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Design, Fabrication and Performance Test of an Improved Solar Water Heater

K. H. Pulok[1]*, S. N. Shaily[1], M. M. Hasan[1], Manik[2], Dr. Md. Shamim Akhter[1]
[1]Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh
[2]Department of Mechanical Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh
E-mail: pulok_ruet@yahoo.com

Abstract

Solar water heater is a device or combination of equipment which works to heat water and this project of solar water heater have no requirement of utilizing other energy. Many works have been done on this topics but the major intension of the authors are to construct an improved version of the existing one (in case of performance efficiency, size and so on). In the way of this the design and construction materials have changed for the improved version. In case of design- alignment, spacing of the absorber pipe, absorbing surface analysis has emphasized more. And in case of material- heat absorption capacity, insulation nature, radiation capability etc. has emphasized more. As a result performance efficiency has increases. In case of achieving same performance, its size also reduces than previous collectors. Because of its less size it also required less material and cost reduces in that case also (though the materials used in this project are more expensive).

Keywords: Solar energy, solar water heater

1. Introduction

The form of energy- basically called electromagnetic energy is one of the basic forms of energy which comes from the sun source by electromagnetic wave or radiation is termed as solar energy. Now-a-days while more convenient energy sources like coal, gas, oil or any other fossil fuel are reducing their resources and at the same time – harming adversely to the atmosphere. In this situation, solar energy can plays a vital role on energy convenience. Its use is increasing day by day because it satisfying three "E"s (energy, economy and ecology). A solar water heater industry in South Florida was started in 1900. It is estimated that about 30000 to 50000 units were installed by 1950, but around that time their popularity began to decline due to readily available cheap energy from fossil fuel [1].

2. Solar energy as a renewable source of energy

Hence it is a matter of concern, not only for better living standard but also for very survival of the world, to device, develop and deploy all possible techniques to extract energy from renewable energy sources. The fascination of renewable energy is that it is not dwindling or reducing its intensity and it does not damage environment and rather it contributes towards a pollution free environment. Solar radiation is produced by the nuclear fusion of different elements inside the sun (basically conversion of Hydrogen and Helium nucleus). And this radiation emits in the form of sunlight, infrared rays, ultraviolet rays, cosmic rays, x-rays etc. The rate of solar emission from the sun is 4.3x109 kg/sec. The power from the sun intercepted by the earth is approximately 1.8 x 1011 MW [2]. Most of the sun's energy that makes the 93,000,000-mile journey is in the form of visible and ultraviolet light.

3. Availability of solar energy in Bangladesh

Solar energy is one of the most available and enormous sources of energy in Bangladesh, where the maximum and minimum day times are 12.5 and 10 hours respectively in the year round. The geographical position of Bangladesh is between 20º34′ and 26º38′ North latitude and longitude 90.50&90.80 E. the total potential is estimated at 22.2-28.5 x 108 MW years [3]. In Bangladesh, the solar energy that reaches 6414 sq-Km in one hour is equal to the total yearly energy consumption of Bangladesh. However the use of solar energy, as a commercially energy source as not yet received by popular acceptance in the region.

4. Prospect of solar energy in Bangladesh

Bangladesh is endorsed with an abundance of sunshine during most of the year.
The various uses of solar energy in Bangladesh are described below:

- ❖ Traditional use: Traditionally solar energy is used for drying of agriculture products, fishes, fruits, cloths and production of salt.
- ❖ Preheated water: It is used for normal cooking, cottage industries, hotels etc. Hot water (between 60ºC to 100ºC) is used in textile and paper industries.
- ❖ Distillation and Purification: Solar distillation unit is a very important device to make fresh water from salty water.
- ❖ Solar electric power: This type of system is most suitable for remote places where electricity from the grid is not available.

In addition to domestic power, solar photovoltaic (PV) cell can be used for the following purposes, such as - PV operated refrigerator , PV operated pump, Telecommunication, Military, Navigation and tower lighting, Domestic use.

5. Solar Water Heater

Water heating typically represents a high percentage of energy consumption in homes and businesses, in some cases 30% or more[4].Solar water heater is nothing but a device which utilizes harnessing energy from the sun to heat water. Solar water heating is a reliable and renewable energy technology used to heat water. Sunlight strikes and heats an "absorber" surface within a "solar collector" or an actual storage tank. Water flows through tubes attached to the absorber and picks up the heat from it. Most of the solar radiation is absorbed and converted to heat [5]. Some of this absorbed heat is conducted through the pipe to the riser tubes and then through the riser tubes walls to the water. The transfer of heat to the water rises the water temperature. Some of the heat is lost to the surroundings. The heat losses should keep as low as possible.

6. Design of the solar water heater

A) Design of the collector [6][7]

The collector overall heat loss is the sum of the top and bottom loss coefficients. Mathematically, $U = U_t + U_b + U_e$

Here, U = Overall heat transfer co-efficient, $W/m^2\text{-}^0K$
U_t = Top heat loss co-efficient, $W/m^2\text{-}^0K$
U_b = Bottom heat loss co-efficient, $W/m^2\text{-}^0K$
U_e = Edge heat loss co-efficient, $W/m^2\text{-}^0K$

The bottom loss coefficient U_b drives from the thermal conductivity K_s and the thickness L_s of the bottom insulator as: $U_b = k_s/L_s$ The top loss co-efficient U_t is evaluated by considering convection and re-radiation losses from the absorber plate in upward direction. Following the basic procedure of Hottel and Woertz, Klein Developed an empirical equation for the top loss coefficient, U_t as (Yehet al., 2003)

$$U_t = \left[\frac{N}{\left(\frac{C}{T_m}\right)\left(\frac{T_m - T_a}{N + f}\right)^{0.252}} + \frac{1}{h_w} \right]^{-1} + \frac{\sigma (T_m^2 - T_a^2)(T_m + T_a)}{\frac{1}{\varepsilon_p + 0.0425 N (1 - \varepsilon_p)} + \frac{2N + f - 1}{\varepsilon_g} - N}$$

Where, $$C = \frac{204.429(\cos\beta)^{0.252}}{L^{0.24}} \qquad f = \left(\frac{9}{h_w} - \frac{30}{h_w^2}\right)\left(\frac{T_a}{316.9}\right)(1 + 0.09N) = 0.429$$

$h_w = 5.7 + 3.8V$

[From Solar Energy Fundamentals and Applications by H P Garg J Prakash]

No. of glass cover, N= 1 & σ = 5.67x10-8 W/m2-k4

$$\varepsilon_p = 0.97, \quad \varepsilon_g = 0.07$$

If the number of tubes is n, then useful heat gain is, $Q_u = n^3 q$
Now, useful heat gain, $Q_u = WC_p \Delta T$ & $\Delta T = Q_u/WC_p$
Collection efficiency can be defined as the ratio, $\eta = Q_u / (A_c I)$
Where, A_c = Collector area & I = Solar Intensity

B) Design calculation of collector plate

Amount of heat absorbed by water , $Q_1 = mc_f (T_{coll.out} - T_{coll.\ in})$
Here, m= mass flow of the water 4 kg/hr

C_f = Specific heat of water =1 kcal/kg = 4.2 kJ/kg. ; $T_{coll.in}$ = 29ºC,$T_{coll.out}$ = 50 ºC
Q_1= mc_f (Tcoll.out-Tcollin) = 4*4.2*(50-29) =352.8 kJ/kg. hr
Amount of heat absorbed by the absorber plate, $Q_2 = F\ [\eta I_t - UL\ (T_{avg} - T_{amb})]$
Here, From Table 2.6:- Solar collector performance parameters (DOC 1977) Ref Books (Fundamentals & applications) H.P Garg J prakash [8][9].
UL = Heat transfer co-efficient = 6.2502 KJ/hr $m^{2\ 0}$ K
(Considering Cu as in absorber material)
And collector efficiency factor F= 0.88 (Cu)
[Table 2.6 solar collector performance parameter (DOC 1977)] From the intensity chart of solar radiation for month of July. I =1100 kJ/hr.m^2 ; η = Absorbtivity factor = 0.7 (For black chrome paint)
Assuming, average temperature and of collector inlet and outlet , T_{ave} = 31 ^{0}C ; T_{amb} = 29 ^{0} C
Q_2 = 0.55[0.7*1100– 6.2502(31-29)] = 0.55[770 – 12.5] = 0.55*757.5
= 416.625 kJ/kg-hr.m^2
As $Q_2 > Q_1$ the design may be considered to be correct.
Specific dimension
Now the collector area = Q_2 / intensity of solar radiation. = 416.625/1100 = 0.378 m^2
Length = 0.6604 m ; Width = 0.558 m (This is available in the market)
Pipe dia. = 0.00635 m
Design Efficiency,

$$\eta = \frac{Q_u}{A_c I} = \frac{\dot{m} c_p \Delta T}{A_c I} = \frac{4 \times 4.2 \times (69 - 35) \times 1000}{0.369 \times 1100 \times 3600} = 48.65\%$$

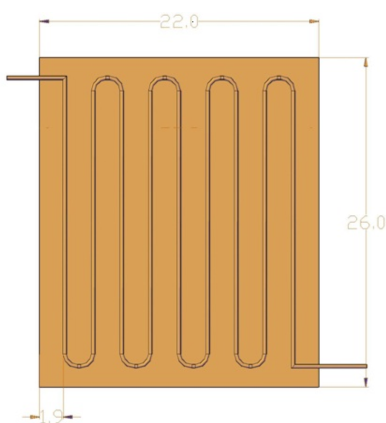

Fig.1 Design of the collector

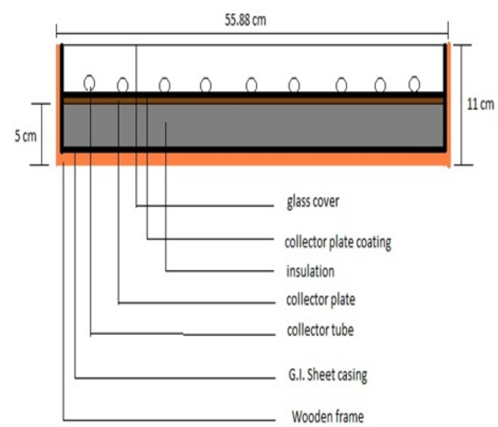

Fig.2 Cross sectional view of the collector

C) Absorber pipe

Absorber pipe absorbs the incoming solar radiation and transfer the resulting heat to the working fluid. Factors that determine the choice of absorber materials are:
High thermal conductivity, Durability, Ease of handling, Availability, Good corrosion, resistance, Compressive strength, Cost.
Thermal conductivity of various materials is investigated. Copper and aluminum are generally preferred as absorber pipe because of its extremely high thermal conductivity and resistance to corrosion. Thermal conductivity of aluminum is 204 W/m/°C and copper is 386 W/m/°C. Copper has a high thermal conductivity as compared with the aluminum for this reason copper is chosen as the absorber pipe material for this project work. Though aluminum is less costly than commonly used materials and easily available in our country but for achieving better efficiency we have used copper as absorber pipe.

D) Absorber pipe coating

The two requirements for an absorber pipe coating are:

- It should absorb a large fraction of the solar radiation falling on it.
- It should not deteriorate at the high temperature, which may be reached by the pipe.

An ideal absorber pipe surface would also be a poor radiator of heat when its temperature rose. However most common surface that is good absorber of radiation are also good radiator of heat. Black coating is a good example of commonly used coating that is a both a good absorber of radiation and a good radiator of heat. Such surfaces may absorb up to 96% of the solar radiation falling on them. The coating used in the absorber pipe must be able to withstand the temperature encountered inside the absorber pipe. But now a days for better performance Black chrome (Chromium oxide) is used for its better thermal absorbing capacity.

E) Insulation

Insulation is necessary to reduce heat losses from the absorbing pipe and pipes of the solar water heater. For insulation, the gap between the absorber pipe and the cover pipe is vacuumed and rubber cork is used to seal the ends of the joint area.

7. Fabrication of the solar water heater

The overall design is divided into two sub-assembly components. The assembled parts are: Wooden frame & Absorber pipe with copper pipe.

A) Specified Dimension of Wooden frame

Length of the frame = 0.68 m
Width of the frame = 0.58 m

B) Specified Dimension of the Absorber pipe

Length of the Copper pipe = 0.45 m
Outer diameter of the Copper pipe = 0.635 cm
Number of Copper pipe = 9

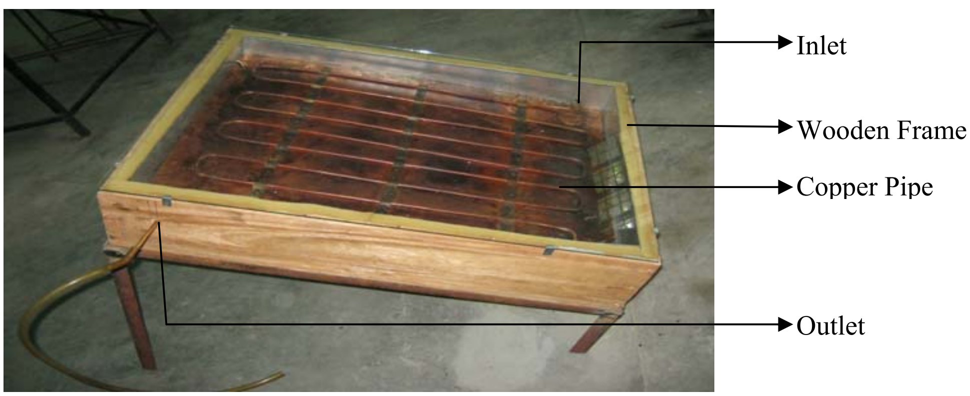

Fig.3 Photograph of our constructed solar collector

8. Performance study of the solar heater system

The performance study represents the study of collector efficiency. This includes the maximum temperature supply of water, useful heat gain collection efficiency etc. To obtain these parameters the collector inlet and outlet temperature, mass flow rates, diameter of the pipe, area of the collector are to be known.

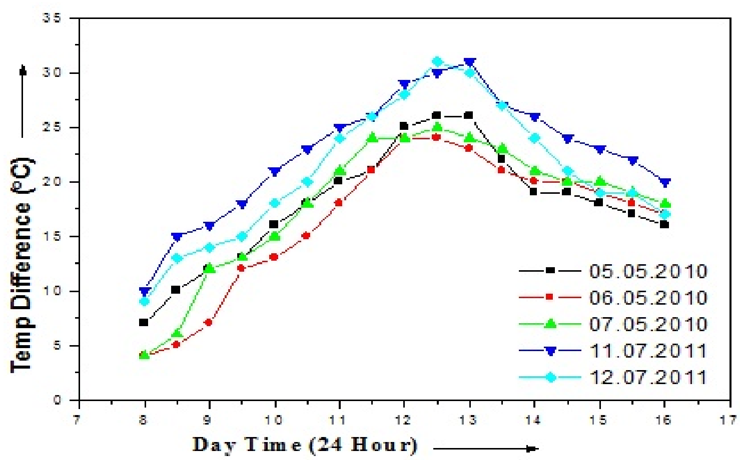

Fig.4 Temperature Difference VS Time Curve

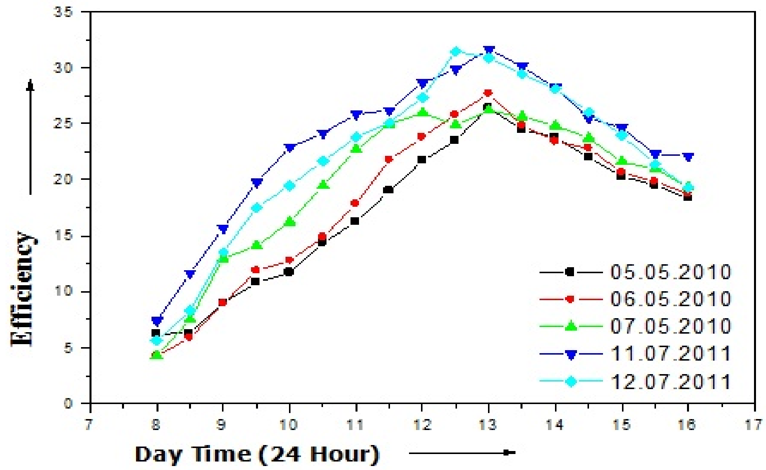

Fig.5 Efficiency Vs Day time curve

Performance of our collector in comparison with previous collector is illustrated in graphical form below- (for mass flow rate of 5kg/hr and Reading was taken in same month)

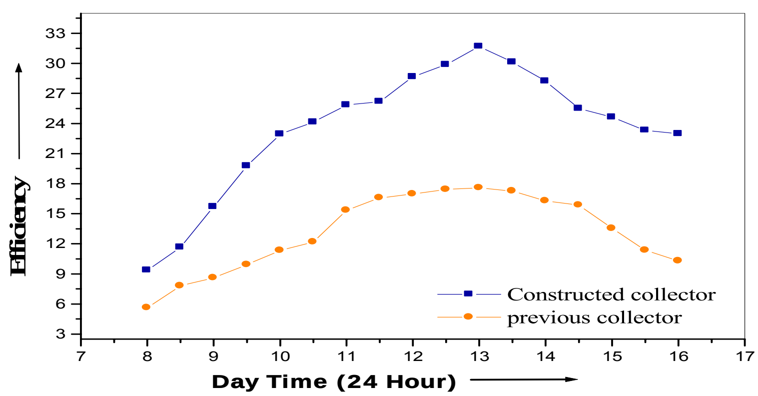

Fig.6 Efficiency VS Day time Curve

9. Result and discussion

The collector efficiency of the solar plate depends on the heat intensity. The more intense heat on absorber plate the more the efficiency. The solar radiation varies according to the position of the sun. Here 1100 W/m2 intensity of solar energy is used average one year for only Rajshahi city. The solar cell was used to measure the intensity of solar radiation. When the sky was cloudy the intensity of solar radiation was less. It was found from the experimental data that the efficiency was high at noon, it increases from 9.00 am to 12.30 pm and decreases after 1.00 pm. For mass flow rate 5 kg/hr the highest efficiency is 31.11% which was more than 14.11% for the previous collector (Reading was taken in same month).

All the figures of temperature differences vs. daytime Fig.4 shows a parabolic curve because up to a particular time of the day the temperature difference is increased and after that it starts to decrease. Again, all the figures of the efficiency v_s temperature difference Fig.5 shows a line of upward direction in rightward because efficiency always increase with the increase of temperature difference.

10. Conclusion

The main objectives of this system are to design and construct such a system which will give better performance efficiency than the existing one. The maximum temperature reached by the setup with glass as cover is 74^0C at that time the inlet temperature was 35^0C The performance of collector maximum efficiency 31.11% which is less than our design efficiency; due to some losses were occurred. Again the fluctuation of solar radiation intensity affects the performance of the system. But also the project improves than the previous one which could increase the temperature up to 68^0C and could utilize the energy up to 23.43% performance efficiency.

11. Recommendation

The solar water heater was made according to the design. But it would be much better if the more number of Copper pipes can be used. If the number of Cu pipe will increase, the absorber area will be increased so that higher efficiency can be achieved. But the number of pipes should not be increased as much so that the construction cost will high. For increasing the number of pipes, the space between the pipes should not be shorter. There must be a minimum distance between the pipes otherwise heat absorbing capacity of the pipes may be decrease. If a cover pipe with fluorescent tube with proper vacuum formation is used then the amount of heat absorbed can be increased and as a result the heater will give a better performance. In the present heater no reflector is used. But the use of a reflector such as mirror can trap more sun radiation which will increase the heat gaining capacity. A storage unit can be arranged with the heater to store hot water.

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