Design and Demonstration of Solar Energy Based Water Heating System for Household purpose: An Experimental Approach

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Abstract: - The demand for energy world-wise is usually met by burning fossil fuels such as charcoal, petroleum, natural gas, kerosene, etc., or by the use of electricity. These conventional energy sources are exhaustible, unstable, and not environmentally friendly. However, electricity generation is not sufficient enough to meet the demand for energy over an extended period of time. Solar energy therefore appears to be the only veritable and viable alternative source of energy to heat water. It is inexhaustible, has no effect on the environment, and can be converted to many other forms of energy. Converting it to thermal energy in order to heat water is done with a solar water heating system. In the present study, the design and demonstration of a solar energy-based water heating system for household purposes is described. In this work, a water heater with a heat pipe for a solar energy collector is designed and demonstrated, which provides a maximum temperature of 46℃ and a maximum rise of about 1℃ within 10 minutes on a typical sunny day, the solar intensity range is about 700 to 900W/m2. With an environment temperature range of 29-33℃, the maximum rise in water temperature was about 6℃ of 3-liter water in one hour. The efficiency of the developed system is found to be 18.75%. It is concluded that this experimental setup works satisfactorily. All the materials used are locally available hence it is cheaper than other solar water heaters which is available in the market. This type of solar water heater can be used as an alternative to an electrical heating system if the desired temperature is less than 50- 55℃.

Keywords: Efficiency, Renewable energy, Solar Energy, Water heating system.

1. Introduction

It is impossible to overstate the significance of energy in today's world since it is essential to both human life and the well-being of any community. Both the expansion of society and the economy depend heavily on the efficient use and supply of energy. Non-renewable and renewable energy sources are the two main categories into which energy sources are divided [1]. Renewable energy is defined as energy that naturally refills itself through ongoing natural processes, whereas non-renewable energy is drawn from the ground and does not reappear quickly after being depleted [2]. For instance, non-renewable energy sources include fossil fuels (such as coal, oil, and natural gas) and some aquifers, but renewable energy sources include sunlight, wind, flowing water, biological.

For a variety of home and commercial uses, solar radiation is used as an alternative energy source. Currently, 20% of all domestic energy is used for water heating, aside from space heating, air conditioning, and lightning [3]. Given that they can save between 70-90 % of the entire cost of water heating, domestic water heating systems are among the finest options for significantly lowering household energy use. Solar water heating has improved in sustainability, efficiency, and economic viability during the last 30 years. The use of solar energy water heating systems (SEWHs) for residential and commercial buildings water heating systems is one of such initiatives. This is because solar thermal energy has become the most plentiful source of thermal energy as the quantity of solar energy that the planet absorbs in an hour is greater than the total amount of energy that the world consumes in a year [4] Unfortunately, most building water heating systems still largely rely on electricity from the power grid to heat water because of the low efficiency of solar thermal collectors and inefficient functioning of the heating system. With targets to improve the efficiency of SEWH, a number of studies have been conducted in the last few years. In which photovoltaic solar water heater, vacuum tube solar collector water heater and compound parabolic collector (CPC) type collector water heaters are generally used [5]. All the solar water heaters mention above are present in market and their prize is too high and it is not affordable for common people. In comparison of this solar water heater novel heat pipe solar water heater is cheaper and simple in design and it is efficient to heat water [6]. As the material used in solar panel are costly common people do not often use solar panel or solar collector. If alternate method is developed which is relatively cheaper and in range of common people budget there will be wide use of solar energy. This is of great importance because it helps in controlling global warming as our dependency of conventional energy source will reduce this reducing carbon di oxide emission. The solar energy available in summer is much more than available in winter session. This solar energy can be used to heat water using concave reflector, a black body and a heat pipe. As all these materials are cheaper the whole apparatus will be cheaper.

For design and demonstration of solar energy water heating several studies have been conducted. For example, the authors of [7] describe how flow and geometry characteristics affect how well solar thermal collectors with impinging air jets work. The study in [8] uses a variety of life cycle impact assessment techniques to perform a thorough assessment of the environmental profile of a solar thermal collector in a building. Similarly, Arab and Abbas, 2013- [9] have studied semi dynamic model of a concentric evacuated tube solar water heater is designed to absorb the working fluid effect, and optimize the uses of this solar water heater in house hold. In this study due to environment condition change of thermal resistant and critical heat flux is studied. For the further study three hypothetical working fluids are taken which enhance the performance of solar water heater up to 28%and 50%from thermal and economical point of view. Li and Liao, 2014- [10] studied the performance of solar water heater in congested area where one building is shaded by adjacent building which affects the performance of solar water heater. For finding the daily and annual thermal performance and the energy consumption a study is performed. After this case study it is found that the solar water heater with typical configuration is consume more solar energy than a traditional solar water heater. Wei et al., 2014- [11] have studied a relationship between domestic solar water heater and building integrated photovoltaic system for less area owned by household. According to this domestic solar water heater generate more heat than building integrated photovoltaic system for less area. Kumaresan et al., 2014- [12] studied the thermal performance of sintered and mesh wick heat pipe by using different fluids, inclination angle and heat input. Thermal conductivity, thermal resistance and temperature distribution plays important role in study of performance of sintered and mesh wick heat pipe. It is observed that sintered wick in heat pipe reduce the thermal resistance and increase the heat transfer capacity up to 20 watts in comparative to mesh wick. Mahadi et al., 2014 [13] constructed a serpentine type thermosyphon flat plate solar water heater with local available chip material. In this system a serpentine type copper tube is used which is connected with a flat plate and is also made of copper and black panted, copper tube is connected with flat plate. An insulated water tank is used to collect the hot water. It is analysed that the glazed collector is more efficient than not glazed collector. This solar system is used where about 60-65℃ hot water is required. Deng et al., 2013- [14] designed a flat plat solar collector solar water, heat collector uses micro heat pipe array which having excellent heat transfer capacity. Its surface area is taken as 2 m^2. Experiment is done in a whole year, daily, monthly and seasonal performance are analysed. This study conclude that the system performance is 58.29%. Kumar and Rosen, 2010 [15] Kumar developed an integrated collector solar water heater. A corrugated absorber is used in this system, corrugated surface increases the expose surface area of solar absorber plate. In this paper it is studied that the performance of solar water heater is depends up on the heat transfer capacity of absorber plate to the water and solar radiation. When the expose surface area of absorber increases incident solar radiation also increases hence absorber absorb more heat and more transfer to the water.

From the above literature review based on design and demonstration for solar energy-based water heating system, a lot of researches have gone into the solar energy field over the past few decades. This is mostly due to the growing recognition on a global scale of the environmental consequences associated with using fossil fuels as a source of energy. The design and building of a transportable solar water heating system that would produce hot water would be the outcome of the current study. Compared to importing these goods, using locally sourced materials would need fewer financial resources. This article describes the design and development of an experimental apparatus for demonstrating solar water heating. It has tried to developed efficient solar water heating system for rural area.

2. Proposed Design: Material selection, design and fabrication

The material selection, design and fabrication of solar energy-based water heating system (SEWHs) is done in such a way that the developed system can achieve the sufficient heating capability and can be used for household purpose. The developed system contains four major parts including a solar collector, a black body, a heat pump and a storage tank. The water heater tank was fabricated of diameter 15 cm with 3.017-liter capacity. These numeric values have been selected based various previous studies and research for small scale water heating system.

2.1. Fabrication of hollow spherical collector

A hollow spherical collector has been design using hollow spherical transparent glass vessel having dimensions of 15 cm and 15.5 cm inner diameter and outer diameter, respectively. The inner surface area of hollow spherical collector is 2827 cm^2 and its half portion is coated with highly reflecting material silver nitrate and remaining half portion transparent to pass the ray of solar light. Upper portion of collector is not purely spherical and its surface is also kept transparent. To prevent the coating of silver-nitrate a general paint is also used on the outer side of the coated layer. The bottom side of collector is open to insert black body and its bottom is stable on the flat table. The transparent portion and coated portion of fabricated hollow spherical collector is shown in Figure 1.

(a) (b)

Figure 1: Fabricated hollow spherical collector (a) transparent portion and (b) coated portion

2.2. Fabrication of black body

A hollow cylindrical object of copper material is fabricated as a black body. The black body has dimensions of 25 cm in length, 2 cm of outer diameter and 1.98 cm of inner diameter. It has 128.8 cm^2 outer surface area. The bottom portion of black body has a diameter of 1.3 cm and made from copper sheet. The bottom portion of black body is made with specific shape by rolling under the application of 200 ^0C. Upper portion of cylindrical part is packed with copper circular plate by welding for increase the absorptivity of copper its outer surface is black panted. Figure 2 shows the fabricated black body.

Figure 2: Fabricated black body

2.3. Fabrication of heat pipe

Heat pipe is an efficient heat transfer device. It is made of copper tube of diameter 12 mm and length 39 cm having excellent heat transfer capacity. A wick of cotton is inserted in the heat pipe that has 60% porosity, 35 cm effective length and 2 mm thickness. First of all, pipe is packed of one end and wick is inserted then other end is packed. A valve is created on the pipe to evacuate and inserted working fluid. A certain amount (40%) of working fluid is filled in the pipe and then evacuated through the vacuum pipe till the vacuum pressure reach 0.012 bar, at this pressure water is evaporate at 50℃, after evacuation valve is packed. Saturation pressure of water at 50℃ is 0.012 bar. There are three sections in heat pipe: (a) Evaporation section; (b) Adiabatic section; (c) Condenser section. Heat is added at evaporation section and heat is release at condenser section, adiabatic section is that where there is no heat loss. For insulation of this section a climaflex polyethylene-based insulator is used. Adiabatic section of length 13 cm is covered with climaflex (k=0.03 at 50℃). Fabricated heat pipe with inserted cotton wick is shown in Figure 3. The heat pipe with adiabatic section covered by climaflex is shown in Figure 4.

Figure 3: Fabricated heat piper with inserted cotton wick

Figure 4: Heat pipe with adiabatic section covered by climaflex

2.4 Water Tank

It is an aluminum square shape box having capacity of 3.017-liter inner side length 14.5 cm, for insolation inner wall of tank is coated with deco past. There are two holes first of them is to set heat pipe and second small hole is to set digital thermometer. Water tank figure is shown in Figure 5.

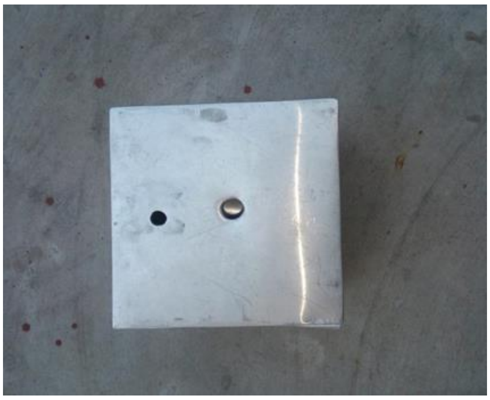

Figure 5: Water tank

2.5. Temperature measuring device

There are two digital thermometers used for measuring accurate temperature of black body and water of water tank. Pin type sensor of digital thermometer set with setup for measuring temperature. It has measuring rang -50℃ to +80℃ and ±2℃ error fig shows the digital thermometer which was used in the experimental set up. The figure of digital thermometer is shown in Figure 6.

Figure 6: Digital thermometer

2.6. Pressure gauge

Pressure gauges are simple in function; they read positive pressure and negative pressure, or both. The gauge used in this experiment measure up to 200 Psi and also reads from 0 to 30 Psi for vacuum. In the set-up vacuum pressure of heat pipe is to measure by this equipment.

3. Working Principle of solar water heating system

Working satisfactory depends up on efficiency of solar collector, black body, heat pipe and water tank. It also depends on solar altitude angle, solar intensity and environment temperature. Schematic diagram for functioning of solar water heating system is shown in Figure 7 reflects that sun energy incident on solar reflector, reflected radiation absorb by absorber and it transfers heat to heat transfer device heat pipe and then heat is used for water heating.

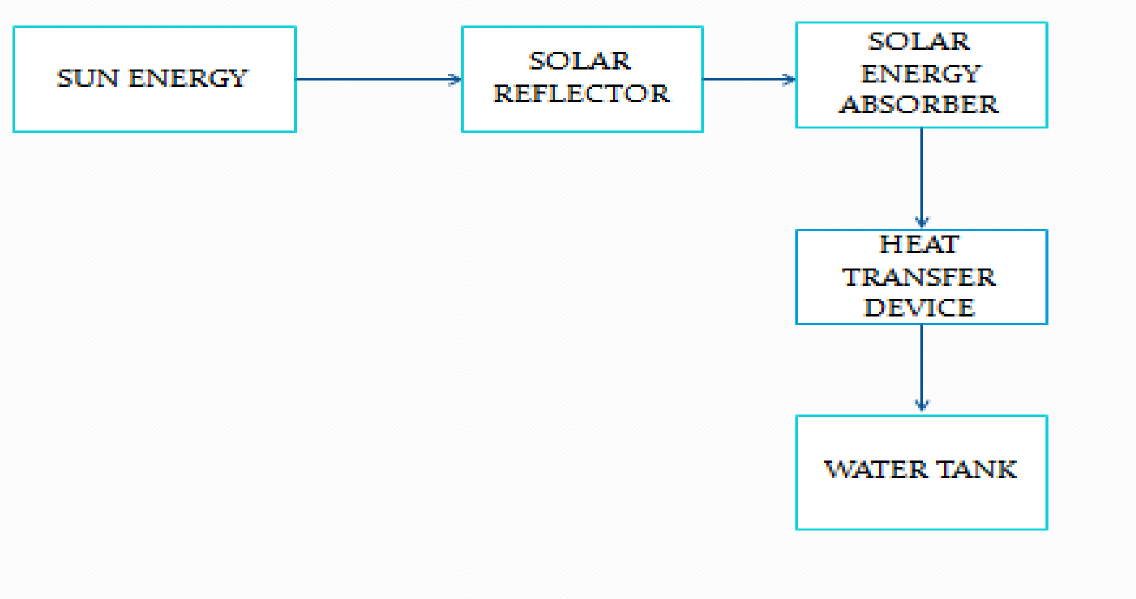

Figure 7: Schematic diagram for functioning of solar water heating system

3.1. Working Principal of heat pipe

The major objective of this study is to transfer the maximum amount of radiation energy to the water. Heat pipe is a heat transfer device which transfers heat from black body to the water. In evaporation section heat is added in which working fluid is in liquid phase and it absorb heat energy and get vaporize. This heat energy transferred by working fluid from evaporator to condenser. In heat pipe heat transfer in two ways including (a) Conduction; heat pipe is made of copper tube, copper having good heat transfer capacity its thermal conductivity (K) is 385 W/mK and (b) Convection; a wick is inserted in the heat pipe and 40% of heat pipe filled with working fluid. This fluid evaporates at 50°C in evaporator and evaporated fluid travel from evaporation section to condenser section through vapor line. Schematic diagram for the working process of heat pipe is shown in Figure 8.

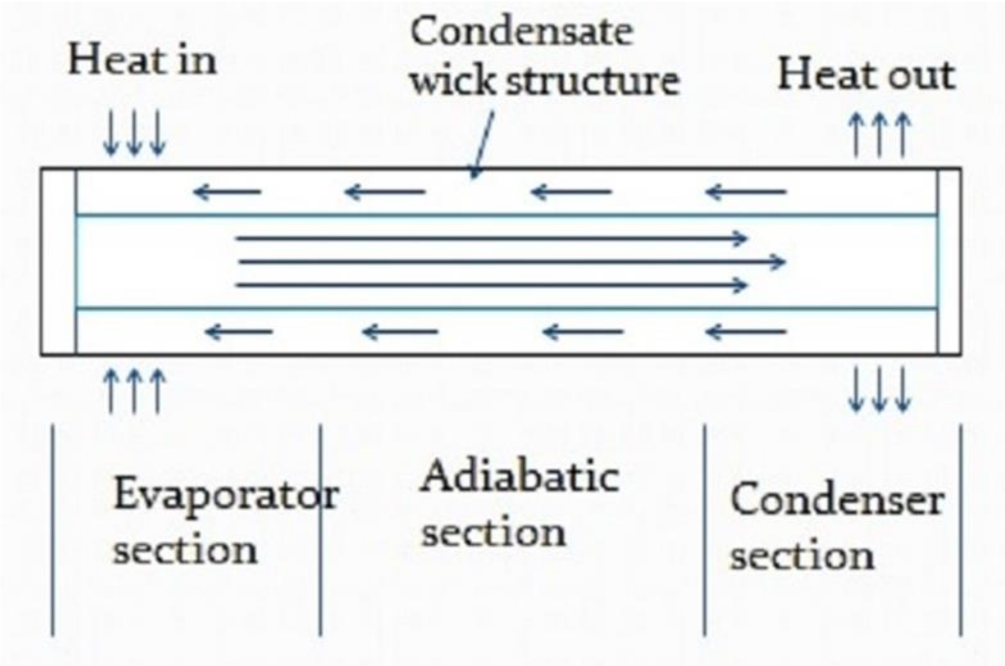

Figure 8: Schematic diagram for the working process of heat piper

3.2. Efficiency calculation of set-up

Efficiency of solar water heating system (SEWHs) can be calculated based on total heat energy absorbed by water and total incident solar energy on the solar collector.

$$\eta_{SEWHs}\,(\%) = \frac{Total\ Heat\ Energy\ absorbed\ by\ water}{Total\ incident\ solar\ energy\ on\ the\ solar\ collector} \times 100 \qquad (1)$$

For calculating the efficiency of solar water heating system, various parameters need to be calculated.

Surface area of collector	$= 4\pi r^2$
Coated surface area	$= 2\pi r^2$
Average solar intensity in testing area (I_n)	= 820 KJ/m^2
Water tank capacity	= 3.107 liter
Specific heat capacity of water (C_p)	= 4.2 KJ/kg-k
Temperature rise of water/hr. (dT)	= 6^{0}C

$$Total\ incident\ solar\ energy\ on\ the\ solar\ collector\ per\ hr\ (IE) = Coated\ surface\ area\ of\ collector\ \times average\ solar\ energy\ \times 3600 \qquad (2)$$

Total incident solar energy on the solar collector per hr. (IE) $= 2\pi r^2 \times I_n \times 360$
$= 0.1413 \times 820 \times 3600$
$= 417$ KJ

$$Total\ solar\ energy\ absorbed\ by\ water\ for\ heating = mC_p dT \qquad (3)$$

Total solar energy absorbed by water for heating $= 3.071 \times 4.2 \times 6$
$= 77.4$ KJ

η_{SEWHs} $= 77.4 \times 100/417$
$= 18.56\%$

4. Results and Discussion

The performance of the developed solar water heating system is evaluated by measuring the temperature change in black body and water temperature in the tank using digital thermocouple. The developed solar water heating system is exposed in solar energy environment and reading obtained from digital thermocouple is noted in the interval of 30 mins. The experiment has been started at 8:00 am and ended at 5:00 pm. For the repetition of performance at least 7 days of experiment has been conducted. For all days of experiments, the output responses have been similar pattern and therefore only two different days of results have been presented. The reading obtained from digital thermocouple for black body and water temperature on first day and last day of experiments are shown in table 1 and 2, respectively. The value of temperature at different time interval for black body and water is shown in Figure 9. From the experimental study shows that as the environmental temperature changes the temperature for black body and simultaneously water temperature changes. It is also observed that at the morning when intensity or solar energy is low the temperature for black body and water remains low and getting increased at the afternoon and again started to decrease as the intensity of solar energy decreased. The experimental study shows that the developed solar water heating system has excellent performance and can be used for heating the water. This system may really helpful for the rural people.

Table 1: The reading obtained from digital thermocouple for black body and water temperature on first day of experiment

Time	Environment temperature in °C	Black body temperature in °C	Water temperature in °C
8:00am	27	27	27
8:30am	28	55	29
9:00am	29	59	30.2
9:30am	29.3	59.5	32.6
10:00am	29.9	60	33.9
10:30am	30	60.6	35.9
11:00am	30.6	61	37.4
11:30am	31	61	39.6
12:00am	31.4	61.8	41
12:30pm	31.9	63	42
1:00pm	32.4	63.4	43.6
1:30pm	32.6	64	44.5
2:00pm	33	64.2	45
2:30pm	33.8	64.2	45.3
3:00pm	35	64.4	45.5
3:30pm	34.4	64.1	45.4
4:00pm	32	62	44
4:30pm	30	61	43
5:00pm	29.3	59	42
5:30pm	28.6	58.2	40.3

Table 2: The reading obtained from digital thermocouple for black body and water temperature on last day of experiment

Time	Environment temperature in °C	Black body temperature in °C	Water temperature in °C
8:00am	28	28	28
8:30am	29	55	29.8
9:00am	29.8	60	32
9:30am	30.4	62	34.2
10:00am	31	62.2	37
10:30am	32	62.6	39.6
11:00am	33.6	63	41
11:30am	34	63.2	43
12:00am	35.4	64	44
12:30pm	36	64	45
1:00pm	35.9	64.2	45.5
1:30pm	36.2	64.4	46
2:00pm	37	64.5	46
2:30pm	36.9	64.2	46.1
3:00pm	37	64.3	46
3:30pm	36.7	63	45.8
4:00pm	35	62	45
4:30pm	34	61.6	44

5:00pm	31	61	43.3
5:30pm	29	59	42

5.

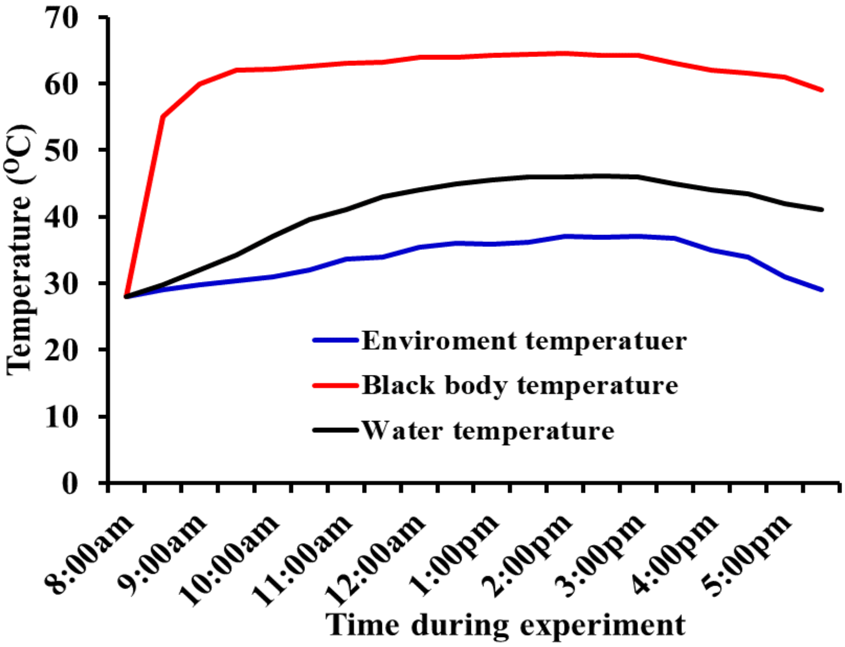

Figure 9: Temperature reading for different conditions.

5. Conclusion

In this work a water heater with heat pipe for solar energy collector is used, which provides a maximum temperature 46℃ and a maximum rise of about 1℃ within a span of 10 minute in a typical sunny day, solar intensity range is about 700 to 900W/m^2. The maximum water temperature can be obtained in high solar insolation. Water temperature also depends on the amount of water with increase the amount of water temperature rise decrease. With environment temperature range 29-33℃ the maximum rise in water temperature was about 6℃ of 3-liter water in one hour. Solar collector collects about 115.87W solar energy and converge on to the black body and it absorbed total heat. Heat pipe transfer about 13 KJ of heat in span of 10 minute to the water. Heat transfer rate of heat pipe is 21.5 KJ/S. Efficiency of set up is 18.75%. It is concluded that this experimental set up works satisfactorily. All the material used are locally available hence it is cheaper than other solar water heater which is available in the market. This type of solar water heater can be used as alternative to electrical heating system if desire temperature is less than 50- 55℃.

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