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Thermal Performance of Modified V-Trough Solar Water Heater

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***Abstract*— There are various types of solar water heater system available in the commercial market to fulfil different customers' demand, such as flat plate collector, concentrating collector, evacuated tube collector and integrated collector storage. A cost effective cum easy fabricated v-trough solar water heater system using forced circulation system is proposed. Integrating the solar absorber with the easily fabricated v-trough reflector can improve the performance of solar water heater system. In this paper, optical analysis, experimental study and cost analysis of the stationary v-trough solar water heater system are presented in details.**

To increase the thermal performance of solar water heater. A cost effective and easy fabricated v - trough solar water heater was modified by parallel flow thermosyphon water heater. Integrating the solar absorber with the easily fabricated v-trough reflector can improve the performance of solar water heater system. The performance of v - trough solar water heater is compared with flat plate solar water heater at same operating condition.

***Keywords*— Solar Water Heater (Swh), Integrated Collector Storage (Ics), V-Trough Reflector, Heat Transfer, Temperature Difference.**

I. INTRODUCTION

Renewable energy sources can play a vital role in developing countries like India, since there is an enormous demand for energy which is mainly obtained from conventional sources of energy like crude oil, coal etc. Energy from these conventional sources pollutes the environment, causes global warming and acid rain, limited reach and very costly production cost. Moreover they consume huge amount of foreign exchange which directly affects the economy of the nation. Hence there is an urgency to improve the share of renewable energy in the power sector and it can be promoted through R&D, demonstration projects, dissemination projects/programmes supported by Government and fiscal incentives.

Among all renewable energy technologies, solar thermal technologies have a natural advantage in India due to fact that average solar radiation available is 4.5 - 6 kW hr/m^2 per day with 280 clear days over the year. The technical potential has been estimated as 140 million square meter of collector area. India was the first country in the world to set up a ministry of non-conventional energy resources, in early 1980s.

India's cumulative Grid interactive (excluding Large Hydro) has reached 26.9GW, of which 68.9% comes from wind, while solar PV contributed nearly 4.59% of the Renewable Energy installed capacity [1]. Renewable energy in India comes under the purview of the Ministry of New and Renewable Energy.The Government of India upgraded the Department of Non-Conventional Energy Sources to Ministry of Non-conventional Energy Sources (MNES) in 1992 due to the increasing importance of renewable energy sources. The National Solar Mission is a major initiative of the Government of India and State Governments to promote ecologically sustainable growth while addressing India's energy security challenge. It will also constitute a major contribution by India to the global effort to meet the challenges of climate change. Based on the mission document the country would be capable of generating 1,000 mw of solar power every year by 2013.

II. INDIAN ENERGY SECURITY

An Energy security is a term for an association between national security and the availability of natural resources for energy consumption. Access to cheap energy has become essential to the functioning of modern economies. However, the uneven distribution of energy supplies among countries has led to significant vulnerabilities. The following are considered as the threats of energy security.

- Political instability of energy producing countries
- Manipulation of energy supplies
- Competition over energy sources
- Accidents and natural disasters

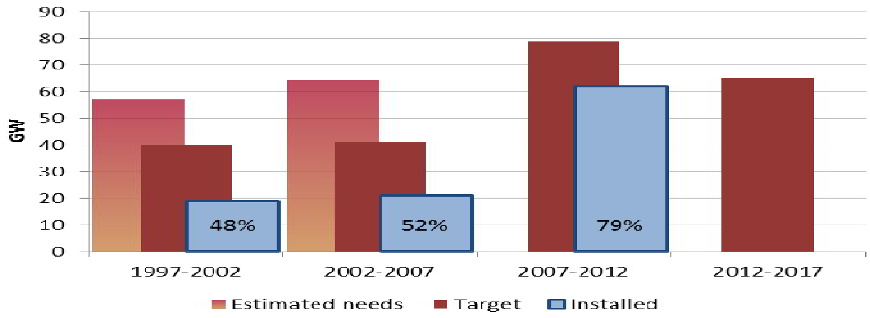

Fig. 1 Energy supply and demand pattern in India

The estimated need, targets and actual installed capacities in India over the last three plans. As seen from the figure, the gap between the energy supply and demand increases with year. This clearly implies that the energy security of India is imbalanced. Energy exploration and exploitation, capacity additions, clean energy alternatives, conservation, and energy sector reforms will, therefore, be critical for energy security. Energy conservation has also emerged as one of the major issues in recent years.

A. Water heating – requirements and applications

Domestically, water is traditionally heated in vessels known as water heaters, kettles, cauldrons, pots, or coppers. These metal vessels that heat a batch of water do not produce a continual supply of heated water at a preset temperature. Appliances that provide a continual supply of hot water are called water heaters, hot water heaters, hot water tanks, boilers, heat exchangers, geysers, or clarifiers.

TABLE 1.1.1 SOLAR WATER HEATER POTENTIAL UNDER REALISTIC SCENARIO (MM2)

No. Of Years	2010	2013	2017	2022
Residential	2.58	4.25	7.68	15.74
Commercial/Institutional				
Hotels	0.19	0.35	0.61	0.97
Hospitals	0.10	0.17	0.27	0.43
Others	0.18	0.27	0.39	0.52
Industry	0.19	0.33	0.57	1.05
Total	3.24	5.37	9.52	18.70

B. Classification of thermal collectors

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days.

The following are the list of some popular types of commercially available solar thermal collectors.

1) Glazed flat-plate solar collectors
2) Unglazed flat-plate solar collectors
3) Unglazed perforated plate collectors
4) Vacuum tube solar collectors
5) Concentrating solar collectors

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TABLE.1.1.2 COMPARISON OF VARIOUS COLLECTORS

Motion	Collector type	Absorber type	Concentration ratio	Temperature range (oC)
Stationary	FPC	Flat	1	30-80
	ETC	Flat	1	50-200
	CPC	Tubular	1-5	60-240
Single axis tracking	LFR	Tubular	15-45	60-250
	PTC	Tubular	15-45	60-300
	CTC	Tubular	10-50	60-300
Multi axis tracking	PDR	Point	100-1000	100-500
	HFC	Point	100-1500	150-2000

III. ANALYSIS OF V-TROUGH

A. Optical Analysis of Stationary V-Trough Collector

Stationary V-trough collector was designed with the initiative to increase the solar concentration ratio of the absorber plate up to two suns. The schematic diagram to describe how a flat reflector to be inclined at a certain angle $\angle ABE = \theta = 60^{\circ}$, can map all the vertical rays from the inclined reflector to the absorber plate. To verify the sunlight fallen on the proposed V-trough reflector can be uniformly mapped onto the absorber plate, a 2-D ray-tracing method was used in our preliminary analysis.

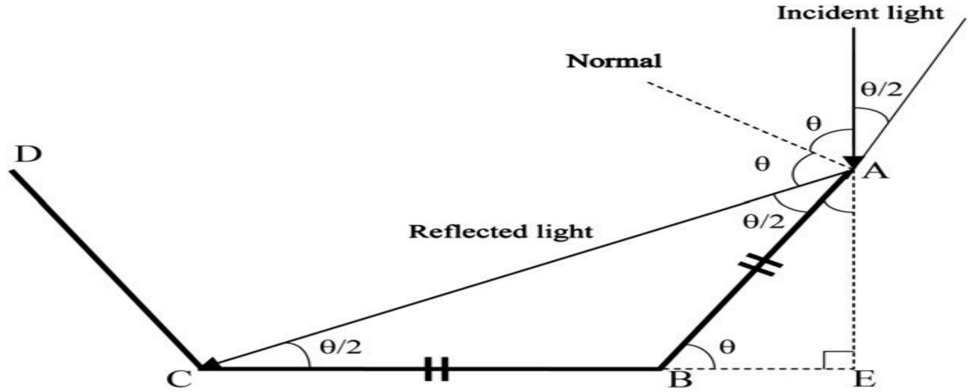

Fig.2. The schematic diagram to describe how a flat reflector to be inclined at a certain angle $\angle ABE = \theta = 60^{\circ}$ can fully map all the vertical rays from the inclined reflector to the absorber plate purely based on geometrical optics.

B. V-Trough Collector

The solar collector is made from two major parts: a flat absorber Plate and V-trough reflector. The V-trough reflector was constructed using two rectangular facet mirrors with a dimension of 14cm (width) ×100 cm (length) ×0.5 cm (thickness) each and inclined at the angle of 60° relative to the absorber plate. To optimize the optical performance, the V-trough reflector was aligned horizontally along south direction. Ideally the V-trough reflector should be south facing and inclined at the angle of 11.4° the local latitude.

Five rectangular float glasses with the dimension of 28 cm (width) × 100 cm (length) × 0.5 cm (thickness) each were fixed on top of the each V-trough reflector with silicone adhesive.

Trapezium-shaped float glasses were used to cover both ends of the V-trough reflector and the remaining gaps were filled with extruded polystyrene extruded Polystyrene was also employed to insulate the external surface of V-trough reflector from heat loss through both conductive and convective processes. Extruded polystyrene is chosen as main insulating material of the prototype SWH due to its low cost and weather proof characteristic that is in line with our design concept.

Storage tank of prototype SWH was simply a standard with a dimension of 42 ×28.5 × 26 cm^3 capable of storing at least 100 L of hot water for domestic usage. Two holes were drilled where one hole was at the bottom of the tank for the connection to the absorber inlet and the other hole was at the top part of the water tank's side wall for the connection to the absorber outlet. Fibre glass and aluminium foil were utilized to enhance the heat insulation of the water tank from convective and radiation losses respectively due to their easy availability, cost effectiveness and light weight.

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Fig no: 3 Construction of v-trough

IV. EXPERIMENTAL SETUP AND DATA COLLECTION

The experimental setup consists of a flat plate thermosyphon solar collector and a storage tank for natural circulation system with necessary instrumentation. Four collectors (Plain tube, full length V troughed tape, V troughed tape with rod, V troughed tape with spacer) are kept in open atmospheric condition and experimentation has been carried out.

A. Description of the experimental setup (Flat plate)

The experimental setup consists of a flat plate collector of 1 m^2 aperture area connected to a well insulated storage tank of 100 litres capacity and named as plain tube collector as shown in Fig.3. Basically it is a commercial solar water heating system for domestic applications which is available in the market with some minor design modifications.

The cold water from the storage tank enters the collector from the lower header and is evenly distributed in the nine parallel riser tubes. The riser tubes are brazed to the bottom of a black absorber plate and the absorbed solar radiation is conducted to the riser tubes. The heat is then transferred by convection from the riser tube wall to the fluid. Finally the hot water is collected from the upper header and stored in the insulated storage tank.

B. Data Collection

No.	Design materials/parameters	Specifications
Collector		
1	Tilt angle	11.4^o (South facing)
2	Aperture area, Ac	1 m2
3	Collector glazing	Single transparent glass of 3 mm thickness
4	Lower header	ID 25.5 mm
5	Upper header	ID 25.5 mm
6	Riser tubes	OD 12.5 mm, ID 11 mm, length 1000 mm
7	Absorber plate	Width 122 mm, length 1000 mm
8	Bottom insulation	100 mm glass wool
9	Side insulation	60 mm glass wool covered by aluminium frame
10	Absorber plate coating absorptive	0.92
11	Transmittance of glazing	0.91
12	Number of riser tubes	9

Storage tank and piping		
13	Tank type	Horizontal
14	Tank volume	100 litres
15	Tank wall thickness	4 mm
16	Tank insulation thickness	50 mm
17	Connecting pipe size	ID 25 mm

V. WORKING FOR PLAIN TUBE COLLECTOR

A. Description o Thermosyphon solar water heating system

Thermosyphon system operates on the temperature difference between the hot and cold water in the storage tank that accelerates the driving force. Convective movement of the liquid starts when liquid in the loop is heated in the riser tube, causing it to expand and become less dense, and thus more buoyant than the cooler water in the bottom of the loop. Convection moves heated liquid upwards in the system as it is simultaneously replaced by cooler liquid returning by gravity. Ideally, the liquid flows easily because a good thermosyphon should have very little hydraulic resistance. The characteristics of this thermosyphon solar water heating system are as demonstrated below.

B. Description o Thermosyphon solar water heating system

Average riser tube velocity = 0.0406 m/s
Outside diameter of riser tube = 0.0125 m
Inside diameter of riser tube = 0.011m
Length of riser tube = 1 m
The RTD readings for an average inlet temperature and the outlet temperature are:
Water inlet temperature Tin = 39.39 ^{oC}
Water outlet temperature Tout = 42.13 ^{oC}

Bulk mean temperature, Tf $= \left[\dfrac{T_{in} + T_{out}}{2}\right]$

$= 40.76\ ^{oC}$

For the corresponding fluid mean temperature at Tf = 40.76 ^{oC} , the properties of the fluid are calculated from MATLAB programme as follows

ρ = 991.865 kg/m^3
µw = 0.0006703 kg/m sec
Cp = 4174 J/kg $^{o\,C}$
k = 0.62397 W/m $^{o\,C}$

Mass flow rate of the riser tube, $\dot{m}$ = ρ A V
= 991.865 x 9.50 X10-5 x 0.0406
= 3.827 x 10-3 kg /sec

Heat gained by water in riser tube, Q

= ($\dot{m}$ X Cp X ΔT)
= (3.827 x 10-3 X 4174 X 2.74)
= 43.76 W

Thermal Performance
Useful heat gain from collector Q = 402.49 W

Transmitance-absorbtance of
Collector = 0.84 from

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Input Solar radiation	= 846 W/m^2
Absorber plate temperature	= 54.98 ^{oC}
Atmospheric temperature	= 29.5 ^{oC}
Water inlet temperature	= 39.33 ^{oC}

Instantaneous efficiency of collector

$$\eta = F_R(\tau\alpha) - F_R U_l \frac{T_{in} - T_a}{H_t}$$

$$Q = H_t(\tau\alpha) - U_l(T_p - T_a)$$

$$U_l = \frac{402.49 \times 846(0.84)}{(29.5 - 54.98)} \; 12.09 \text{ W/m2}$$

= 12.09 W/m^2

The collector heat removal factor (FR) is calculated as follows from the above reference

$$Q = F_R(H_t(\tau\alpha) - U_l(T_{in} - T_a))$$

$$F_R = \frac{Q}{H_t(\tau\alpha) - U_l(T_{in} - T_a)}$$

$$F_R = \frac{402.49}{846 \times 0.84 - 12.09(39.33 - 29.5)}$$

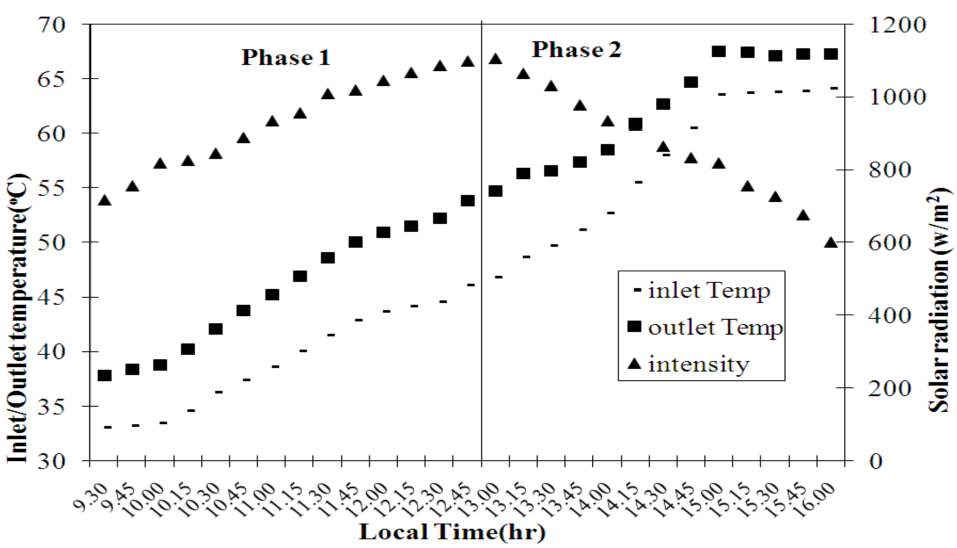
The instantaneous efficiency of the collector

$$\eta = 0.68 \times (0.84) - 0.68 \times 12.09\left(\frac{39.33 - 29.5}{846}\right)$$

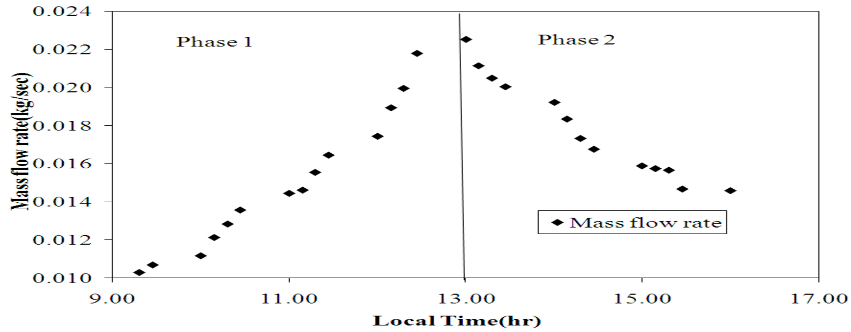
= 47.58 %

V. GRAPHICAL INTERPRETATION

GRAPH NO.1 THERMAL PERFORMANCE FLATE PLATE COLLECTOR CASE (I)



Case (II)



VI. CONCLUSION

It may be seen that man has changed everything which is available in nature, according to his need .Solar is naturally available, Inexhaustible source of energy. By proper recognition this energy could supply all the present and future be utilised in many ways. It can also be used for power generation. We throughout the project work have projected on utilisation of solar energy with the help of parabolic trough as a solution to energy crisis. .

The novel stationary V-trough solar water heater with the maximum solar concentration ratio of 1.8 suns has been proposed to improve the thermal efficiency of the whole system. The advantages of the new proposal are that easy to be fabricated, cost effective and high thermal efficiency. The collected data has shown that the prototype has achieved the optical efficiency of 70.54% or1.41 suns and the temperature of 85.9 _C. The prototype can be easily constructed through DIY using off-the-shelf materials with total cost of RM 1489.40 and total payback period of 12.2 year for discounted form or 8.9 years for undiscounted form.

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