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Study and Design of a Solar Water Heater and Analysis of Heat and Transfer Rate by Installing Different Types of Tube Material with and Without Installing Fins

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Abstract: Engineers are continually being asked to improve processes and increase efficiency. These requests may arise as a result of the need to increase process throughput, increase profitability or accommodate capital limitations. Processes which use heat transfer equipment must frequently be improved for these reasons. The project focus on "Design a Solar Water Heater and analysis its heat transfer rate by installing different types of material with and without installing fins". The material which we are using is copper, aluminum, mild steel and PVC. The purpose of the selection of these materials is because of their thermal conductivity and some are selected because of their low cost. The calculation and the conclusion shows that the temperature difference at inlet and outlet is efficient in Al and PVC, material having the high and efficient heat transfer rate. As the availability of these two materials is in sample amount in market and are economical to so, we concluded that the manufacturing of SWH should be done with the hybrid combination of these two materials.

Key words: Different materials, SWH (Solar Water Heater) fins, temperature difference, log mean temperature difference, heat transfer rate, manufacturing

INTRODUCTION

Solar water heater is a device which provides hot water for bathing, washing, cleaning, etc. using solar energy. It is generally installed at the terrace or where sunlight is available and heats water during day time which is stored in an insulated storage tank for use when required including mornings (Christopher and Homola, 2010; Sklar and Sheinkopf, 1991). Solar air heaters have low efficiency due to low convective heat transfer coefficient between the air and absorber plate that leads to higher temperature of the absorber plate leading to maximum thermal losses to environment.

Solar water heater comprises of a or an array of solar collectors to collect solar energy and an insulated tank to store hot water. Both are connected to each other (Lanjewar *et al*., 2010). During the day time, water in solar collectors gets heated which is either pumped or flown automatically on thermo syphon principle to the storage tank. Hot water then stored in the tank can be used for various applications.

Two types of solar water heaters are available, one based on flat plate collectors and the other based on evacuated tube collectors Fig. 1. Flat Plate Collector (FPC) based systems are of metallic type and have longer life as compared to Evacuated Tube Collector (ETC) based system because ETCs are made of glass which are of fragile in nature.

Both these systems are available with and without heat exchanger (Keisling, 1983). They can also work with and without pump. Systems without pump are known as thermo syphon systems and those with pump are known as forced circulation systems.

ETC based systems are cheaper than FPC based system. They perform better in colder regions and avoid freezing problem during sub-zero temperature. FPC based systems also perform good with anti-freeze solution at sub-zero temperature but their cost increases. In other regions, both perform equally well.

Systems working on thermo syphon principle are simple and relatively inexpensive. They are suitable for domestic and small institutional applications, provided water quality is good and it doesn't have large chlorine contents (Zalba *et al*., 2003). Forced circulation systems are generally preferred in industries or large establishments.

Additional system requirements: It is necessary to have solar water heating system with the right technology, features and capacity to ensure a long term reliable and

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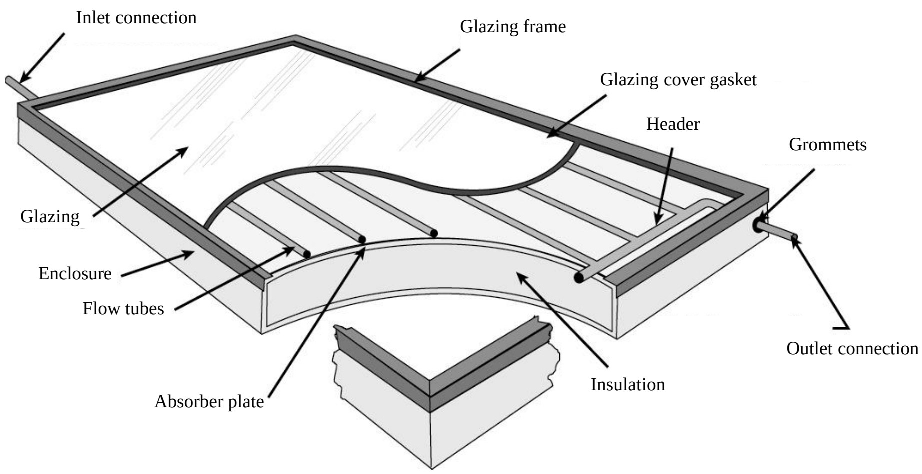

Fig. 1: Flat plate collector

smooth operation of the system. Installation of the solar water heater in the right manner, suitable for the specific site conditions is very important for optimal performance of the system (Hasnain, 2011). In case of a large system located at the rooftop of buildings, provision of lightening arrester must be made in case it is not already provided.

The name plates should be easily visible to the installers. Safety instruction must be provided along with the system to ensure installation safety at site.

Forced circulation system: For systems of size larger than 3000 L per day, customer may choose forced circulation system. These systems may also be used for smaller than 3000 L/day capacity also where thermo-siphon system cannot be used due to limitation of height of the cold water tank.

Environmental benefits (Christopher and Homola, 2010): Solar water heaters do not pollute. Solar water heaters help to avoid carbon dioxide, nitrogen oxides, sulphur dioxide and the other air pollution and wastes created when the local utility generates power or fuel is burned to heat domestic water. When a solar water heater replaces an electric water heater, the electricity displaced over 20 years represents more than 50 tons of avoided carbon dioxide emission alone.

Long-term benefits:

- Solar water heaters offer long term benefits that go beyond simple economics
- In addition to having free hot water after the system has paid for itself in reduced utility bills, owners could be cushioned from future fuel shortages and price increases
- Solar water heaters can assist in reducing this country's dependence on Foreign oil
- It is estimated that adding a solar water heater to an existing home raises the resale value of the home by the entire cost of the system

Motivation: Normally, the cost of solar water heater is high, this has brought a key concern for application in rural parts of nation. The focus of this research will aim to the selection of materials for building an efficient and low cost solar water heater which can benefit domestic needs.

MATERIALS AND METHODS

The study is done on heat transfer rate by installation of different types of material with and without fins (extended surface) expecting to enhance the heat transfer rate. The material which we are using is copper, aluminum, mild steel and PVC. The purpose of the selection of these materials is because of their thermal conductivity and some are selected because of their low cost (Fig. 2).

The calculation and the conclusion has been carried out on the basis of the material which having the high and efficient heat transfer rate which is been calculated with the help of "Log Mean Temperature Difference Method". For the increment of the heat transfer rate in our SWH, we have installed a circular fins of material aluminum (Fig. 3).

Manufacturing process:

Tube material used: The tubes which are used in the manufacturing of SWH are AL, CU, MS and PVC, the selection of the material is according to their thermal conductivity, heat transfer rate and according to their costing. The material of fins installed is also of Al because of its low cost and good thermal conductivity.

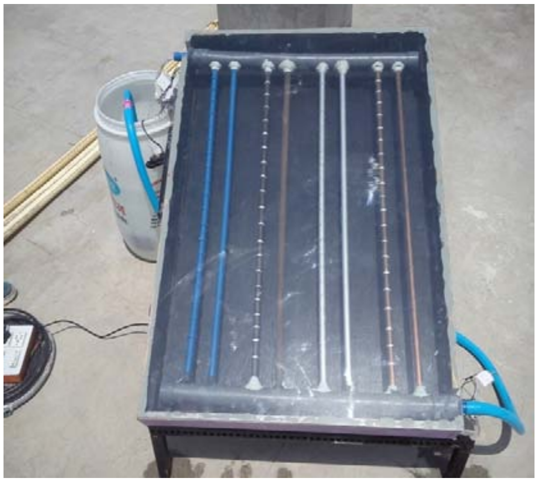

Fig. 2: Experimental setup using different materials (with a ply wood casing with AL, Cu, PVC, MS pipes with and without fins)

Fig. 3: Copper pipe (top) and aluminium pipe (with fin)

Header tube material: The material of header plate is of PVC as the reason of this material selection is because of the low cost of PVC (Fig. 4).

Electric pump and plastic drum: The drum is used for the storage of the water coming out from the outlet which can be stored and can be supplied whenever its required and the pump is used for circulating the water to inlet at proper constant flow rate.

Thermocouple and temperature reader: To calculate the temperature difference at the inlet and outlet of the tube, so that, the temperature difference can be calculated a J type thermocouple is used with the help of the thermocouple the temperature reader detects the temperature and a proper reading has being carried out.

(a)

(b)

Fig. 4: a, b) Header pipe marking and drilling holes for other pipes

What influences the amount of solar radiation?: The solar radiation is a key component of the heat transfer occurring in SWH. The intensity of solar radiation is influenced by the following as mentioned below in the next subsections.

Atmosphere: The atmosphere absorbs certain wavelengths of light more than others. The exact spectral distribution of light reaching the earths surface depends on how much atmosphere the light passes through as well as the humidity of the atmosphere. In the morning and evening, the sun is low in the sky and light waves pass through more atmosphere than at noon. The winter sunlight also passes through more atmospheres versus summer. In addition, different latitudes on the earth have different average “thicknesses” of atmosphere that sunlight must penetrate. Figure 5 illustrates the atmospheric effects on solar energy reaching the earth. Clouds, smoke and dust reflect some solar insolation back up into the atmosphere, allowing less solar energy to fall on a terrestrial object. These conditions also diffuse or scatter the amount of solar energy that does pass through.

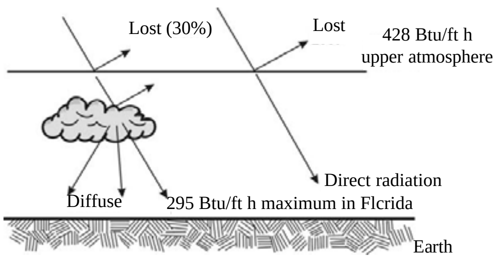

Fig. 5: Atmospheric effects energy reaching the earth

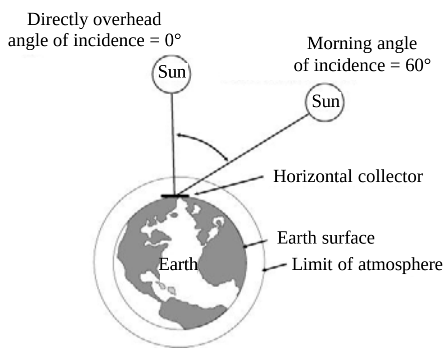

Fig. 6: Solar window

Angel of incidence: The sun's electromagnetic energy travels in a straight line. The angle at which these rays fall on an object is called the angle of incidence. A flat surface receives more solar energy when the angle of incidence is closer to zero (i.e., perpendicular) and therefore, receives significantly less in early morning and late evening. Because the angle of incidence is so large in the morning and evening on earth, about 6 h of "usable" solar energy is available daily. This is called the "solar window" (Fig. 6).

Absorptance vs. reflectance: The materials used to absorb the suns energy are selected for their ability to absorb a high percentage of energy and to reflect a minimum amount of energy. The solar collectors absorber and absorber coating efficiency are determined by the rate of absorption versus the rate of reflectance. This in turn, affects the absorber and absorber coatings ability to retain heat and minimize emissivity and reradiation. High absorptivity and low reflectivity improves the potential for collecting solar energy.

Insolation: In Florida (at about sea level), an object will receive a maximum of around 300 Btu/ft^2 (about 90 W/ft^2 or 950 W/m^2) at high noon on a horizontal surface under clear skies on June 21 (the day of the summer equinox).

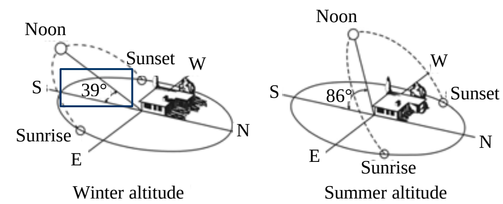

Fig. 7: Season variatins

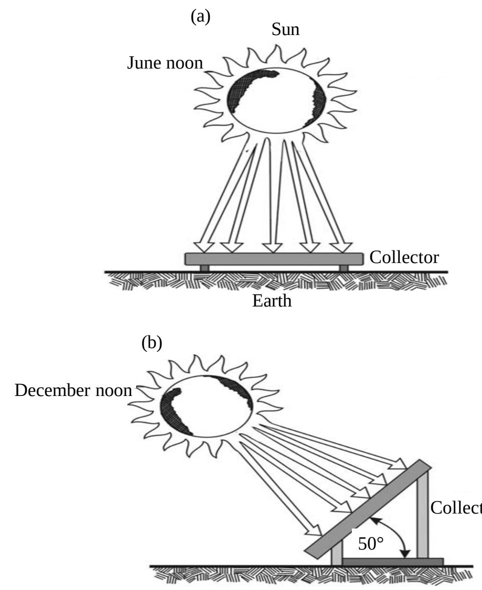

Fig. 8: Collected energy varies with time of year and tilt: a) Collector receives most sunlight for mid Summer and b) Collector receives most energy at noon, mid-December, maximum Winter collection, tilt = latitude +15, maximum Summer collection, tilt = latitude -15, maximum annual collection, tilt = latitude

Optimum performance considerations

Optimum tilt:

- To latitude for greatest performance or up to latitude -5°
- Optimum summer load: latitude -15° (e.g., solar air conditioning)
- Optimum winter load: latitude +15° (e.g., solar space heating)
- Optimum azimuth: toward the equator (e.g., facing South in Northern hemisphere)

Seasonal variations: The dome of the sky and the sun's path at various times of the year are shown in Fig. 7 and 8.

Tilt angle: For many solar applications, we want maximum annual energy harvest. For others, maximum winter energy (or summer energy) collection is important. To orient the flat-plate collector properly, the application must be considered, since, different angles will be "best" for each different application. Solar water heating systems are designed to provide heat year-round. In general:

- Mounting at an angle equal to the latitude works best for year-round energy use
- Latitude -15° mounting is best for Summer energy collection
- Latitude +15° mounting is best for Winter energy collection

RESULTS AND DISCUSSION

After deploying the experimental setup the following observations were recorded for the temperature of water at both inlet and outlet for all the materials pipe at the same instance. The observations are carried out as the temperature of each material at inlet and outlet both. Table 1 and 2 is drawn to give details of the observation carried out at inlet (Fig. 9). Observations of SWH have been carried at proper time interval (Fig. 10).

Conclusion carried at 1st observation: As from the above observation the temperature difference occurred at both inlet and outlet, it has been find out that the temperature difference of (T_1-T_1'), i.e., cooper without fins and temperature difference of (T_4-T_4'), i.e., aluminum with fins have maximum temperature difference.

Conclusion carried at 2nd observation: As from the above observation the temperature difference occurred at both inlet and outlet, it has been find out that the Temperature difference of (T_2-T_2'), i.e., cooper with fins and Temperature difference of (T_8-T_8'), i.e., PVC with fins have maximum temperature difference.

Table 1: Inlet temperatures at different time instances from (11:30 a.m. to 01:00 p.m.)

	Inlet temperature in °C at the time duration				
Materials	Temperature (°C)	11:30 p.m.	12:00 p.m.	12:30 p.m.	1:00 p.m.
Cu	T'1	28	32	35	40
Cu with fins	T'2	29	33	35	41
Al	T'3	29	34	35	41
Al with fins	T'4	29	39	35	41
MS	T'5	29	34	35	41
MS with fins	T'6	26	32	35	41
PVC	T'7	30	34	35	42
PVC with fins	T'8	30	35	36	42

Conclusion carried at 3rd observation: As from the above observation the temperature difference occurred at both inlet and outlet, it has been find out that the Temperature difference of (T_3-T_3'), i.e., aluminum without fins and Temperature difference of (T_5-T_5'), i.e., mild steel without fins have maximum temperature difference.

Conclusion carried at 4th observation: As from the above observation the temperature difference occurred at both inlet and outlet, it has been find out that the Temperature difference of (T_2-T_2'), i.e., cooper with fins and Temperature difference of (T_8-T_8'), i.e., PVC with fins have maximum temperature difference.

Cost report: The total project cost at the time of the manufacturing of solar water heater is being discussed in Table 3.

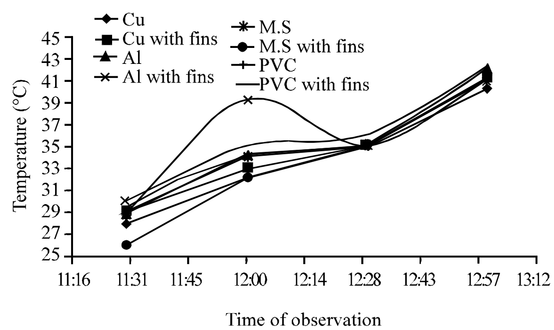

Fig. 9: Graphical representation of outlet temperatures in °C various materials with and without fins at different time instances; Inlet temperature (°C) vs. time

Table 2: Outlet temperatures at different time instances from (11:30 a.m. to 01:00 p.m.)

	Inlet temperature in °C at the time duration				
Materials	Temperature (°C)	11:30 p.m.	12:00 p.m.	12:30 p.m.	1:00 p.m.
Cu	T1	28	32	35	40
Cu with fins	T2	29	37	36	46
Al	T3	29	35	39	42
Al with fins	T4	29	39	37	42
MS	T5	29	36	38	42
MS with fins	T6	26	34	36	41
PVC	T7	30	35	36	45
PVC with fins	T8	30	37	37	37

Table 3: The cost summary of purchased material

Parameters	Values
Tubes cost of each material	Cooper dia(1") -300 INR/m Aluminum dia (1") -80 INR/m Mild steel dia (1")-100 INR/m PVC dia (1") -60 INR/m
Glass (dimension 33.5" X 44")	450 INR
Thermocouple (J-type) (12 m)	40 INR/m
Electric pump	250 INR
Multichannel temperature Indicator (8 channels)	1450 INR
Miscellaneous cost	500 INR
Total cost	3670 INR

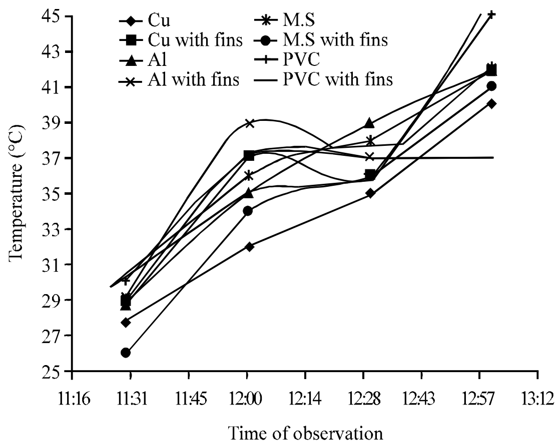

Fig. 10: Graphical representation of outlet temperatures in °C various materials with and without fins at different time instances; Outlet temperature (°C) vs. time

CONCLUSION

The analysis and observations shows that the temperature difference at inlet and outlet is efficient in Al and PVC, material having the high and efficient heat transfer rate. As the availability of these two materials is in ample amount in market and are economical too, so, we concluded that the manufacturing of SWH should be done with the hybrid combination of these two materials. By using these materials the heat transfer rate can be improved efficiently and in economic terms too.The capital investment is required at smaller scale as the availability of these materials is in ample amount and it's economic too. So, the profit can be made at a good extend and it will fulfill all the needs of a human being who cannot afford a actual SWH.

RECOMMENDATIONS

The enhancement is based upon reliability and effectiveness of the project as two of the materials have been concluded as efficient in heat transfer and are economical too, so, the future is concerned on these two materials only. The future setup will be the hybridcombination of these two materials in SWH which would increase the heat transfer rate and work effectively. There is one more probability of introducing solar cell panel inside the SWH box setup, so that, two works can be done at the same time. The first is to obtain hot water and second is to obtain electricity through solar cells. This is done by introducing solar panel in place of black painted box from inside, so that, work of blackened surface can be done with help of solar panel. By this way the setup can fulfill two requirements at the same time. The future enhancement is totally based on increasing effectiveness and serving economically.

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