Comparative Study of Thermal Performance of Spiral Tube Solar Water Heater with Straight Tube Solar Water Heater

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Abstract— The sun which is source of all energy the solar energy which is available from sun can be used for many application water heating, air heating and power generation like solar water heater are the system those collect solar energy and transfer the heat to passing water. The present work includes to carry out comparative study for thermal performance of the straight tube solar water heater with the proposed spiral tube solar heater experimental set up; it consists copper tube in shape of spiral shape, flat plate collector, K type thermocouple the change in water temperature for 100 litter per day water capacity. The thermal performance was evaluated extensively throughout the month of May; a maximum temperature difference of 16 ◌̊C between inlet and outlet of the solar water heater. The efficiency of spiral tube solar water heater was calculated. The maximum value during the experimental period was found to be 47.63% which was more than the straight tube solar water heater.

Key words: spiral tube solar water heater, sswh

I. INTRODUCTION

Solar energy is responsible for all of the light and most of the heat we experience on Earth. That's a lot of free energy floating around. The sun's heat can be harnessed with absorption and conduction in solar thermal collectors to heat water. It can be concentrated with mirrors to cook food and applied to rooms in need of heating with some well-placed windows. Photons (light) from the sun can even be converted into electricity through photovoltaic cells. As renewable energy sources go, the sun is by far the largest and most accessible here on Earth.

A. Solar water heater

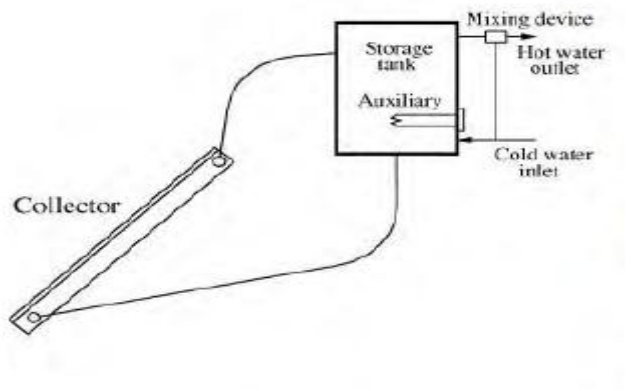

Fig. 1: Schematic diagram of natural circular system

A solar water heater consists of a collector to collect solar energy and an insulated storage tank to store hot water. The solar energy incident on the absorber panel coated with selected coating transfers the hat to the riser pipes underneath the absorber panel. The water passing through the risers get heated up and are delivered the storage tank. The re-circulation of the same water through absorber panel in the collector raises the temperature to 80 ◌̊C (Maximum) in a good sunny day. The total system with solar collector, storage tank and pipelines is called solar hot water system.

B. Salient Features of solar water heater (SWH) system.

Solar hot water system turns cold water into hot water with the help of sun's rays.

- Around 60◌̊ C - 80◌̊ C temperatures can be attained depending on solar radiation, weather conditions and solar collector system efficiency.
- Hot water for homes, hostels, hotels, hospitals, restaurants, dairies, industries etc. can be installed on roof-tops, building terrace and open ground where there is no.
- Shading, south orientation of collectors and over-head tank above solar water heating system. SWH system generates hot water on clear sunny days (maximum), partially clouded (moderate) but not in rainy or heavy overcast day.
- Only soft and potable water can be used.
- Stainless steel is used for small tanks whereas Mild steel tanks with anticorrosion coating inside are used for large tanks.
- Solar water heaters of 100-300 liters capacity are suited for domestic application.
- Larger systems can be used in restaurants, guest houses, hotels, hospitals, industries etc.

C. Classification of Solar Water heater Based on Collector System

1) Flat plate collector (FPC) based solar water heater

The solar radiation is absorbed by Flat plate collectors which consist of an insulated outer metallic box covered on the top with glass sheet. Inside there are black ended metallic absorber (selectively coated) sheets with built in channels or riser tubes to carry water. The absorber absorbs the solar radiation and transfer the heat to the flowing water. There are 60 BIS approved manufactures of solar Flat plate collectors.

2) Evacuated Tube Collector (ETC) based solar water Heaters

Evacuated Tube collector is made of double layer borosilicate glass tubes evacuated for providing insulation. The outer wall of the inner tube is coated with selective absorbing material. This absorption of solar radiation and transfer the heat to the water which flows through the inner tube.

3) Thermo syphon systems (passive)

- Thermo syphon systems heat potable water or heat transfer fluid and use natural convection to transport it from the collector to storage.

- The water in the collector expands becoming less dense as the sun heats it and rises through the collector into the top of the storage tank.
- There it is replaced by the cooler water that has sunk to the bottom of the tank, from which it flows down the collector.
- The circulation continuous as long as there is sunshine.
- Since the driving force is only a small density difference larger than normal pipe sizes must be used to minimise pipe friction.
- Connecting lines must be well insulated to prevent heat losses and sloped to prevent formation of air pockets which would stop circulation.

4) Integrated collector storage systems (passive)

- Integrated collector storage (ICS) systems use hot water storage as part of the collector, i.e., the surface of the storage tank is used also as an absorber.
- The main disadvantage of the ICS systems is the high thermal losses from the storage tank to the surroundings since most of the surface area of the storage tank cannot be thermally insulated as it is intentionally exposed for the absorption of solar radiation.
- Thermal losses are greatest during the night and overcast days with low ambient temperature. Due to these losses the water temperature drops substantially during the night especially during the winter.

5) Direct circulation systems (active)

- In direct circulation systems a pump is used to circulate potable water from storage to the collectors when there is enough available solar energy to increase its temperature and then return the heated water to the storage tank until it is needed.
- As a pump circulates the water, the collectors can be mounted either above or below the storage tank.

6) Direct or forced circulation type domestic Solar Water Heater

- In this system only the solar panels are visible on the roof.
- The hot water storage tank is located indoors in a plant room.
- The system is completed with piping, pump and a differential thermostat.
- This type of system is more appealing mainly due to architectural and aesthetic reasons but also more expensive.

7) Indirect water heating systems (active)

- Indirect water heating systems circulate a heat transfer fluid through the closed collector loop to a heat exchanger, where its heat is transferred to the potable water.
- The most commonly used heat transfer fluids are water/ethylene glycol solutions, although other heat transfer fluids such as silicone oils and refrigerants can also be used.
- The heat exchanger can be located inside the storage tank, around the storage tank (tank mantle) or can be external.
- It should be noted that the collector loop is closed and therefore an expansion tank and a pressure relief valve are required.

II. LITERATURE REVIEW

Nosa Andrew Ogie et al [1] designed and construction of a solar water heater based on the thermo-syphon principle. Solar energy is received by a flat-plate collector consisting of a thin absorber plate integrated with underneath grids of fluid carrying tubes and placed in an insulated in the system. The radiation emitted by the absorber plate cannot escape through the glass, thus increasing its temperature. The water gets heated and flows into a storage tank through thermo-syphon principle.

The system designed in this work requires little or no maintenance because of the thermo-syphon principle and was made basically from locally available raw materials and also no moving parts and also the system works automatically.

C.C. Chien et al [2] worked on theoretical and experimental investigations of a two-phase thermo-syphon solar water heaters. In this work, the performance of this innovative solar water heater at different solar radiation intensities and tilt angles was experimentally discussed.
The experimental results show that the best change efficiency of the two phase thermo-syphon solar water heater is 82% and the charge efficiency decreases no more than 5% when the tilt angle of the system was less than 15 ◌C.

K.K. Chong et al [3] studied solar water heater with stationary V-trough collector using forced circulation system. In this paper, experimental study and cost analysis of the stationary V-trough solar water heater system are presented in details.
In this work, the performance test was carried out I two different cases: without glazing and thermal insulation and with glazing and thermal insulation installed to the prototype SWH including reflector, absorber and storage tank.

With V-trough solar water heater, improve the thermal efficiency of the whole system. The main advantages of this type system are that easy to be fabricated, cost effective and high thermal efficiency. This prototype system had achieved the optical efficiency of 70.54% and the temperature of 85.9 ◌ C.

Rakesh kumar et al [4] carried out thermal performance of integrated collector storage solar water heater with corrugated absorber surface. In this investigation, the surface of the absorber is considered to be corrugated, with small indentation depths, instead of plane. The modified surface has a higher characteristic length for convective heat transfer from the absorber to the water, in addition to having more surface area exposed to solar radiation. The corrugated surface based solar water heater is determined to have a higher operating temperature for longer time than the plane surface.

Hussain Al-Madani [5] designed and manufactured a cylindrical solar water heater. In this system, it contains of

a cylindrical tubes made from high quality glass having a length of 0.8, 0.14 m outer diameter and a thickness of 6 mm. a copper coil tube in the shape of spiral rings, with the tube inner diameter of 2 mm and outer diameter of 3.175 mm, painted black, serves as a collector to the incident solar energy on the cylindrical wall.

In this system maximum temperature difference of 27.8 ◌̊ C between inlet and outlet at water mass flow rate of 9 kg/h was observed. The efficiency of the cylindrical solar water heater was found to be 41.8%.

A major advantages of this system is that it is not necessary to direct it to the sun because of its circular shape, whereas the flat plate collector should always be directed to face the sun with a certain tilted angle to get the best efficiency.

I. Budihardjo et al [6] studied the thermal performance of water-in glass evacuated tube solar water heaters and is evaluated using experimental measurements off optical and heat loss characteristics and a simulation model of the thermo syphon circulation in single-ended tubes.

The performance of water-in-glass evacuated tube solar collector system are compared with flat plate solar collector shows that an evacuated tube system with 30 tubes has slightly lower energy saving than a two panel flat plate system.

Xinyu Zhang et al [7] worked on experimental investigation of the higher coefficient of thermal performance for water-in glass evacuated tube solar water heater in china. In this test, the performance of more than 1000 water-in-glass evacuated tube SWHs according to Chinese standards and found that the heat loss from the storage tank and capacity of the solar collector affected their thermal performance.

In this study, they found that a shorter evacuated tube exhibited better thermal performance than longer tube. A shorter tube is also less likely to be damaged during transportation. The experimental results showed that the distance between the centre of the tubes will have an effect on the thermal performance of a water-in-glass evacuated solar water heater without diffuse reflectors.

Y. Taheri et al [8] investigated a new techniques for solar water heater using black coloured sands immersed into the water storage tank established the main portion of the collector absorber section.

The most important feature of CSWH systems include having a large storage capacity per unit volume, a suitable operating temperature range, high storage efficiency, long life, and inexpensiveness. In this study all experiment results, thermal efficiencies achieved higher than 70%.

Jinbao Huang et al [9] worked on experimental investigation on thermal performance of thermo syphon flat plate solar water heater with a mantle heat exchanger.

In this work done the result show that mean daily efficiency of the thermo syphon flat plate solar water heater with a mantle heat exchanger can reach up to 50%, which was lower than that of thermo syphon flat plate solar water heater without heat exchanger but higher than that of glass evacuated tubular solar water heater.

Behrooz M. Ziapour et al [10] study of an improved integrated collector-storage solar water heater combined with the photovoltaic cells. An integrated collector storage solar water heater (ICSSWH) system due to its simple and compact structure, offers a promising approach for the solar water heating in the varied climates.

In this paper, simulation of an enhanced ICSSWH system combined with the photovoltaic (PV) panels has conducted and design acts passive.

The PVT system provides a higher energy output than PV modules and could be cost effective if the additional cost of the thermal unit is low. The PVT system was an enhanced ICSSWH system combine with a PV solar system. The important results are the high solar cell packing factor was caused to-the high solar cell and the tank water temperatures, the low solar cell efficiency and the high thermal and total system efficiencies.

A. Conclusion of Literature Review

The major conclusion drawn from the present work is that the performance of solar water heater is highly influenced by shape of absorber plate, orientation of solar water heater, material used for pipes and arrangement of pipe etc. and by referring the literature available the comparative studies of conventional solar water with spiral tube solar water heater is not reported.

III. DEVELOPMENT OF EXPERIMENTAL SETUP

By study the literature review it was find that there are many work is done on solar water heater. So In the present work for one set will be fabricated out which one having spiral tubes with flat plate collector and thermal performance will be carried out to compare which arrangement is more efficient with 100LPD conventional solar water heater available in market. Design of spiral tube solar water tube heater discuss below.

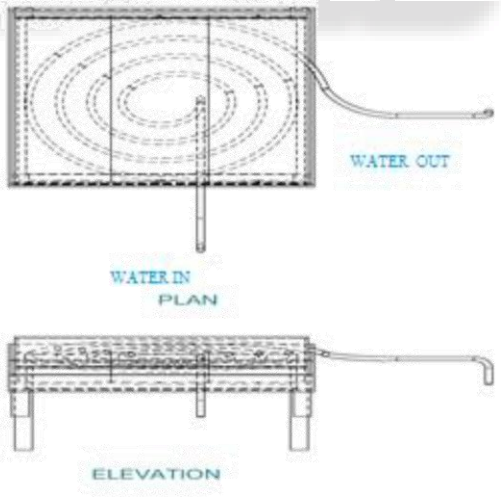

Fig. 2: line diagram of spiral tube solar water heater

A. Specification of spiral tube solar water heater.

1) ½ inch copper pipes with 20 gauge of sheet of 17 m length.
2) 2 mm thick ss sheet with 2 X 1 m X 0.08m as solar heater
3) Plain glass with above mention size and 4 mm thick
4) K type thermocouple
5) Digital Temperature indicator

B. Description of Experimental Setup

- In the arrangement of experimental set up flat plate collector (2×1×0.0.08) m in spiral tube solar water heater with 17 m length of copper pipe shown in fig. 4.2
- The absorber plate is stainless steel sheet with 2 mm thickness and attached at the bottom of wooden box in spiral tube solar water heater and the whole assemblies coated with black colour.
- The temperatures of water at inlet and outlet are estimated using K type thermocouples and readings will be obtained using digital temperature indicator.

C. Experiment set-up of spiral tube solar water heater.

Solar water heater consists of absorber plate, transparent cover, insulation material, and frame. A photograph of experimental set-up, construction detail and main properties of different solar water heaters are shown in fig.4.2 and fig.

Fig. 3: front view of spiral tube solar water heater

The dimension of solar water heater in which flat plat collector 2m×1m×0.08m for spiral tube solar water heater. Single glass cover were used in solar water heaters. The skeleton of solar water heater was manufactured by plywood of 8mm thickness and absorber plate was manufactured by stainless steel sheet of 2mm. Transparent glass cover was taken which have thickness of 4mm.Insulation was provided to reduce heat loss. Two holes were made at both sides of skeleton for inlet and outlet in the dimension of 30mm in diameters. The tilt angle of solar water heater was taken 45° by adjustable part. Solar water heater was placed in direction of north-south without any shadow. water is circulated by radial thermo siphons principal.

D. 100LPD conventional solar water heater

In conventional solar water heater, Smallest size of a system is 100 litre per day. which means that it can deliver 100 litres of hot water in a day at 60°. A 100lpd capacity system is sufficient for a family of 3-4 members and it may cost Rs. 15,000 to Rs. 22,000 in planes depending on the type of system. A solar water heater of 100 litres capacity can prevent emission of 1.5 Tonnes of carbon dioxide per year.

E. Technical specification of 100LPD solar water heater

No. of collector = 1
Collector size = 2m×1m×0.08m
Absorber area = 2 Sq. meter
Space require for hot water tank = 1 Sq. meter
Riser = 12.7 mm diameter of copper tube and 9 Nos of 75 inch
Header = 25.4 mm diameter of copper tube

F. Experimental procedure:

Experiments on solar water heaters were performed in clear days of May at Navsari (21°07′N,73°40′ E) , Gujarat. Tests were conducted between 9:00AM to 3:00PM solar times. The water inlet and outlet water temperatures were taken in every 60 minutes interval periods and data is logged to data logger and respective graphs were plotted. Thermocouples were used for measuring different temperatures at different point of solar water heaters.

G. Observation table of spiral tube solar water heater.

The observation table of spiral tube solar water heater is reading measure from 10th May, 2015 to 11th May, 2015, during 9:00 a.m. to 4:00 p.m. and experimental data was recorded after regular interval of hour.

Date	time	T_{in} (°c)	T_{out} (°c)	Time required to fill 1 litre tank in second	ΔT	Solar Radiation (KW/m^2)
10/05/2015	09:00	32	42	65	10	0.856
	10:00	34	46	64	12	0.925
	11:00	35	47	62	13	1.021
	12:00	36	51	60	15	1.123
	1:00	36	52	58	16	1.209
	2:00	37	52	58	15	1.195
	3:00	36	49	59	13	1.026
11/05/2015	9:00	31	40	68	9	0.820
	10:00	32	43	67	11	0.911
	11:00	34	46	65	12	0.988
	12:00	35	49	64	14	1.095
	1:00	36	51	63	15	1.180
	2:00	36	50	63	14	1.121
	3:00	35	47	64	12	1.095

Table 1: observation table for spiral tube solar water heater

Performance and testing of spiral tube solar water heater and straight tube solar water heater has been carried out extensively throughout 10/5/15 and 11/5/15. The variation of inlet and outlet temperature of spiral tube solar water heater and straight tube solar water heater with time shown in fig. The variation of solar radiation with time shown in fig. the variation of Temperature difference of spiral tube solar water heater and straight tube solar water heater with time shown fig. The comparison of efficiency of spiral tube solar water heater and straight tube solar water heater shown in fig

date	**Time**	**Mass flow rate(kg/s)**		**Useful energy gained**		**Efficiency(%)**	
		spiral	**straight**	**spiral**	**straight**	**Spiral**	**straight**
10/5/15	9:00	0.0153	0.0126	0.6404	0.4219	37.40	24.64
	10:00	0.0156	0.0129	0.7836	0.5399	42.35	29.18
	11:00	0.0161	0.0131	0.8761	0.6580	42.73	32.22
	12:00	0.0166	0.0133	1.0423	0.7194	46.40	34.70

	1:00	0.0172	0.0135	1.1519	0.8476	47.63	35.05
	2:00	0.0172	0.0135	1.0799	0.7911	45.18	33.10
	3:00	0.0169	0.0133	0.9196	0.6680	44.81	32.55
11/5/15	9:00	0.0147	0.0117	0.5538	0.3428	33.76	20.90
	10:00	0.0149	0.0119	0.6860	0.4483	37.65	24.60
	11:00	0.0153	0.0121	0.7685	0.5571	38.89	28.19
	12:00	0.0156	0.0123	0.9142	0.6693	41.74	30.56
	1:00	0.0158	0.0125	0.9920	0.7325	42.03	31.03
	2:00	0.0158	0.0125	0.9259	0.6802	41.29	30.33
	3:00	0.0156	0.0123	0.7836	0.5663	35.78	25.85

Table 2: Result table for spiral tube and straight tube solar water heater

The efficiency of spiral tube solar water heater and straight tube solar water heater versus time is approximately steady as shown in fig.4 The maximum value for the day of 10 May 2015 is 47.63% while for the day of 11 May 2015 is 42.03% of spiral tube solar water heater. For straight tube solar water heater, the maximum value for the day of 10 May 2015 is 35.05% while for the day of 11 May 2015 is 31.03%. These observations reveal that the spiral tube solar water heater design has a reasonable efficiency compared to straight tube solar water heater.

The measurements of the temperature difference are elaborated in fig. The figure indicates that maximum temperature difference of 16 ◌c during the day at 1:00 p.m. for the 10/5/2015 and 15 ◌c during the day at 1:00 p.m. for the 11/5/2015 for spiral tube solar water heater and maximum temperature difference of 15 ◌c during the day at 1:00 p.m. for 10/5/2015 and 14 ◌c during the day at 1: p.m. for the 11/5/2015 for straight tube solar water heater.

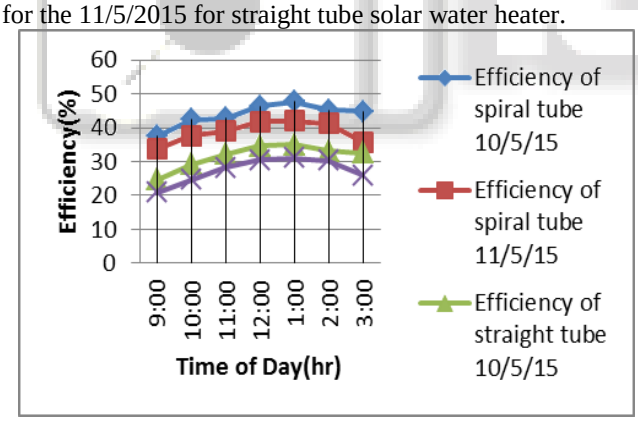

Fig. 4: efficiency versus time

IV. CONCLUSIONS

Today, hundreds of thousands modern solar water heaters are in use throughout the world. While the initial purchase and installation cost of a solar water heater is higher than an equivalent conventional water heater this extra cost can be recovered over a period of time through lower energy bills.

Solar energy can reduce the national demand for conventional fuels, reduce the damage to the environment, as it is a non-polluting free energy, and reduce the need to build new power station which require huge investment.

On the basis of the results obtained in this study, the following conclusions can be drawn.

- A spiral tube solar water heater has been designed and performance evaluated and compare with conventional 100LPD solar water heater performance. The outlet temperature of spiral tube solar water heater more than the conventional 100LPD solar water heater.
- A maximum temperature difference of 16 ◌c between inlet and outlet water temperature which is more than the conventional solar water heater.
- The efficiency of spiral tube solar water heater and straight tube solar water heater was calculated. The maximum value during the experimental period was found to be 47.63% for spiral tube solar water heater and 35.05% for straight tube solar water heater. As compare this efficiency, the spiral tube solar water efficiency is more.
- This strongly suggests a good capability of the system to convert the solar energy to heat which can be used for heating water compare to straight tube solar water heater.
- The more time is required to fill the 1000 ml water tank in case of straight tube solar water heater compare to spiral tube solar water heater.
- More rate of heat transfer compare to straight tube solar water heater in case of spiral tube solar water heater.
- The thermal efficiency and the outlet temperature is more in case of spiral tube solar water heater compare to straight tube solar water heater.

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