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Experimental Analysis and Cost Comparison of Evacuated-Tube Solar Water Geyser with Flatbed Solar Water Geyser Fabricated as per Local Conditions of Pakistan

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Abstract—**Surging demand for energy and the current energy crisis in the world has forced initiatives to look for alternative and cheaper energy sources and one of them is solar energy. The motivation is to provide a clean pollution free source of energy which is environmentally friendly, renewable and cheaper. A large population around the globe uses open fire for water heating, thus solar water geyser has economic and environmental benefits as well. This study is aimed to explore the possibility of designing and fabricating cheap SWHs, calculating their performance through experimentation and estimating the costs involved, so that cheaper SWHs can be used in developing countries like Pakistan. Once such renewable solutions are available to meet energy demands, it can greatly help lower the consumption of fuels and hence uplifting economy for the betterment.**

Index Terms— Solar Water Heaters, Performance Calculation, Renewable Energy, Design and Fabrication.

I. INTRODUCTION

A solar heater (or geyser) uses energy from the sunlight for heating water in winters. Solar heaters are easily available in the market most of them are relatively in expensive and low technology, while others are expensive and advanced. As solar water heaters require no fuel, many organizations are thus promoting its use in less developed countries for saving fuel and avoiding environmental pollution. Solar heating is used in situations where fuel or electricity consumption has to be reduced or in places where chances of accidental fires are very likely or the health and environmental consequences of alternative form of heat generation to heat up the water are severe. With the increase in the prices of electricity and fuel there is a demand for cheaper source of energy. Solar energy has thus become a viable option. Solar heater has begun to be used widely in a number of developed and under developed countries and especially in remote areas where fuel or electricity is scarce.

Flatbed solar water geyser consist of silver tube, Wooden frame, silver sheet, Glass cover and storage tank for later use. Water tank is insulated with glass wool to reduce the loses of heat energy losses. No requirement of fuel not only reduces cost but also protects the environment from damages caused by fuel use. These heaters can heat up water in a few hours depending upon the availability of sunlight and the design of the heater. Most importantly people don't have to walk for miles just to get the fuel that they require. Using a solar geyser, they just have to go outside and use the heat given by the sun for free. It is estimated that using a solar heater for a year can eliminate the need for 1 ton of firewood.

Solar heater also helps reduce environmental pollution. Burning wood releases smoke filled with particulates that are not only bad for the environment but also harmful for the people who are breathing it. These particulates produced by open fires can cause health problems including lung and heart diseases. According to an estimate 1.5 million people die every year from this type of air pollution. A solar heater eliminates the need for an open fire thus reducing the danger of air pollution.

In countries like Pakistan facing the energy crises due to shortage of liquid and gaseous fuels, in such cases the demand of solar energy techniques is increasing rapidly. The solar energy is environmentally friendly. The solar energy has no cost, sales tax and shortages. Due to which it is a permanent source of energy. This study is aimed to introduce cheap SWHs fabricated and then tested through experimentation and compared with available commercial product in Pakistan. Fabrication materials are available and can easily be accessed in Pakistan, and the design is validated by performing necessary calculations.

II. Working Principle

A Solar water geyser takes in the stream of cold water through an inlet pipe which leads it to steel tank that is actually a heat exchanger. Cold water stream then flows the solar collector where solar energy is harnessed and water becomes hot by taking this heat of sunlight. Hot water again passes through the heat exchanger tank in a counter flow fashion so that the heat transfer can take place effectively between the two streams of water. This helps is more efficient heat transfer. Hot water is then delivered or utilized for specific purposes as per requirement. A diagram that depicts the working of solar water heater is shown below (figure 1).

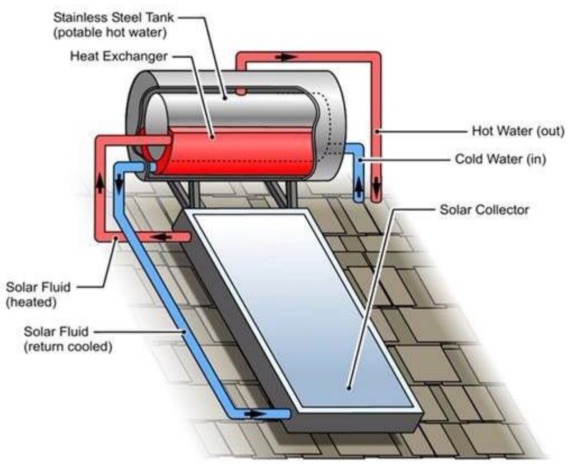

Figure 1. Working principle of solar water heater.

III. Literature Review

Since 1980, solar energy's global use has increased up to 30% [1]. RE Policy Network reported in 2010 that approximately 70 million homes are using Solar Water Heaters in the world [2]. SWH originated in 1767 when Swiss naturalist DeSaussure made an insulated painted black box that was covered from the top by two glass panes [6]. The first SWH on commercial level was named as climax and was built by Clarence Kemp in 1891[7]. In Pasadena, California a large number of residential buildings installed SWHs by the year 1897[8]. William Bailey introduced Thermosiphon effect for the very first time and defined circulation paths of water and steam [9]. Until 1930, coal fired boilers were commonly used all over the world for space and water heating [10]. SWH was considered as a commercial product in 1960s. In 1927, T.G.N.Haldane introduced HP technology for the first time. Despite of very high efficiencies, HP technology is expensive and hence cannot be used in places where cost becomes as limitation.

SWHs are not complex machines, having simpler designs having a variety of benefits. Assessment of resources, appropriateness of the technology and cost estimation contribute towards evaluating such project. There have been various studies conducted regarding the science of collectors' location and size, and how the heat can be transferred efficiently [11]. Water is most commonly available fluid with properties that are often taken as standard values at room temperature conditions.

In cold climate, the choice of fluids can vary. Similar is the case for hot climates, high boiling fluids are required there. Pumping required for any specific case is determined by fluid properties such as viscosity and freezing/boiling points. Other properties also help for estimating the appropriateness of a fluid such as stability and corrosiveness. On large scale the electrical backups are required which tend to lower the energy savings. However, it is still difficult to understand the piping systems for SWH in underdeveloped countries as there are specific standards for all areas [12].

The synchronization of solar collector with sun's motion has shown an increased thermal efficiency [13]. Solar Water Heaters that work on Thermosiphon effect eliminate the need of pump and hence a better option. Collector efficiency can be improved by the use of fins over the external surface of collector [14]. If the overall performance of a Solar Heater can be improved, it can help bring down the costs [15].

In 2019, Esdras Nshimyumuremyi and Wang Junqi [16] designed a solar water heater in Rwanda for the analysis of thermal efficiency and performance. Similar work has also been done in India in 2014 by P. Veeraboina [17] where solar factors and different performance indicators have been analyzed for a designed Solar Water Heater. This study is based on the extract of these two recent works and our system has been analyzed accordingly.

IV. Methodology

SWHs are usually responsive to solar irradiance intensity I and ambient temperature (outside air). In cold climates, at nighttime, inside space and all parts of solar water heater are cooled up to the ambient negative temperature tout. In the morning, after sunrise, there is a rise in solar intensity and hence temperature of outside air rises. As a result, solar radiation penetrates into solar water heater and absorber sheet absorbs it, which causes a growing of the temperature in the inside space of solar water heater. For exact calculations of SWHs performance, solar intensity and ambient temperature of air must be taken into account.

For the purpose of experimentation, a commercial Evacuated-tube SWH has been selected (shown in figure 2) for performance analysis. Then using cost analysis, an alternative cheap SWH (Flatbed SWH) has been designed using

SOLIDWORKS software and later fabricated as shown in figure 3. Mathematical calculations are performed for both the machines to see whether fabricated product matches in performance with the commercial product.

Figure 2. Fabricated flatbed solar water heater using cheap materials.

Figure 3. Fabricated flatbed solar water heater using cheap materials.

Efficiency is the ability to avoid any possible heat losses. The lesser amount of heat losses means more input can be converted into useful output.

Efficiency, ɳ = Heat Energy Output/Heat Energy Input

Efficiency, ɳ = Q_{out}/Q_{in}

Solar Energy Fraction (SEF) is ratio in energy terms between the useful output that machine has produced and the required input. There can be various forms of energy inputs and outputs such as electrical, chemical or thermal etc.

$$SEF = \frac{Q_{del}}{Q_{Aux} + Q_{part}}$$

Q_{del} - Energy that is delivered to water.

Q_{Aux} – Heat consumed by any auxiliary element on daily basis.

Q_{par} – parasitic energy means the electrical energy in AC form that is used to run various components.

Solar Fraction (SF) is the net amount of energy that is provided by using solar technology to the machine. It is an important performance indicator and can be calculated by using the mathematical relation;

$$SF = 1 - \frac{EF}{SEF}$$

The EF for standard auxiliary tank is taken as 0.9. Calculations for both systems (flatbed solar water geyser & evacuated tube solar water geyser) have been performed. Different methodologies for calculations of performance of both systems are used to determine which system is more efficient.

Experiments were on the evacuated tube solar water geyser to study temperatures that it achieves during different days. The experimental tests on solar water geyser were carried out different days from 11 March 2019 till 11 April 2019. Each experiment starts from 08:00am-10:00am, 12:00pm-02:00pm and 05:00pm-07:00pm. All electrical and electronic parts are carefully tested and calibrated before starting experiments. The experimental work was fully carried out on the roof of Fatima Mosque, Ali Town, Lahore.

Experiments were conducted on the Flatbed solar water heater to study the temperatures that it achieves during different days. The experimental tests on the solar water geyser were carried out on different days from 22th may 2019 till 29th may 2019. Each experiment starts from 10:00am-11:30am and 02:00pm-04:00pm. The experimental work is carried out on the roof of US Hostel Ali Town, Thokar Niaz Baig, Lahore.

During experiments, flatbed solar water geyser was placed in a position of 55degree so that the projection of sun rays falls directly upon the frontal face of solar collector. Water geyser was placed in the sun for several hours i.e. A time period long enough to ensure steady state conditions to prevail. Temperature of the collector was then recorded through a temperature probe.

ɳ = Heat Energy Output / Heat Energy Input

= Q_{out}/Q_{in}

For calculating output Heat energy Q_{out} = Heat energy absorbed by water is $\rho \times V \times Cpw \times (Tf - Ti)$. P_{in} is taken as 1170 W/m^2.

$Q_{in} = P_{in} \times$area of panel$\times \Delta t$

V. Results and Discussion

These calculations have been performed for both SWHs for morning, afternoon and evening time and results are obtained in tabular as well as graphical form. The Solar Energy Factor is calculated to be 5.04049 as heat delivered to the system has been taken as 46064kJ/Day (given as per data by Meteorological Department) and parasitic energy is zero. For the sake of instance, a table and solar fraction results in graphical form have been shown as follows.

TABLE 1.
PERFORMANCE CALCULATIONS OF EVACUATED-TUBE SWH (MORNING)

Inlet Temp	Outlet Temp	Delta T	Solar Fraction	Q solar
17.2	68	50.8	0.91430338	90929
17.1	73	55.9	0.905699979	81855
16.1	78	61.9	0.895578331	73095
16	77	61	0.897096579	74299
19.7	81	61.3	0.896590496	73894
14.6	67	52.4	0.911604274	87892
17.8	78	60.2	0.898446132	75400
16.9	77	60.1	0.898614826	75539
17.4	77	59.6	0.899458296	76245
19.8	82	62.2	0.895072249	72701
19	77	58	0.902157403	78583
22	72	50	0.915652933	92520
21.5	68	46.5	0.921557228	100125
22.4	77	54.6	0.907893003	84007
19.7	92	72.3	0.878034142	61355
20.1	82	61.9	0.895578331	73095
25.1	74	48.9	0.917508569	94793
23.7	82	58.3	0.90165132	78135
22.4	78	55.6	0.906206062	82343
20.1	81	60.9	0.897265273	74435
21.2	81	59.8	0.899120908	75961
22.9	80	57.1	0.90367565	79956
23.2	82	58.8	0.90080785	77398
25.4	81	55.6	0.906206062	82343
27.1	79	51.9	0.912447745	88821
27.4	70	42.6	0.928136299	110072
29.6	76	46.4	0.921725922	100359
28.4	74	45.6	0.923075475	102270
22.9	69.2	46.3	0.921894616	100595
24.1	73	48.9	0.917508569	94793

These results have also been calculated for other phases of the day. A graphical representation is shown in figures 4 and 5 as per results obtained through calculations.

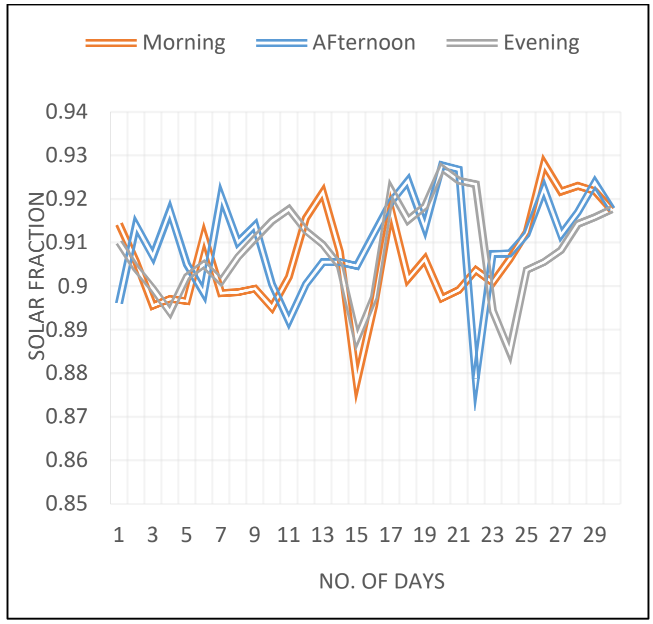

Figure 4. Solar Fraction analysis for Evacuated-Tube SWH. The values lie in the range of 0.87-0.93.

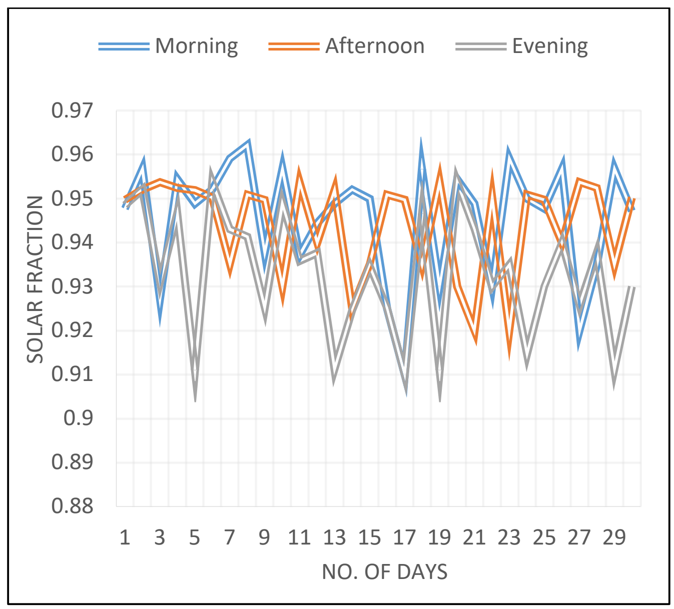

Figure 5. Solar Fraction analysis for Flatbed SWH. The values lie in the range of 0.9-0.97.

As shown in figures 4 and 5, the solar fraction values for Flatbed SWH are higher as compared to Evacuated SWH. It means that Flatbed SWH shows better performance characteristics. Also, a cost comparison has been conducted, Flatbed SWH designed by students of UOL costs almost 40% less than the commercial Evacuated-tube SWH, cost analysis being shown in table 2 (prices estimated in 2018). This means that Flatbed design can be utilized for household as well as domestic purposes as a cheaper and better alternative to commercial products.

TABLE 2.
COST COMPARISON (IN PKR)

Evacuated Solar Water Heater		Flatbed Solar Water Heater	
Machine cost	16000	Wood	500
Assembling	2000	Thermophore	500
Installation	4000	Silver Sheet & Pipe	4500
		Glass cover	2000
		Extra utilities	2500
		Tank & Glass Wool	1200
		Temp. Sensor	500
Total	22000	Total	11700

VI. CONCLUSIONS

For the sake of a cheaper machine for water heating purposes, a Flatbed Solar Water Heater has been compared with a commercial product (Evacuated-Tube SWH) on the basis of performance and cost. After mathematical calculations, the performance of Flatbed SWH comes out to be slightly better than Evacuated Tube SWH and also more than 50% cost is saved. This shows that Flatbed SWHs can be used as a cheaper alternative to Evacuated-tube SWH in countries like Pakistan. The efficiency of this design may be improved by considering following factors:

- This design may be improved by adding one or more absorbers (storage tanks), when water is heated in one cylinder, it will move to next cylinder and its temperature will be improved further. Initially we wanted to design such solar water geyser but there were cost issues.
- It is assumed that all days are clear (sunny) but practically it is impossible, so considering each day according to weather will be helpful in improving the efficiency
- It is considered the temperature of absorber and water same but there will also be few heats loses due to convection between absorber and water. So, the consideration of these loses will also help to decrease our efficiency loss.
- The insulating material also plays a major role for SWH's efficiency. As we used the wood sheet, if we use double ply wood, it will be more useful and efficient with Silver sheet.
- The reflectors of parabolic shape may also be used instead of rectangular box which will also further improve the reflection of light on absorber and consequently temperature will be increased.

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