International Journal of Engineering Works
Kambohwell Publisher Enterprises
ISSN: 2409-2770 Vol. 4, Issue 10, PP. 172-177, October 2017
www.kwpublisher.com

Fabrication of Flat Plate Solar Geyser with Flat Grooved Heat Exchanger Having Special Exit System

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Abstract— The main objective of this paper is to introduce the concept of novel flat plate solar geyser with integrated heat exchanger and open loop passive system.The heat exchanger acts both as collector for solar radiations and as a heat exchanger its self for cold water beneath it. Contrary to the conventional flat plate solar collectors, water is in direct contact with the collector or flat grooved heat exchanger. A safety control box is installed to minimize hydraulic pressure of cold water reservoir on the flat grooved heat exchanger as contrary to tube a plate cannot sustain high pressures. The heat exchanger has circular grooves which adds in sustaining hydraulic pressure, increase heat exchanger exposed area to the sun and also cause turbulence in flowing cold water to increase heat rate. A special exit system for hot water is used having a float tube which enable user to withdraw hot water without pressure of cold water from cold water reservoir

Keywords— Flat plate solar geyser,Integrated grooved heat exchanger,open loop passive system,Safety control box,solar collector.

I. INTRODUCTION

Sun is a huge source of solar energy. Solar energy is basically due to continuous fusion reactions occurring in the sun as hydrogen is abundantly present on the sun . The energy travels to the earth in the form of electromagnetic radiations.Solar energy consisting of Heat and light which can be utilized for various purposes. Light energy can be used to generate electricity using solar panels where photons strikes PN Junction and creates a potential difference [1]. Similarly electricity can also be generated using concentrating mirror techniques to boil the water and to run the steam turbine which in turn runs the generator to produce electricity. Various techniques are used to boil the water using specialized design of collectors and then day by day cost of solar equipments is decreasing and new and more efficient equipments are available in the market.to use this hot water for domestic use [2].It is a renewable and clean energy source.These systems have long life hence gives value for investment.A solar water heater can wok trouble free for up-to 20 years.Working of solar heaters depends up on abundance and availability of direct sun light. Sun heats only in day time, however if the storage tank is well insulated, heated water can be stored and used even.There are two main types of solar geysers.Evacuated tubes Solar Geyser in which vacuum glass tubes are used which are coated inside with a good absorbing material mostly by sputtering different gases. Each tube acts as independent collector[3].Flat plate Solar Geyser in which a flat collector first collects solar energy and then transfer it to the water commonly through tubular heat exchanger [4]. The aim is to fabricate flat plate solar geyser with flat grooved heat exchanger having special exit system & thermoelectric power generation.

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II. CONSTRUCTION MATERIALS & COMPONENTS

Conventional flat plate solar geysers have a collector made of metallic material and is coated with some high absorptivity substance like chrome black coating.A tubular heat exchanger made of high conductive metal like copper or aluminium.This heat exchanger is designed in tubular form because tubes can sustain high hydraulic pressure of cold water reservoir.Contrary to the conventional Flat plate solar geysers having tubular heat exchanger, our geyser has a flat grooved heat exchanger which also acts as collector for solar radiations with carbon black coating over it having absorptivity of 0.96.This has minimized fabrication and material cost by eliminating expensive copper tubular heat exchanger.

III. OPERATION/WORKING

It has a flat grooved heat exchanger which also acts as collector for solar radiations as shown in figure 1.

Figure 1 : Integrated grooved heat exchanger

The water is in direct contact with the lower surface of collector which also minimizes heat leakages as heat has now to flow from collector directly to water with no tubular heat exchanger between them.

To compensate for the hydraulic pressure of cold water reservoir, a safety control box with mechanical float ball feedback system is installed which cuts off hydraulic pressure of cold water storage tank to be exerted on the flat heat exchanger.

Float pipe is installed inside the hot water storage tank and connected to the exit valve which is connected beneath the hot water storage tank. It allows the hot most water present at the top portion of the hot water tank to be drained off first. This special exit system also helps eliminating diffusion effect. If for example the inlet valve is turned off and a portion of hot water is consumed after the sunset then there is no flow of cold water to the collector and as such there is no diffusion of cold and hot water which results in lowering the overall temperature of hot water. And when water from the geyser is drained off the next morning before the sunrise it is relatively hot as compared to conventional geysers where there is cold and hot water diffusion. The 3D View of this project is shown in figure 2.

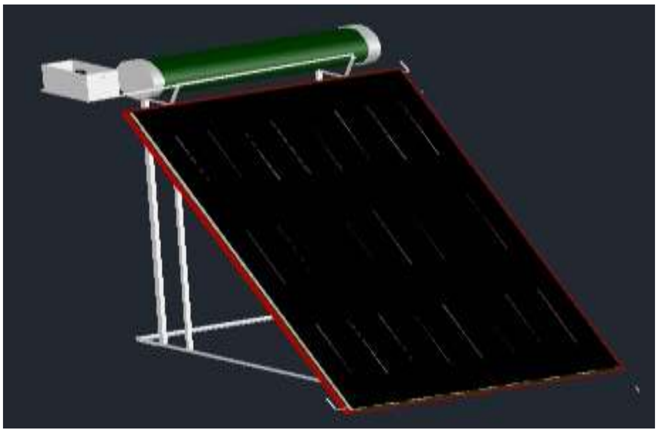

Figure 2 :flat plate solar geyser with grooved heat exchanger

IV. MATHEMATICAL CALCULATIONS

(a) Pressure on the heat exchanger without safety valve:

$$P = \gamma . H ....(I)$$

$$P = 62.4(H_1 + H_2)$$

$$P = \frac{62.4(6.84 + 4.92)}{144}$$

$$P = 5.096 \ PSI$$

(b) Pressure on the heat exchanger with safety valve :

$$P = \gamma H_2 ....(II)$$

$$P = \frac{62.4(4.92)}{144}$$

$$P = 2.132 \ PSI$$

Where

H_1 = Height of the water in the supply tank with respect to water in the safety box.

H_2 = Height of the water in the safety box with respect to water in the collector.

γ = specific weight of water.

So the pressure values with safety and without safety is calculated and results are expressed [5].

(c) Thermal Expansion in the Heat Exchanger:

Dimensions of solar collector

Length(Inch)	Width(Inch)	Thickness(Inch)	Area (Inch2)
60	36	0.04	2260.8

Change in temperature (per Hr) ,

$$\Delta T = 161.6 - 78.8$$

$$\Delta T = 82.8 F$$

Free expansion: If the sheets were free to expand (Non-riveted) longitudinally and crosswise then expansion would be

(d) Lengthwise expansion:

$$Lengthwise \ Expansion = cL \Delta T ....(III)$$

$$Lengthwise \ Expansion = 7.2 x 10^{-6} x 60 x 82.8$$

$$Lengthwise \ Expansion = 0.034 \ Inch$$

where

C=Coefficient of thermal expansion
L =length of sheet in inches

ΔT= change in temperature F

(e) Crosswise expansion :

$$CrosswiseExpansion = cw\Delta T .... (IV)$$

$$CrosswiseExpansion = 7.2x10^{-6} x36 x82.8$$

$$CrosswiseExpansion = 0.0214 \ Inch$$

Where

C=Coefficient of thermal expansion.

w = width of the sheet.

ΔT= change in temperature F

(f) Thermal stresses developed in the Heat exchanger:

Let x denote the length wise direction and y denote direction across the sheet. If ex and ey be unit strains in respective directions, then

$$ex = \frac{Sx}{E} - \frac{mSy}{E}$$

$$ey = \frac{Sy}{E} - \frac{mSx}{E}$$

Where Sx and Sy are compressive stresses,

m is Poisson's ratio

E, the modulus of elasticity of the material.

Solving the simultaneous equations for Sx and Sy we have

m=0.28 & E=29x10 ^{6} psi (Galvanized steel)

ex = total elongation in x direction in inches / length of sheet in inches

$$ex = \frac{0.035}{60}$$

$$ex = 0.000583$$

ey = total elongation In y direction In Inches /.width of sheet in inches

$$ey = \frac{0.0214}{36}$$

$$ey = 0.000596$$

Now it is possible to evaluate Sx and Sy.

$$Sx = \frac{E(ex + mey)}{1 - m^2}$$

$$Sx = \frac{29x10^6 (0.000583 + 0.28(0.000596))}{0.9216}$$

$$Sx = 23596 \ psi$$

$$Sy = \frac{E(ey + mex)}{1 - m^2}$$

$$Sy = 29x10^6 (0.000596 + 0.28(0.000583)) / 0.9216$$

$$Sy = 23891 \ psi$$

Total compressive force on sheet in length wise = (thermal stress)x (cross sectional area)

Compressive force on sheet in length wise=(23596)(60)(0.04)

Compressive force on sheet in length wise= 56630 pounds

Compressive force on sheet in crosswise = (23891) (36) (0.04)

Compressive force on sheet in crosswise= 34403 pounds

Force developed in each rivet = total force on sheet in x-direction / no of rivets

Force developed in each rivet= 56630/36

Force developed in each rivet= 1573 lb

Bearing stress in x-direction = force per rivet / d . t

Bearing stress in x-direction= (1573)/(0.11811 inch)(0.04 inch)

Bearing stress in x-direction= 332.9 (Kpsi)

Force developed in each rivet crosswise = total force on sheet in crosswise / no of rivets

Force developed in each rivet crosswise= 34403/36

Force developed in each rivet crosswise= 955.6 lb

Bearing stress in Y-direction = fy / d . t

Bearing stress in Y-direction= (955.6)/(0.11811)(0.04)

Bearing stress in Y-direction = 202.2 Kpsi [6].

(g) Effectiveness Calculation:

1st test of the project on 20 February 2017

$$Effectiveness = \frac{Q_{Actual}}{Q_{Mazimum}}$$

$$Effectiveness = \frac{mC_{p}\Delta T}{Q_{Maximum}}$$

$$Effectiveness = \frac{(1000)(0.004)(1.4584)(20)}{(3600)(170)(1.4584)}$$

$$Effectiveness = 0.54$$

m= mass flow-rate of water

C_p= Specific Heat

Q_{actual} = Heat transferred

$Q_{maximum}$ = Heat reached to the collector

The above calculated efficiency calculations represents the relationship between the effect value of output to the input [7].

V. GRAPHICAL REPRESENTATION OF EXPERIMENTAL DATA

From figure 3 & 4 it is crystal clear that the temperature of water rises with the passage of time. The horizontal axis represents the starting and ending time in hours whereas the vertical axis represents the temperature of the water in centigrade.

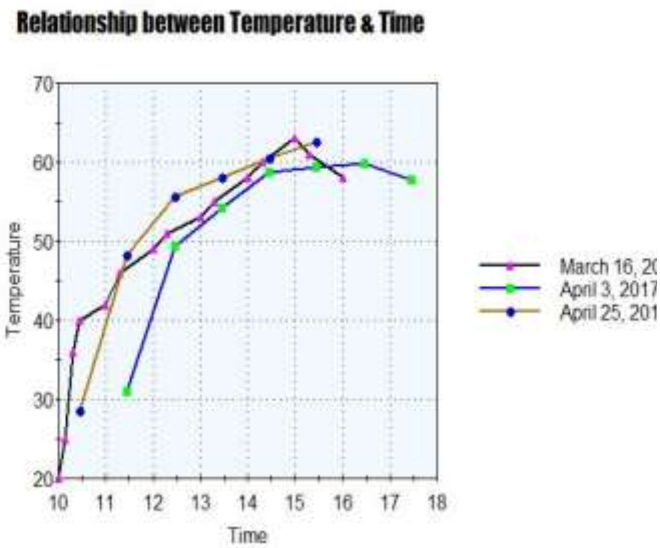

Figure 3: Result of 1st set of 3 days data.

Initial Temperature(°C)	Final Temperature(°C)	Time (Hours)
17	37	1

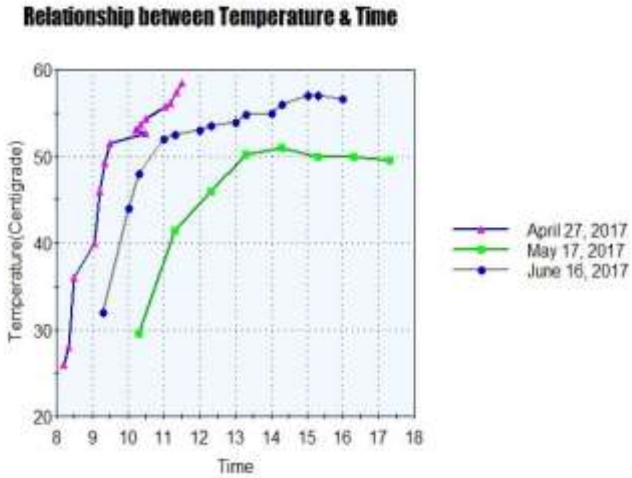

Figure 4: Result of 2nd set of 3 days data.

VI. COST BENEFIT ANALYSIS

Average daily total water needs of a single household person = 350 litre

Average daily hot water needs of a single household person = 150 lit (15 Oct-15 Apr)

Average (Whole Year) daily hot water needs of a single household person = 75 lit

For 5 persons family, it comes to be 375 liter hot water per day.

Now,

PESCO per unit lowest electricity rate = 10.2 (1-100 units per month range)

1 unit of electricity = 1 KWh

Assuming a 100% efficient resistance heater (that's near enough to real values), and ignoring tank losses during the heating period.

375 liters of water is nearly equal to 375 kg.

The specific heat capacity of water is approx 4.2 J / g.K

The increase in temperature is 30 Kelvin (15 °C- 45 °C)

So the energy needed is 375,000 x 30 x 4.2 = 47.25 MJ

1kWh = 1000W x 3600s = 3.6 MJ

ISSN: 2409-2770

Hence, the energy needed is 47.25/3.6 = 13.125 kWh

It is equal to 13.125 units of electricity

Now, per day charges = 13.125 x 10.2 = PKRs 133.875/-

Per year charges = 133.875 x 365 = PKRs 48,864/-

Cost of solar geyser is PKRs 19800/-

so payback period of geyser comes out to be 8.56 months ~ 9 months

CONCLSION

This paper puts forward a new & improved design of heating water. Most of the people of Pakistan can't afford to buy commercially available solar geysers due to its high cost. Contrary to this, we have used a novel Integrated heat exchanger which decrease material and labour cost and this makes it more compelling for such people to enjoy hot water in winter seasons.

Besides economical benefits, we have also upgraded the flat plate solar geyser technology by using integrated heat exchanger which involves direct heat transfer and thus making it more efficient.

There is also a special exit system for hot water which helps eliminate hot and cold water diffusion during night time and thus one can enjoy hot water during the next morning before the sun rise.

ACKNOWLEDGMENT

Thanks to Almighty Allah, by the grace of whom we succeeded in accomplishing this research. Then, we would like to thank Solar geyser, clean energy solutions Islamabad. Thanks to our parents too for their support and precious prayers. We then forward our sincere apologies to all those whom we might not succeed to mention.

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