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Design and Development of Solar Water Heater using Porous Medium and Agitator

Mayank Bagaria[1], Sudhir Kumar[2] and Gaurav Kumar[3]

[1,3]*Department of Mechanical Engineering Birla Institute of Technology, Mesra, Ranchi*
[2]*Department of Production Engineering Birla Institute of Technology, Mesra, Ranchi*
E-mail: [1]mayank1149@gmail.com, [2]sudhir1261.09@bitmesra.ac.in, [3]gauravkmr014@gmail.com

Abstract—*The research paper focuses on increasing the efficiency of the solar water heater system using porous material and downsizing the size of the system with nominal increase in the cost of the system.*
"Design and Development of Flat plate Solar Water Heater Using Porous Medium and Agitator".
The objective of the paper is achieved through the technique of using porous medium like pebbles and metal chips and their selection can be varied according to the requirement like increase of heat absorption utilizes metal chips for increasing the temperature of water in the system and the increase in heat retention of the system along with agitator utilizes pebbles which increases working duration of the system. The working design of solar water heater system has been fabricated and its simulation in the real time environment has been brought up in this paper. The design model has shown significant improvement in its heating efficiency from 18% to 22 % when the system is incorporated with metal chips along with agitator and further increase in working duration of two hours with the utilization of pebbles with agitator in the design of solar water heater.

1. INTRODUCTION

With the rapid rise in the population and the living standards, the world seems to engulf into major crisis, called energy crisis. If this growth continues with the same pace the condition would go from bad to worse. The reverse of conventional sources of energy like coal, petroleum and natural gas are depleting at a very fast rate to fulfill the demand of the growing population. So there is a need to look for some other energy sources that could meet this growing demand. One such source is solar energy, which is cheap available in abundance. Solar energy has been utilized in many ways. Some of its thermal applications are as follows: 1. Water heating 2. Space heating 3. Power generation 4. Space cooling and refrigeration 5. Distillation 6. Drying 7. Cooking

1.1 Solar collector

A solar thermal collector is a solar collector specifically intended to collect heat, that is, to absorb sunlight to provide heat.

1.2 Flat-plate collectors

Flat-plate collectors are very common and are available as liquid- based and air-based collectors. These collectors are better suited for moderate temperature applications where the demand temperature is 30- 70 C and/or for applications that require heat during the winter months. The air-based collectors are used for the heating of buildings, ventilation (Fig. 1.1below), Flat plate collector air and crop-drying. In this type of collector a flat absorber plate efficiently transforms sunlight into heat. To minimize heat escaping, the plate is located between a glazing (glass pane or transparent material) and an insulating panel. The glazing is chosen so that a maximum amount of sunlight will pass though it and reach the absorber.

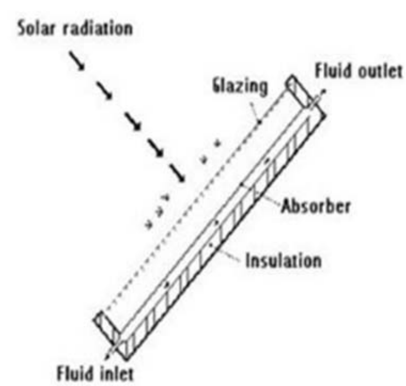

Fig. 1.1: Flat plate collector

1.3 Solar Water heater

In Solar water heater water is heated by the use of solar energy. Solar heating systems are generally composed of solar thermal collectors, a fluid system to move the heat from the collector to its point of usage. Fig. 1.2 shows the different parts of solar water heater. The system may use electricity for pumping the fluid, and have a reservoir or tank for heat storage and subsequent use.

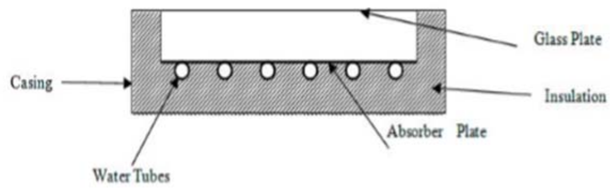

Fig. 1.2: Solar Water Heater

1.4 Heat Transfer

Heat transfer is the thermal energy exchange between bodies when there is a temperature difference between them. Thermal energy is transferred from the higher temperature, to the lower temperature. Temperature is a measure of the amount of energy molecules a body holds. In SI units, heat is typically denoted by the symbol Q and it is expressed in joules (J). The rate of heat transfer q is measured in watts (W), which are joules per second. The rate of heat transfer per unit area, heat flux, is measured in watts per area (W/sq. m).

1.5 Heat Transfer Enhancement Techniques

The flow distribution through the finned tubes of a collector clearly affects the operational efficiency of the collector system. Therefore, the more uniform the flow through the tubes, then the higher efficiency of the collector, and vice versa. The flow distribution can be evaluated by temperature measurements at various points of the collector.

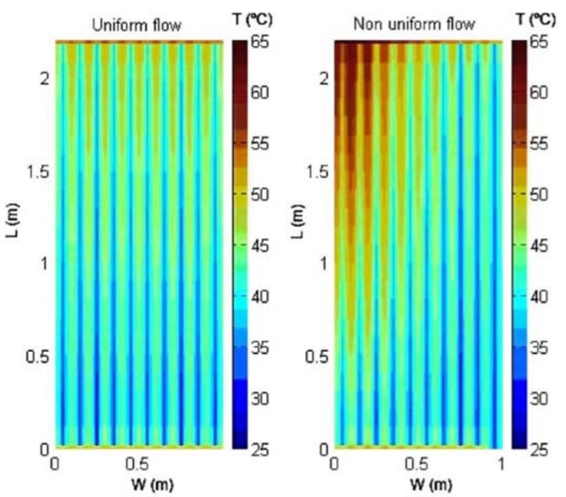

Fig. 1.3: Temperature control for uniform and non-uniform flow

In the case of a uniform flow, the increase of temperature experienced by the fluid in each riser was practically the same in all of them. The outlet temperature difference between risers is less than 0.4ºC. Very close to the walls of the pipe the viscosity of the fluid reduces its velocity and a fairly thin boundary layer is developed in which the fluid is virtually stationary. However, the velocity increases slowly to reach the free-stream velocity not much further away. Outside the boundary layer the fluid behaves as if it had no viscosity. The boundary layer insulates the body and provides a resistance to heat transfer. The thicker the boundary layer, the higher the conduction length. Hence the higher the resistance to heat transfer, and the lower the heat transfer coefficient. Heat transfer enhancement methods can be classified into two categories:

(a) Passive methods requiring no direct application of external power e.g Agitator

(b) Active methods which require external power.

2.1 Agitator

Where it is necessary agitator is inserted in tubes for flow separation and better heat transfer. Agitated flows create turbulence which is considered to be an irregular movement of particles of the fluid. This produces eddies in the flow, and it causes boundary layer separation. It is known that turbulence and dispersion enhances heat transfer and increases the performance and efficiency of the heat exchanger. This is the work of an agitator. As such, utilizing the agitator leads to smaller and lighter heat exchangers. The presence of metal agitator medium, i.e. copper, aluminum, inside a pipe causes a better thermal dispersion and also it increases the interface between the fluid and absorber. The overall thermal conductivity in this case is higher than that of the water.

3. EXPERIMENTAL MODEL

The experiments were conducted at the solar laboratory at the mechanical engineering department, BIT Mesra. The coordinates of the place are 23.4120N, 85.4390E.

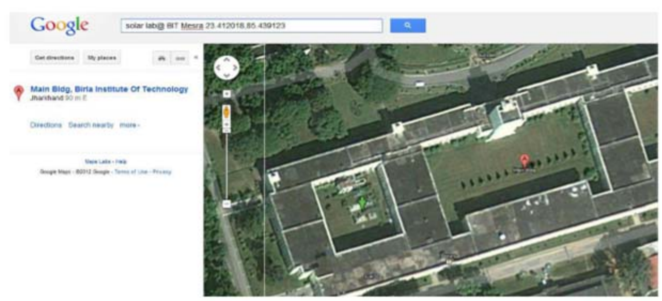

Fig. 3.1: Satellite image of the solar lab, BITMesra

The basic parts of the working model were

1) Flat plate water heater

2) Insulated Water Storage Tank

3) Instruments used

a) Eppley Pyranometer

b) Digital Thermometer

4) Agitator using Copper Wire

5) Packing Media

a) Pebbles

b) Stainless Steel chips

3.2 Flat plate solar collector

The frame of the solar collector was cuboidal in shape and made of plywood 10mm thick. The internal dimensions of the collector were 1.2m x 0.6m x 18cm. 5 pieces of plywood were sawed off from a larger piece and then attached to each other with nails. The top surface of the collector was left open for the glass cover plate. Aluminum channels were nailed onto the top of the frame to secure the glass cover. The corners and joints of the frame were sealed off by using putty-an epoxy adhesive. The inside walls were painted black with black enamel paint.

Fig. 3.2a: Working model of the flat plate solar water heater

3.2.1 Absorber Plate

Aluminium sheet was used to cover the entire floor area of the collector. This sheet has grooves to increase contact surface between sheet and tubes. Channel was attached to the absorber plate using steel wires. The Aluminium sheet along with pipes was painted black to increase absorptivity of heat. This was fixed to the wooden box using nails.

Fig. 3.3: Absorber plate with pipes

3.2.2 Agitator

Agitator was made by curling Copper Wires with approximate diameter of 1cm. Wires were curled on a rod of diameter 1cm in the form of helix with a pitch of approximately 0.8cm.

Fig. 3.4: Pipes with Agitator

3.4 Packing Materials

Pebbles

A layer of pebbles used in construction sites is used to increase the heat retention in the collector box. It has density of 6.9 gm/cubic cm.

Iron Chips

Iron Scraps from machining processes can be used for packing the solar bed , which in turn can increase the thermal efficiency by trapping solar radiation and reducing the conductive and convective losses from top. 3.5 Instruments used The following set of instruments was used to record various input and output parameters during the process.

1. 3.2bWorking model with agitator and pebbles

2. Experimental Data and Analysis

Author names and affiliations are to be centered beneath the title and printed in Times 12-point, non-boldface type. Multiple authors may be shown in a two- or three-column format, with their affiliations below their respective names. Affiliations are centered below each author name, italicized, not bold. Include e-mail addresses if possible. Follow the author information by two blank lines before main text.

EXPERIMENTAL DATA FOR THE PERFORMANCE OF THE FLAT PLATE WATER HEATER UNDER VARYING CONDITIONS TABLE 4.1 WITH AGITATOR ONLY (24thAPRIL)

Time	Global Radiation (W/sq.m)	Diffused Radiation (W/sq.m)	Beam Radiation (W/sq.m)	Ambient Temp. (deg. C)	Temp. of Water (deg. C)
09:00 am	730	144	576	25	28
09:20 am	786	157	629	26	31
09:40 am	863	177	686	27	32
10:00 am	905	186	719	28	34
10:20 am	956	200	756	29	38
10:40 am	995	209	786	31	39
11:00 am	846	177	669	32	40
11:20 am	1023	214	809	33	42
11:40 am	982	206	776	35	42
12:05 pm	1135	244	891	36	44
12:30 pm	1159	249	910	36	45
01:20 pm	1206	265	941	37	49
01:40 pm	1113	244	869	37	49
02:00 pm	956	215	741	38	50
02:20 pm	843	193	650	38	49
02:40 pm	653	150	503	37	49
03:00 pm	528	124	404	37	48
03:20 pm	318	76	242	35	48
03:40 pm	420	100	320	35	47
04:00 pm	325	81	244	34	46
04:20 pm	286	72	214	32	44
04:40 pm	234	59	175	31	45
07:40 pm					39
10:00 pm					30

Average Global Radiation= 784.63 W/sq.m Average Diffused Radiation= 170.09 W/sq.m Average Beam Radiation= 614.54 W/sq.m

Efficiency = 17.38 %

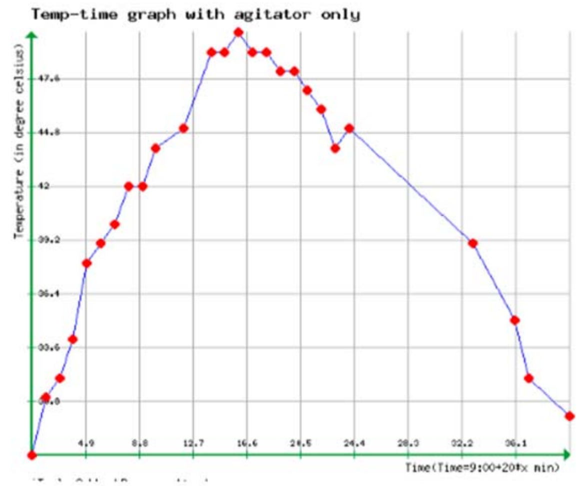

Fig. 4.1.1: Temp-Time graph with agitator only

Fig. 4.1.2: Intensity-Time graph on 24th April

Table 4.2: With Agitator and Pebbles as Packing Media (25th APRIL)

Time	Global Radiation (W/sq.m)	Diffused Radiation (W/sq.m)	Beam Radiation (W/sq.m)	Ambient Temp. (deg. C)	Temp. of Water (deg. C)
10:40 am	658	138	520	26	31
11:00 am	813	170	643	28	32.5
11:20 am	769	161	608	30	35
11:40 am	837	180	707	31	35.5
12:00 am	863	186	677	32	37
12:20 pm	995	218	777	32	38.4
12:40 pm	740	163	577	33	39
01:00 pm	925	203	722	34	40
01:20 pm	870	196	674	37	41
01:40 pm	230	52	178	37	42
02:00 pm	736	166	570	37	42.5
02:20 pm	708	163	545	37	42.5
02:40 pm	650	152	498	36	43
03:00 pm	410	98	312	36	43.5
03:20 pm	140	35	105	36	43.5
03:40 pm	420	105	315	35	43.4
04:00 pm	348	89	259	35	43.3
06:30 pm	0			32	40
10:00 pm	0			24	33

Average Global Radiation= 653.65 W/sq.m Average Diffused Radiation= 145.59 W/sq.m Average Beam Radiation= 507.94 W/sq.m
Efficiency = 21.91 %

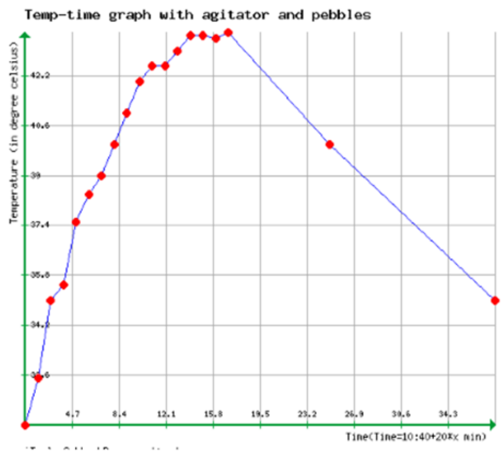

Fig. 4.2.1: Temp-Time graph with agitator and pebbles

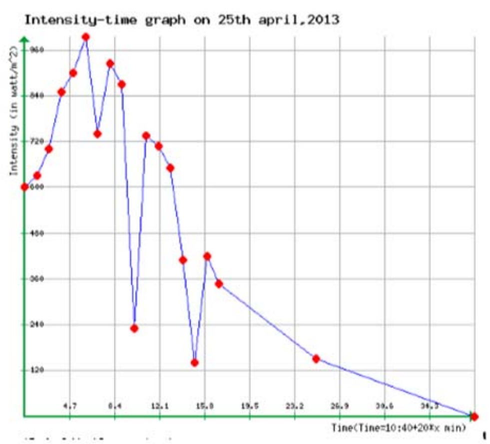

Fig. 4.2.2: Intensity-Time graph on 25th April

Table 4.3: With Agitator and Metal Chips as Packing Media (26th April)

Time	Global Radiation (W/sq.m)	Diffused Radiation (W/sq.m)	Beam Radiation (W/sq.m)	Ambient Temp. (deg. C)	Temp. of Water (deg. C)
10:20 am	857	172	685	30	34.9
10:40 am	924	185	739	32	36.7
11:00 am	903	181	722	32	38.3
11:20 am	950	200	750	33	40
11:40 am	320	70	250	34	41.5
12:00 am	975	205	770	34	42.5
12:20 pm	940	188	752	35	45
12:40 pm	850	171	679	35	45
01:00 pm	520	114	406	36	45
01:20 pm	500	100	400	36	46
01:40 pm	550	121	429	36.5	46.5
02:00 pm	670	134	536	37	47
02:20 pm	600	138	462	37	47.5
02:40 pm	530	127	403	35	47.6
03:00 pm	150	31	119	34	47.1

Average Global Radiation= 682.6 W/sq.m Average Diffused Radiation= 142.5 W/sq.m Average Beam Radiation= 540.1 W/sq.m Efficiency = 22.19 %

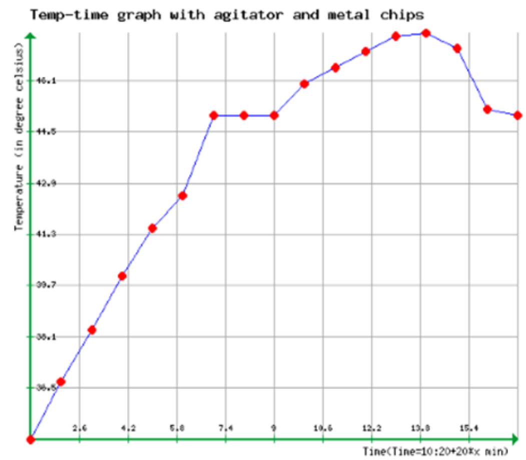

Fig. 4.3.1: Temp-Time graph with agitator and metal chips

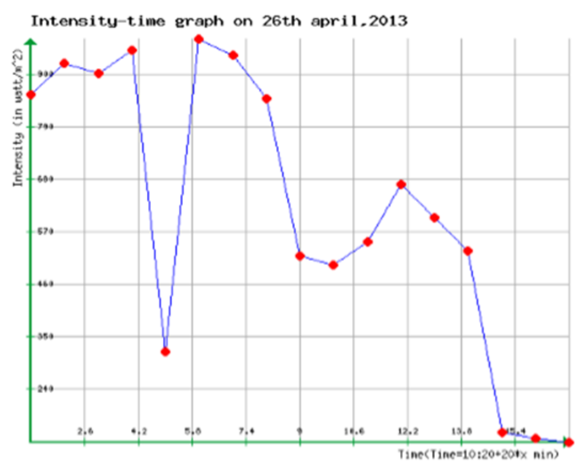

Fig. 4.3.2: Intensity-Time graph on 26th April

4.4 TEMPERATURE VARIATIONS IN WATER TANK WITH HEIGHT

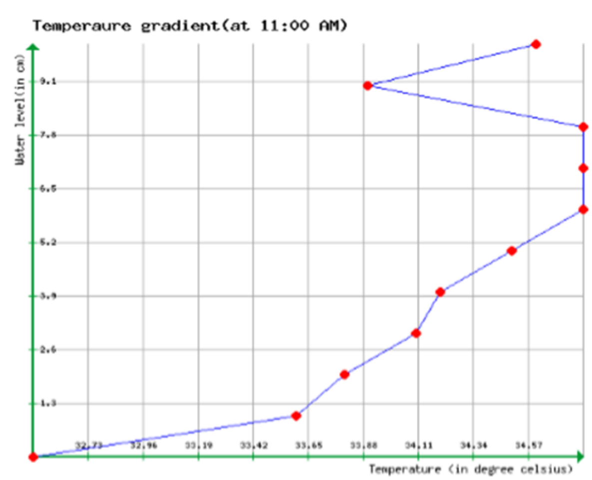

Fig. 4.4.1: (on 26th April)

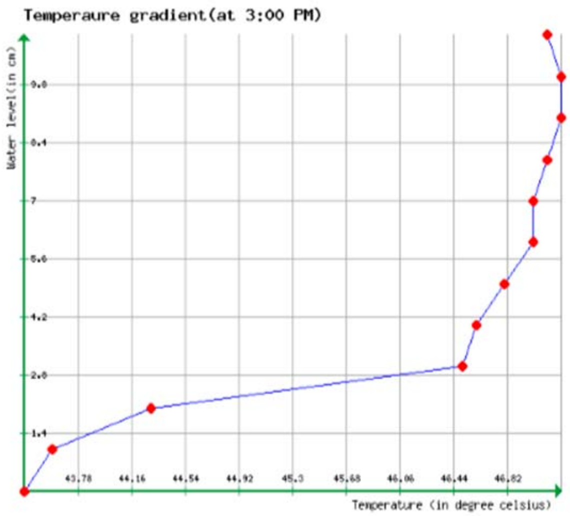

Fig. 4.4.2 (On 26th April)

With agitator only	17.38
with agitator and pebbles	21.91
with agitator and metal chips	22.19

4.6 ANALYSIS

The Temp-time graph of first model (using agitator only) dips more than that of second model (using agitator and pebbles) during later part of the day. This justifies better heat retention capacity and longer duration purpose fulfillment over a day of second model as compared to first model.

As it can be seen from the thermal gradient curve, temperature of water rises with height. This can be attributed to the property of warm water to stay **above** cold water layer because of difference in density. The hottest layer is slightly below the top layer, this is due to conduction and convection losses from the top layer, which is in contact with air. This graph can be utilized practically in drawing hot water from the point slightly below the point of hottest layer.

4. CONCLUSION

Project work has been performed with the aim of enhancing the heat transfer in a passive flat plate solar water collector using cost effective techniques that could be easily applied in a typical (conventional) flat plate collector without changing or redesigning its shape. Such technique would allow the reduction of the solar collector area and its associated manufacturing costs.

The presence of the copper agitator inside the channels changed the flow pattern in such a way which increased heat transfer from fluid present in the near-wall zone to the internal layers of the water.

The efficiency has been further improved by packing the collector box with a layer of pebbles. This presented an added advantage that warm water was retained for a longer duration of time till 10:00 PM in night. Hence this model can be used to fulfill requirements of hot water even after dusk. Also this model has a very good scope of implementation in rural areas where there is lack of electricity.

The model also shows a good result by using metal chips as packing media. It improved the heat transfer coefficient considerably. It has a promising industrial scope.

Overall conclusion from the project work undertaken is that using such a low cost modifications in design, using a metallic agitator insertion, pebbles and metallic chips as packing media, considerably improves the performance of the solar collector.

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