Differentiating the Performance of Solar Water Heater under Natural and Forced Circulation

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Abstract - *There are many solar water heater systems available in the commercial market to fulfill different customer's demand such as flat plate collector, concentrating collector, evacuated tube collector and integrated collector storage. A cost effective cum enhance thermal performance of solar water heater using integrated system of Natural & Forced circulation is proposed.*

The Natural Accumulation type hot water systems are widely used in domestic application due to caused effectiveness however, efficiencies are lower due to lower collector flow rate under Natural circulation. Forced circulation system (FCS) offered higher efficiency but required electricity for operation & thermal loss should be avoided.

In this Study we show that, the temperature of water inlet & outlet the collector are determined with natural & forced circulation to calculate the collector efficiency. The Series of tests are conducted to determine the efficiencies for 15 min periods over a range of temperature difference between average water temperature and ambient temperature.

Keywords— **Solar Water Heater; FCS; Natural Circulation; Thermosyphon Principle; Efficiency***.*

1. INTRODUCTION

The solar system for providing domestic hot water and heating of buildings using the current technology, are marginally competitive with heating using another forms of energy as oil, gas, etc. The present work is diverted towards the utilization of solar energy for water heating. They studied the effect of various parameters (Such as local climatic conditions and design factors) on the performance of different types of solar water heaters. However the compact solar water heater i.e. (the absorber and the storage tank are integrated together into our system) has not taken much attention from the researchers.

In the last five years, solar hot water system has gained considerable popularity due to financial incentives provided by the Central & State Governments. To maintain the quality of collectors in such an expanding market, facilities for conduction standards testing have become an urgent requirement.

The heat requirements in various sectors of the India economy can be met partially by utilizing solar energy, enabling the conservation of conventional sources of energy. Among various applications of solar thermal energy, solar hot water systems have found widespread acceptance in India. To promote the use of these devices, Govt. of India launched various schemes, which led to the establishment of a large industrial infrastructure within the country. In view of this, the accurate testing methods and testing instruments appear more than ever to an essential prerequisite for an orderly penetration and effective diffusion of solar energy into our society.

2. LITERATURE REVIEW

In this chapter, reviews various studies carried out in the field of solar hot water systems, in particular natural and forced circulation mode of operation in the past and the present.

Zerrouki et al. (2002) have analysed the natural circulation of thermosyphone domestic solar water heater in Algeria and found that the flow rate of such water heaters can be increased by increasing the relative height between the collector and storage tank but it does not have much effect in the system efficiency.

Shariah et al. (1996) have analysed the optimum values for storage tank height and volume of thermosyphon type solar hot water system for the operating range of 50 to 80ºC.

Hussein (2003) has investigated the two phase natural circulation thermosyphon flat plate solar water heater and predicated that storage tank volume to collector area ratio and storage tank dimensions ratios have significant effects on the heater performance, while the height between the heater tank and collector has little effect and optimum values are suggested for the same.

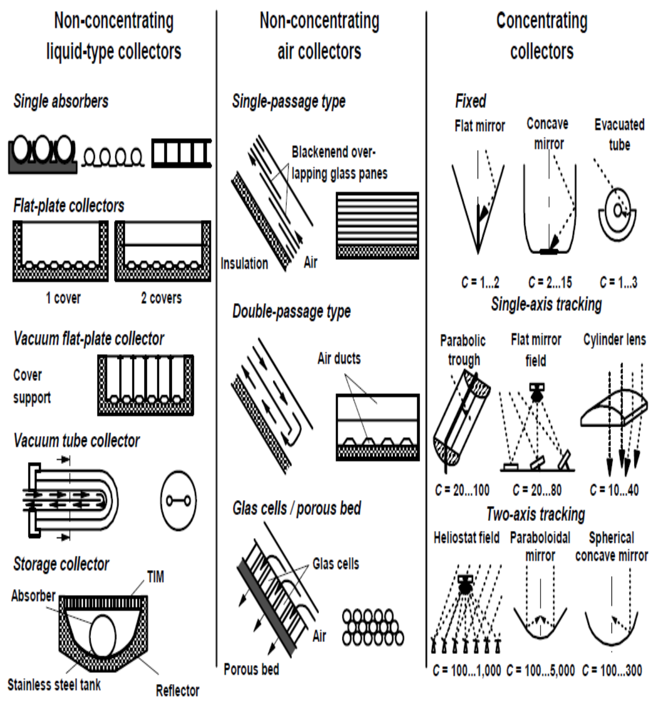
Cadafalch (2009) has devised a one dimensional transient numerical model for flat plate solar thermal devices and described the fundamentals of a model for the design and optimization of flat plate collectors. This model can be utilized to analyze different components such as multiple glazing, transparent insulation, air-gaps, surface coatings, opaque insulation and energy accumulation in water.

Dagdougui et al. (2011) have analysed the performance optimization of solar water heater flat plate collector based on the impact of number and type of cover plate on top heat loss and tests were conducted in Morocco. The experiments were conducted with single glass cover plate, double glass cover plate, plastic cover and plexigal. The authors have found that top heat loss is reduced by the use of double cover plate than single and by combining glass and plexigal cover gives better performance of flat plate solar collector.

Holck et al. (2003) have emphasized on the design of collectors to solve the moisture problems. Humidity existing inside collector will lead to the decrease in service life time of absorber coating. The authors have developed a simulation program to take care of micro climatic condition existing inside the collector by considering various configuration of the collector like location and size of the ventilation hole, etc. This model gives 16 an idea about design optimization of the collector based on the micro climatic conditions.

Hobbi et al. (2009) have studied the effect of various heat transfer enhancement devices in flat plate solar collectors. The experiments are conducted in the laboratory by inserting twisted tape, coil spring wire and conical ridges inside the collector tubes, one at a time. The comparison of various results shows that heat transfer enhancement devices do not have any influence in improving the heat transfer rate in the studied range and geometry.

Soteris A. Kalogirou (2004) shows performed a study of the different models of solar thermal collectors covering flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors, and the applications.



3. DESIGN, CONSTRUCTION AND FABRICATION

The whole unit comprises of the following components-

1. Combined water storage tank
2. Flat plate collector

3.1 Fabrication of Water Storage Tank

It is a completely insulated box of dimension 24×24×17. The wall of the box is made of two galvanized sheets (each of which is 26 gauge thick) with thermocol in between them. The thickness of the wall is one inch. On the top of the box there is hinged cover plate.

Lower part of the box is used as water storage tank. Dimension of the tank is 22×22×8 internally 63 lit. of water can be stored inside the tank. There are three holes of half inch diameter cut on wall. Two holes on the lower side of the tank, one of them is for water inlet to the flat plate collector and another for outlet of the tank to which a water tap is fitted. Another hole is cut on the opposite wall at upper side of the tank; this hole is as water inlet to the tank as well as water outlet of the collector plate.

All the holes are fitted with nipple (1/2×5 inch) with two check nuts on either side of the wall of storage tank. To prevent leakages adhesive joints (M-Seal) are applied to all the holes. The inside corners of the tank are also made leak proof by applying M-Seal.

3.2 Fabrication of Flat Plate Collector

The solar flat plate collector consists of absorber plate, solar panel (box which contains absorber plate) flexible pipe, copper tube, galvanized pipe.

3.3 Fabrication of Absorber Plate

The material used for flat plate collector is copper. We took a copper sheet of dimension 3ft×2ft, which is used as an absorber plate. This dimension is taken because it is easily available in the market. The copper sheets are made to die by die maker to fix the copper tubes in it. The tubes are placed at a distance of 3 inches apart, six number of copper tubes are taken whose dimensions are ½ inch diameter. The cavities (in the form of semicircle) which are to be made on the copper sheet has taken the dimension half the circumference of copper tube. Then the two copper sheets are connected by double lap joint. The copper tube are inserted in the cavities made on copper sheet and are welded by gas welding against each other. The filler material used for gas welding was taken as bronze.

3.4 Fabrication of Wooden Panel

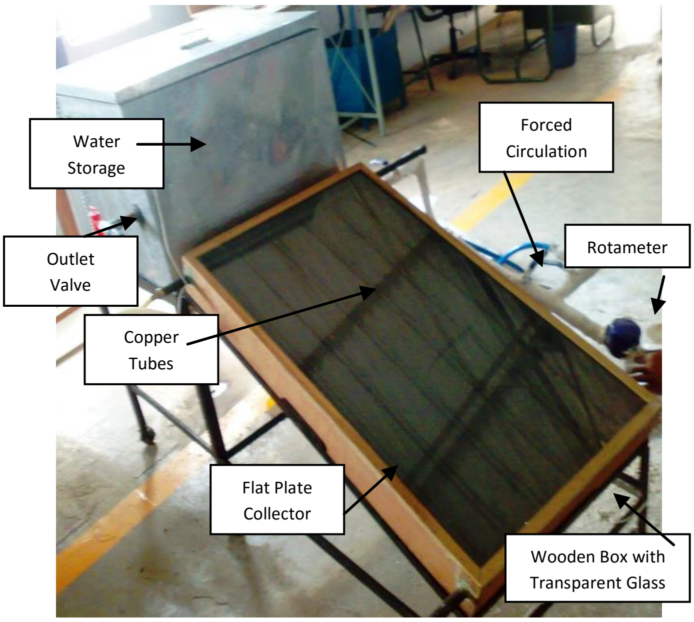
To protect the heat losses which are absorbed by absorber plate the wooden box has been fabricated. The wooden panel is taken because wood is a bad conductor of heat, it is easily available everywhere and is very cheap. We brought a particle board of 6ft×4ft. For the base or back cover of the box the partial board of dimensions 36”×24” has been taken. The thickness of partial board is 12mm. for the side wall of box we took particle board of height 10 cm .two side wall 64 cm length & four side walls of 96 cm are fixed on the base by the nails. Two holes of 1.27 cm diameter are made on each side walls for inserting the header pipes.5 mm channels are fitted for fixing the glass.

3.5 Fabrication of Header Pipe

The material used for header pipe is galvanized iron. Two 0.5 inch diameter header pipes of length 91 cm are taken. One side of two header pipes is blocked by cap nut. 6 holes are made on the header pipe for connecting the copper tubes. The dimensions of holes are 0.6 cm diameter.

3.6 Arrangement of complete solar flat plate collector

1. The copper tubes are welded and brazed on the copper seat by gas welding.
2. The copper tubes are welded to the holes made on the header pipe.
3. The complete (Flat plate collector) is inserted in the wooden box or panel.
4. The thermocol’s are inserted between the bottom of the wooden box & the flat plate collector. This acts as back insulation.
5. Aluminum sheets are provided inside walls.
6. One glass is inserted into the channel to form complete flat plate collector.



The complete arrangement is now ready for taking the readings.

4. WORKING OF SOLAR WATER HEATER SYSTEM

Solar collector is the most important component of solar hot water system. It consist of an absorber, glazing and insulation, all assembled in a suitably designed collector housing. The absorber is bonded with the fluid channel; it absorbs the incident solar energy and transfers it as heat to the fluid flowing through the channels. For an efficient absorber it is required that it has high thermal conductivity, high absorbance for solar radiation and low emmitence for thermal radiation. The glass sheets which are usually used for glazing directly affect the transmission of solar radiation to the absorber and also the convective heat, losses from the heat absorber, checks the conductive heat losses to the surrounding.

When natural circulation system is used then no pump is required. The water is circulated by virtue of its own forces developed by the density difference of the cold and hot water.

When forced circulation system, the principle is as same as natural circulation but in forced circulation an electric pump and rotameter are used for constant mass flow rate. The water heated in the collector rises and flows into the top of storage tank through the rotameter. The cold water in the tank is fed to collector with the help of electric pump.

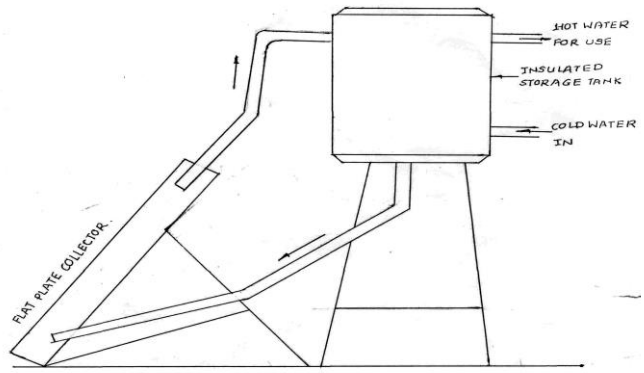


Fig (a) Small Capacity Natural Circulation Water Heating System.

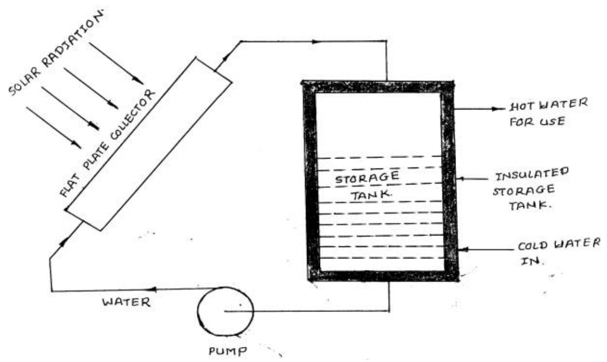


Fig (b) Small Capacity Forced Circulation Water Heating System

4.1 Performance Parameters

Following parameters were monitored during the testing.

1) Inlet temperature [S1]
2) Intermediate Temperature [S2]
3) Outlet Temperature [S3]
4) Mass -flow rate
5) Ambient temperature
6) Surrounding temperature
7) Temperature of water in tank.

Instantaneous values of these parameters are noted for every 15 minutes for forced circulation.

4.2 Experimental Procedure

1. The complete arrangement of solar flat plate collector was placed on the open ground and it was placed in such a way that the face of collector is faced towards south.
2. The water tank was filled by twenty liters of water.
3. Initial temperature of water in the water tank was taken. It is founded as 28 °C.
4. Allowing 15 minutes of time to take the readings by natural circulation system & the readings were noted down in the observation table.
5. Open Side Valve to take the readings by forced circulation system.
6. Now, the electrical pump is started by switching on the switch for forced circulation readings.
7. Again Allowing 15 minutes of time to take the readings & the readings were noted down in the observation table.
8. Another two readings for the mass flow rate of water in m^3/sec are taken for every 15 minutes of interval.
9. The readings are then noted down in the observation table.

5. OBSERVATION TABLES AND GRAPHS

5.1 Observation Table No. 1

1) Natural Circulation Reading On 17/03/2017.

Time	Temp. (°C)		S1	S2	S3
	Ambient Temp	Surrounding Temp			
11 to 11.15	30	35	31	32	54
12.15 to 12.30	41	33	35	36	60
1.30 to 1.45	43	30	35	39	70
2.45 to 3.00	42	33	39	40	68
4.00 to 4.15	42	32	39	41	62

2) Force circulation Reading on 17/03/2017.

With Full Discharge

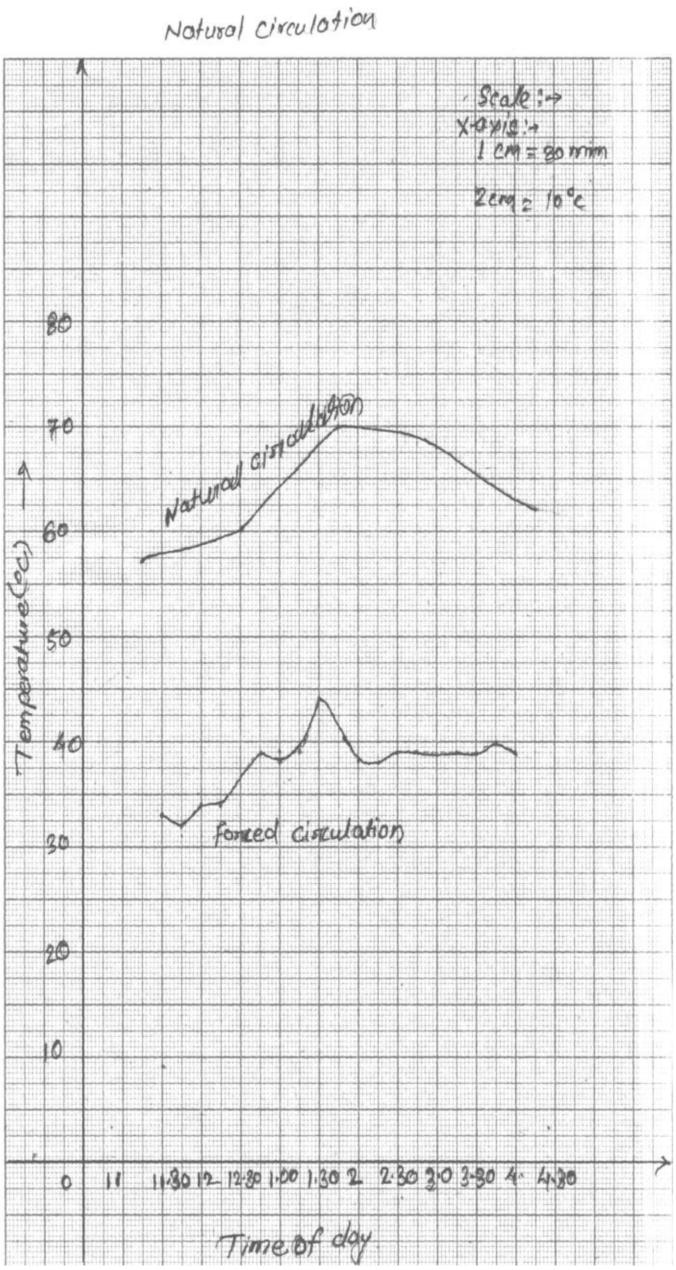
Time	Temp. (°C)		Full discharge (0.654×10^{-4})m^3/sec		
	Ambient Temp	Surrounding Temp	S1	S2	S3
11.15 to 11.30	35	30	30	30	33
12.30 to 12.45	41	33	36	36	38
1.45 to 2.00	43	30	35	37	38
3.00 to 3.15	42	33	35	37	39

With Medium Discharge

Time	Temp. (°C)		Medium discharge					
			Stage 1 (0.58×10^{-4} m^3/sec)			Stage 2 (0.535×10^{-4} m^3/sec)		
	Ambient	Surrounding	S1	S2	S3	S1	S2	S3
11.15 to 11.30	35	30	32	31	32	32	33	34
12.30 to 12.45	41	33	36	37	38	36	37	39
1.45 to 2.00	43	30	35	36	38	37	37	39
3.00 to 3.15	42	33	38	38	39	37	38	40

With Minimum Discharge

Time	Temp. (°C)		Minimum discharge (0.49×10^{-4} m^3/sec)		
	Ambient Temp	Surrounding Temp	S1	S2	S3
11.15 to 11.30	35	30	32	34	34
12.30 to 12.45	41	33	39	39	44
1.45 to 2.00	43	30	36	37	39
3.00 to 3.15	42	33	38	39	39



5.2 Observation Table No. 2

1. Natural Circulation Reading On 18/03/2017

Time	Temp. (⁰C) Ambient Temp	Temp. (⁰C) Surrounding Temp	S1	S2	S3
11 to 11.15	38	32	31	32	58
12.15 to 12.30	42	36	35	37	62
1.30 to 1.45	43	38	36	40	68
2.45 to 3.00	42	35	39	41	63
4.00 to 4.15	41	34	36	40	60

2. Force circulation Reading on 18/03/2017.

With Full Discharge

Time	Temp. (⁰C)		Full discharge $(0.654 \times 10^{-4})m^3/sec$		
	Ambient Temp	Surrounding Temp	S1	S2	S3
11.15 to 11.30	38	32	29	29	30
12.30 to 12.45	42	36	32	32	33
1.45 to 2.00	43	38	36	36	38
3.00 to 3.15	42	35	35	37	38
4.15 to 4.30	41	34	38	38	39

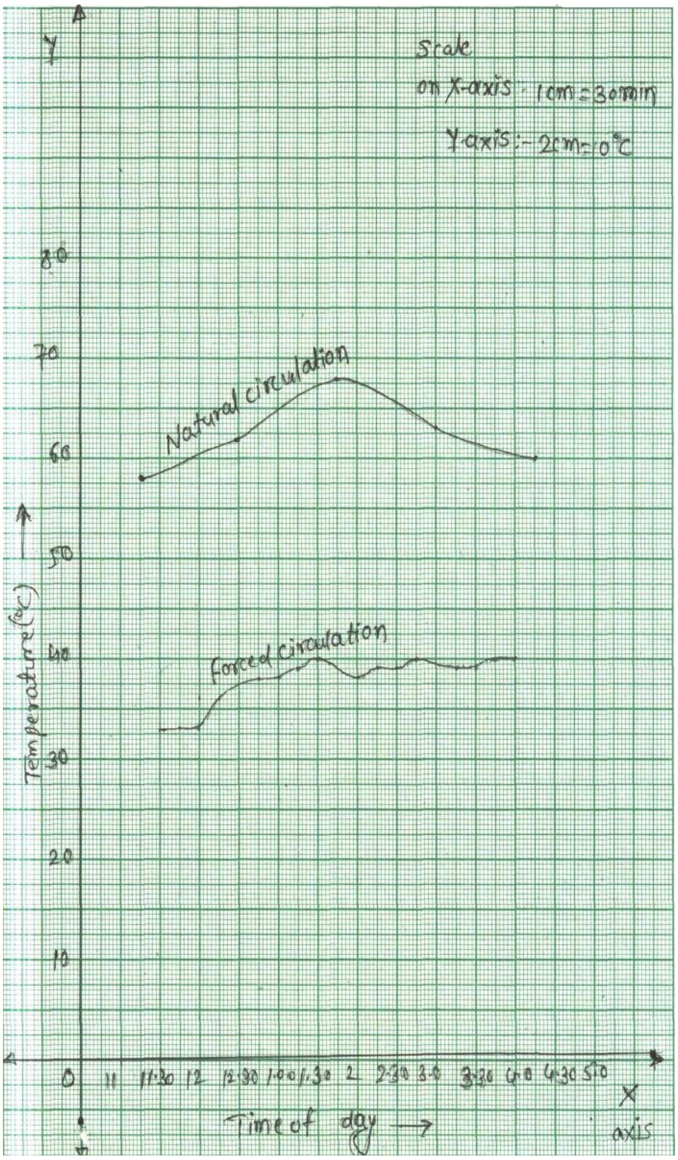
With Medium Discharge

Time	Temp. (⁰C)		Medium discharge Stage 1 $(0.58 \times 10^{-4} m^3/sec)$			Medium discharge Stage 2 $(0.535 \times 10^{-4} m^3/sec)$		
	Ambient	Surrounding	S1	S2	S3	S1	S2	S3
11.15 to 11.30	38	32	30	30	31	31	31	31
12.30 to 12.45	42	36	32	31	33	32	32	33
1.45 to 2.00	43	38	36	37	38	36	37	39
3.00 to 3.15	42	35	35	36	38	37	37	39
4.15 to 4.30	41	34	38	39	40	38	39	41

With Minimum Discharge

Time	Temp. (⁰C)		Minimum discharge $(0.49 \times 10^{-4} m^3/sec)$		
	Ambient Temp	Surrounding Temp	S1	S2	S3
11.15 to 11.30	38	32	30	31	32
12.30 to 12.45	42	36	33	34	36
1.45 to 2.00	43	38	36	36	40
3.00 to	42	35	36	37	40

3.15					
4.15 to 4.30	41	34	38	40	41



6. CONCLUSION

The average hot water temperature is yielded ranged from 30 degree Celsius to 62 degree Celsius, depending upon the solar intensity and weather conditions. The heat lost under the test could be minimized to increase efficiency of the flat plate collector by insulating the flat plate collector completely and by insulating the flexible pipe.

The efficiency of solar flat plate collector by force circulation of water is expected to be greater than natural circulation regarding the same atmospheric temperature but because of following reasons it is coming out to be lesser than natural circulation

Because of the thermal losses in the small water container (the plastic bucket) in which the submersible pump was kept.

The capacity of the pump should have been lesser than the installed one so that minimum mass flow rate could be have been achieved lesser than 0.49 x 10^{-4} m^3/Sec (49.48 ml/Sec) approximately.

REFERENCES

[1] Karagiorgas, M.; Botzios, A.; Tsoutsos, T. Industrial solar thermal applications in Greece heating system in thermosyphonic flow. Sol. Energy 1978, 22, 27–33

[2] Economic evaluation, quality requirements and case studies. Renew. Sustain. Energy Rev. 2001, 5, 157–173.

[3] Chang, K.C.; Lee, T.S.; Chung, K.M. Solar water heaters in Taiwan. Renew. Energy 2006, 31, 1299–1308.

[4] Garg, H.P. Design and performance of a large-size solar water heater. Sol. Energy 1973, 14,303–312.

[5] Shitzer, A.; Kalmanoviz, Y.; Zvirin, Y.; Grossman, G. Experiments with flat plate solar water with hot water removal. Sol. Energy 1984, 32, 655–658.

[6] Young, M.F.; Berguam, J.B. The performance of a thermosyphon solar domestic hot water system.

[7] J.K. Tonui, Improved Pv/T Solar Collectors With Heat Extraction By Forced Or Natural Air Circulation, Renewable Energy 32 (2007) 623–637.

[8] Holman J.P. (2007) Experimental methods for engineers (7th Ed.) New Delhi: Tata Mcgraw hill Publishing Company.

[9] Gao W, Lin, W, Liu, T, Xia C.Analytical and experimental studies on the thermal performance of cross-corrugated and flat-plate solar air heaters. Applied energy 2007; 84:425-41.

[10] Kumar R, Rosen MA. Thermal performance of integrated collector storage solar water heater with corrugated absorber surface. Applied Thermal Engineering 2010; 30:1764e8.

[11] Smyth M, Eames PC, Norton B. Integrated collector storage solar water heaters. Renewable and Sustainable Energy Reviews 2006.

BIOGRAPHIES

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