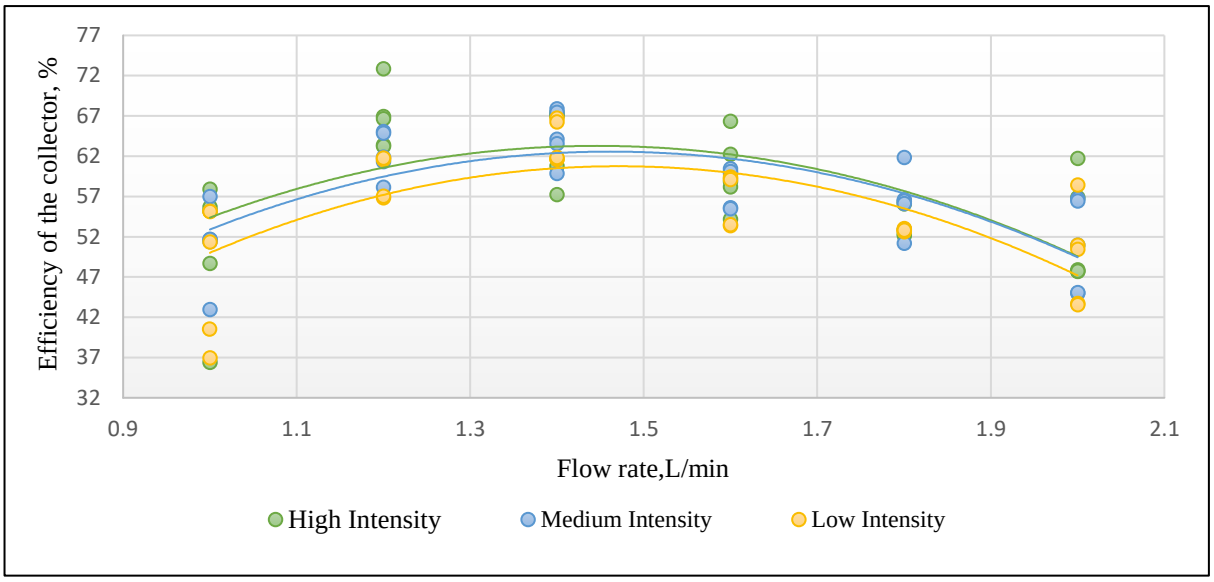


Fig 4.2: Graphical representation of efficiency of the absorber plate with flow rates for different levels of intensity.

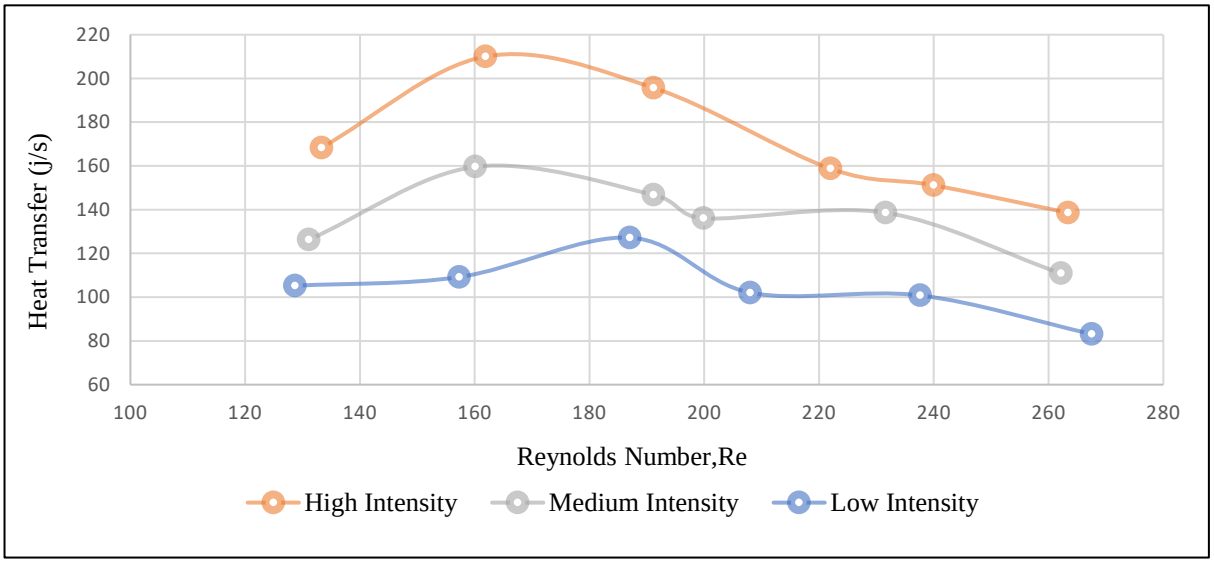


Fig 4.3: Graphical illustration of the correlation between Reynolds number and heat transfer of the absorber plate over 15 minutes at varying light intensities.

4.Conclusion

It is high time for the world to focus on renewable energy as fossil fuels are finishing. As oil and coal are responsible for global warming, the power generation sector should move to green energy. Solar energy comes here with an effective solution and offers various systems of power generation. Flat plate solar collector is the oldest way to absorb solar energy and transform it into heat energy which can be used in homes or building to heat water, room heating, and in swimming pools. A modern flat plate solar collector has been constructed with an artificial light source whose performance has been investigated. The highest efficiency can be attained at an ideal mass flow rate of 1.6 l/min through analysis of various heat transfer factors. If the Reynolds number is increased over that threshold, the efficiency falls as heat transfer reduces. At rapid speeds, the fluid has limited time to make contact with the tube surface, resulting in poor heat transmission. Furthermore, the temperature differential between the intake and output temperatures is directly proportional to heat transfer. The temperature difference decreases as the Reynolds number increases. A small change in temperature difference has a great impact on the efficiency of the absorber plate. The performance of the collector can be improved by using a copper plate as an absorber plate and running the system with an optimum mass flow rate.

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