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PERFORMANCE EVALUATION OF DOMESTIC SCALE FLAT PLATE THERMOSIPHON TYPE SOLAR WATER HEATER

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ABSTRACT

In this experimental study, a domestic scale flat plate thermosiphon type solar water heater has been tested which is installed at Mechanical Engineering Department, Madan Mohan Malviya University of Technology, Gorakhpur, U.P, India (26.73ºN, 83.3ºE). The hourly performance of solar water heater was studied experimentally in the month of November through energy and exergy analysis. Average energy efficiency was measured 18.5% whereas average exergy efficiency was found .27% and such considerable difference between them exhibit that there still persists a vast scope to improve the collector as well as storage barrage material and design requirements to enhance the efficiency of solar water heater.

Keywords: *Solar Water Heater, Thermosiphon, Energy Analysis, Exergy Analysis*

Introduction

Energy needs in the present global energy scenario are satisfied mostly from fossil fuels i.e. coal, oil and natural gas which are limited in stock and will be depleted one day. Alternative energy sources such as solar energy, wind power etc, which are eco-friendly in nature and abundant in availability make them the most pleasant option to satisfy the worldwide growing energy needs. However, low conversion efficiency is the biggest hurdle associated with the renewable energy systems which call for special consideration before implementation of renewable energy systems in various useful applications. Performance of many renewable energy conversion systems is evaluated based on the energy analysis which basically depends upon the amount of energies entering and exiting. Sun is the chief source of all conventional and renewable energy sources, which is abundantly and readily available at all time and therefore can be used directly or indirectly. Solar energy can be utilized directly in photosynthesis or transforming it into electrical power using photovoltaic solar panels. [1]

An Indirect way of using solar energy is to use solar collectors to absorb and transfer the heat to the medium for moderate/low-temperature heating applications e.g. solar water heating systems, solar dryer etc. Also water heating is the most common application of solar energy across the globe

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for low-temperature application. Most commonly used solar water heating systems (SWH) are flat plate collector type (FPC), compound parabolic collectors (CPC) type and evacuated tube collector (ETC) type. [2]

Solar Water Heating Systems

Hot water can be obtained from the solar water heater (SWH) for most of the useful applications i.e. industrial, domestic & commercial applications which area natural and carbon-free process. It mostly consists of insulated storage tank and collector. Insulated tank and solar collector are used for hot water storage and solar radiation collection respectively. Solar water heaters (SWH) are very simple which utilize sunlight only to heat water. Working fluid temperature is raised by bringing it in contact with a black painted surface which is exposed to the solar radiation. If water itself is directly used as a working fluid it is called as directsystem. In indirect system, heat transfer fluids such as water mixture/glycol are used to transfer the heat to water in storage tank through heat exchanger. [3]

These systems are grouped into three categories**;** Active System, Passive System and Batch System.

In active System, water or other working fluid is circulated via collectors using controllers, valves and electric pumps. Depending upon the working fluid used, it further grouped into Open loop or Direct Active System & Closed loop or Indirect Active System.

In passive system, heat transfer fluid or water is circulated between a collector and a raised storage tank situated above the collector through natural convection. The principle behind the passive system is simple, as the temperature of the fluid increases, its density reduces. Reduced density makes the fluid lighter and consequently moved to the top of the collector where it is received into the storage tank. Tap water collected at the bottom of the storage tank slides down to the collector where it is heated and raised back to the storage tank and cycle continues. One of the best methods of passive system is a thermosiphon system.

Batch systems are similar to passive systems. In this system, Insulated enclosure whose one side is transparent to receive solar radiation encloses one or more storage tanks. It doesn't require moving parts such as pumps etc which makes this system inexpensive [4].

Literature Review

A broad writing survey has been performed on both the vitality and exergy investigation of common sustainable non conventional energy frameworks including, solar thermal, and sunlight based photovoltaic and biomass cookstove. Among extremely essential perspectives examined and outlined, it is discovered that the vast majority of the examination completed for renewable power source frameworks so far depend on the energy examination. Likewise, for all sustainable power source frameworks, the execution dependent on exergy examination, by and large, is observed to be lesser than that of the energy investigation. [1]

In light of the broad writing survey on the advancement and most recent improvements of evacuated tube solar collectors, it has been seen that an evacuated tube collector has higher thermal effectiveness than that of other collectors.An evacuated tube solar collector is likewise proficient to be utilized at higher working temperature. [2]

Thermal performance Economies and Envoirmental friendliness offered by domestic scale thermosiphon solar water heater (TSWH) suitable to cater the hot water for a family of four persons was investigated. TSWH can save 70% for electricity or diesel back up as compared to conventional systems. TSWH offer considerable protection to the envoirment and should be employed wherever it is possible to obtain the sustainable future. [3]

An attempt has been made to evaluate the performance of solar water heater based on the exergy analysis. It was observed that the conversion of direct solar radiation into sensible heat of water in SWH leads to very high exergy losses. A large amount of losses has been observed in solar collector and storage tank. Hence, to improve the exergy efficiency and to minimize the losses, proper selection of materials being used to manufacture collector and storage tank should be made. Proper insulation, effective design of collector, connecting pipes and storage tank are necessary to achieve better efficiency. [4]

A new temperature controlled solar water heater (TCSWH) was developed by using process control devices and solenoid valves. This system was compared with thermosiphon solar water heater at different temperatures of 40ºC, 45ºC, 50ºC & 55ºC. Highest average efficiency of TCSWH was obtained at 40º& 45º with the accuracy of ±2ºC. [7]

hree procedure theory was used to evaluate the performance of domestic solar water heater based on the exergy analysis. An attempt has been made to find out the ways to improve the efficiency and save the cost of the conversion device and at the same time, finding the respective exergy losses. [8]

METHODOLOGY

3.1. Experimental Set up

Natural circulation based solar water heating systems (SWHS) or simply thermosyphon is the most significant and widely used devices for collection and exploitation of solar energy. It is made up of storage tank, collector and connecting pipes [5]. Thermal efficiency of solar collector depends upon geographical situations, collector orientation, inclination angle and material of fabrication.Working principle of thermosiphon solar water heater is highly based on thermal stratification in storage tank which governs the heat ejection efficiency of the thermosiphon solar water heater[6]. Conventional thermosiphon solar water heater delivers hot water in the range of temperature uncontrollably where as to get the hot water with close tolerance of ±2ºC in the storage tank, temperature controlled solar water heater could be

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utilized [7]. The sketch of thermosyphon flat plate domestic solar water heater is shown in figure 2.

A. Solar Collector

It is a vital part of the solar water heater. The solar collector, which absorbs the solar radiation and raises the temperature of the water, consists of mainly four parts. Its total area is 2×1.98×.98 m^2.

B. Water Storage Tank

The water storage tank is made up of cast iron material and is well insulated with glass wool having a capacity of 125 liters. Purpose of the storage tank is supply and store hot water.

3.2. Working Procedure

Flat plate thermo-siphon type domestic solar water heater is installed as shown in figure 3 at Mechanical Engineering Department, Madan Mohan Malviya University of Technology, Gorakhpur, U.P, India (26.73ºN , 83.3ºE).

Flat plate collectors are installed at an angle 26.73º due south which is equal to the latitude of the place to get optimum solar radiation throughout the year. During the experiment, at every 1-hour interval, solar insolation was measured by solar power meter. Temperatures at inlet and outlet of collector were measured at every 1-hour interval. Top and Bottom temperatures of storage tanks were also recorded at every 1-hour interval using thermocouples. To evaluate the hourly performance of SWE energy and energy efficiencies different parameters were recorded at hourly basis. The received solar radiation by the tubes is partly delivered to the water moving through the narrow tubes that are connected to the absorber plate. Amount of heat delivered to the water is the useful gain. The remaining part of solar radiation received at the absorber plate is lost to the surrounding by radiation and convection from the top surface and by conduction through the back sides, edges and corners.

3.3 Energy & Exergy Analysis

Conversion of energy takes place in the sun as depicted by three procedure theory. Nuclear fusion reaction in the sun is responsible for the emission of a great amount of energy which is received as electromagnetic waves at the earth surface. This energy utilization takes placeat the flat plate collector. Solar radiation transmits through the cover and is absorbed by the darkly painted absorber plate where the water moving through the tubes is heated up. The procedure of energy recycling belongs to the storage tank. A model called three procedures is used for domestic scale solar water heater [8].

RESULTS & DISCUSSION

Experiments were performed on 5th November2018 at Mechanical Engineering Department, MMMUT, Gorakhpur, Uttar Pradesh. Readings were taken and tabulated below (Table-2) for the purpose of Energy and Exergy analysis of SWH.

Graphs drawn for various tempratures in **Fig.5**. As Inlet tap water is fed directly to

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the storage tank from the bottom which is subsequently taken to the solar collector to raise the temperature after absorption of solar radiation.Inlet tap water temperature at the bottom of thestorage tank T_{BOTTOM}, Inlet water temperature in the solar collector T_{fi}, and ambient temperature T_o are almost samei.e.27ºC as it evident from the graph.Outlet temperature of water from the collector is delivered to the storage tank through connecting insulated pipes. Some heat is lost during transmission which is clearly shown in the graph. Average Outlet water temperature from the collector T_{fo}(59.57ºC) is slightly higher than average water temperature at the top of the storage tank T_{Top}(56.14ºC).

Graph drawn for variation of solar intensity, ambient temperature Vs time as show in **Fig.6**. When the experiment was performed, initial ambient temperature was 25ºC and solar intensity was 760 w/m^2 which then rises to the maximum temperature of 28ºC at mid of the day when solar intensity observed to be its maximum value 850 W/m^2.

It is evident from the experiments performed and graphs obtained for exergy and energy efficiencies in **Fig.7**that ambient temperature increases as the intensity increases and attains its maximum value i.e. 28ºC at solar intensity of 850 w/m^2 at around 01 PM while efficiency first declines till 12 PM and then increases and attains its maximum i.e. 19.1% at 01 PM and at the same time exergy value achieve its maximum i.e. .34% and starts decreasing continiously. It was found that collector water outlet temperature & storage tank top temperature attain their respective maximum at the same time when energy & exergy achieve maximum.

CONCLUSIONS

[1] The average exergy efficiency for the concerned solar water heater is obtained as η_{Xavg}=.27% and the average energy efficiency noticed equals η_{avg} = 18.5%. Hence, there is a considerable difference between average energy and exergy efficiencies. The low value of exergy efficiency exhibits that the output energy of the solar water heater is of poor quality.

[2]Low values of energy & exergy efficiencies of SWH exhibit that there still persists a vast scope to improvement in the collector as well as storage barrage material and design requirements to enhance the efficiency of SWH.

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Nomenclature

E_u	Energy Received from Sun (Input Energy) (W)	E_j	Energy Losses due to Improper Thermal Insulation in Storage Barrel (W)
E_{xu}	Exergy from Sun (Input Exergy) (W)	D_{jR}	Exergy Losses due to Improper Thermal Insulation in Storage Tank (W)
E_o	Energy Transferred from Collector to Storage Barrel (W)	E_R	Energy from Storage Tank to Collector associated with Water Recycle (W)
E_{xo}	Exergy Transferred from Collector to Storage Barrel (W)	E_{xR}	Exergy from Storage Tank to collector associated with Recycle of Water (W)
E_E	Energy Received by End- User from Storage Tank (Output Energy) (W)	T_{top}	Top Water Temperature in Storage Tank (K)
E_{xE}	Exergy from Storage Tank to end-user (output exergy) (W)	T_{bottom}	Bottom Water Temperature in Storage Tank (K)
E_L	Loss of Energy due to improper Thermal Insulation in Collector (W)	m	Mass Flow Rate of Water (kg/s)
D_{ju}	Loss of Energy due to improper	C_P	Specific Heat of Water (J/(kg ^oC)
T_o	Ambient Temperature (K)	T_{fo}	Collector outlet temperature(K)

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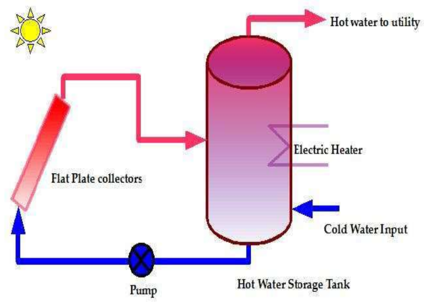

Fig. 1a. Open-Loop Active Systems[4]

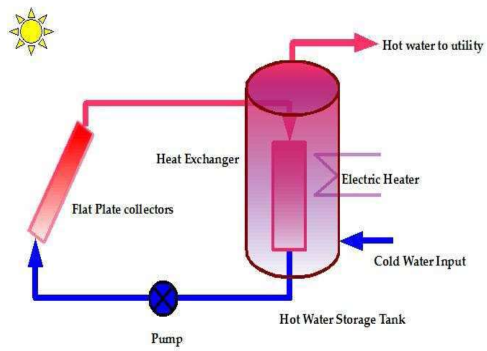

Fig.1b. Closed loop Active System [4]

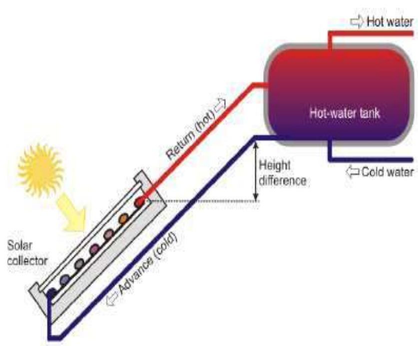

Fig.1c ThermosiphonSystem [4]

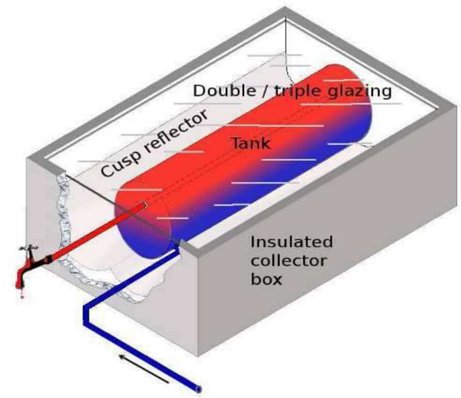

Fig.1d. Batch System [4]

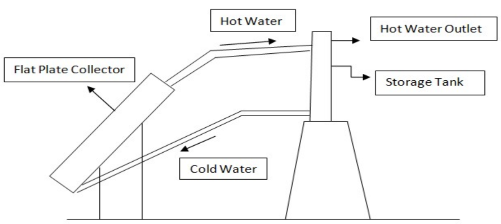

Fig.2 Sketch Of Thermosyphon Flat Plate Domestic Solar Water Heater

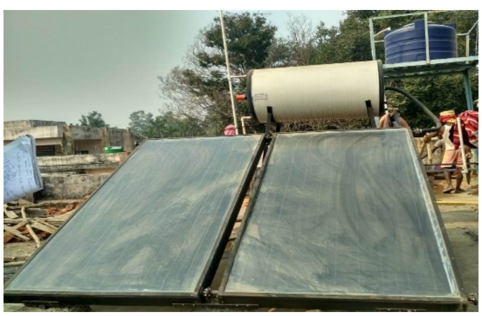

Fig3- Flat Plate Solar Water Heater at MED, MMMUT Gorakhpur

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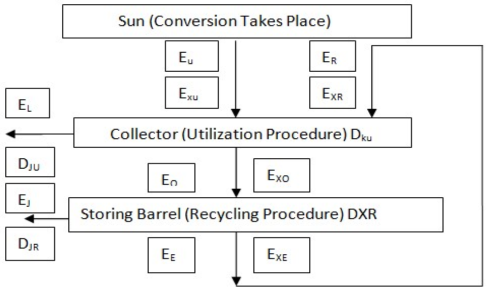

Fig.4.Three procedure theory model for domestic scale solar water heater [8].

Energy Balance Equations :

$Eu + E_R = E_L + Eo$

$Eo = E_J + E_E + E_R$

Equations for Exergy Balance :

$E_{Xu} + E_{XR} = D_{JU} + E_{XO} + D_{Ku}$

$E_{Xo} = E_{XE} + E_{XR} + D_{KR} + D_{jR}$

$E_{XO} = mcp\ (T_{fo} - T_O) - m\ T_O\ cp\ \ln(T_{fO}/T_O)$

$E_{XE} = m\ cp\ [\ \{T_{TOP} + T_{BOTTOM}\}/2 - T_O] - m\ cp\ T_O\ [\ \{\ln(T_{TOP}/T_O) - 1] - [\ \{T_{BOTTOM} \times T_O\}/\{T_{TOP} - T_{BOTTOM}\}]\ m\ cp\ \ln(T_{TOP}/T_{BOTTOM})$

$E_{XU} = A \times I_T \times (1 - T_O/T_S)$

Where A is collecter effective area for solar absorption and I_T is solar radiation intensity and T_S is sun temperature.

$E_E = mcp\ (T_{fo} - T_O)$

$E_U = A \times I_T$

Table.1 Hourly reading of different parameters

Time	Temperature (^{O}C)					SolarIntensity (W/m2)	η (%)	η_X(%)
	T_{TOP}	T_{BOTTOM}	T_{fo}	T_{fi}	T_O			
10 AM	50	25	55	26	25	760	16.27	.23

11 AM	55	25	57	26	25	768	19.92	.21
12 PM	55	28	60	28	27	800	17.84	.26
01PM	60	28	65	28	28	850	19.19	.34
02PM	58	28	60	28	26	830	18.43	.31
03PM	58	27	60	28	26	810	18.88	.30
04PM	57	27	60	27	26	805	19.00	.30

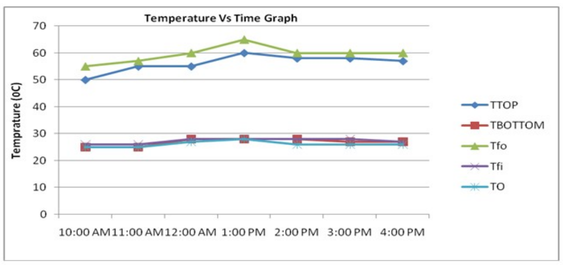

***Fig.5**. Temperature Vs Time Graph*

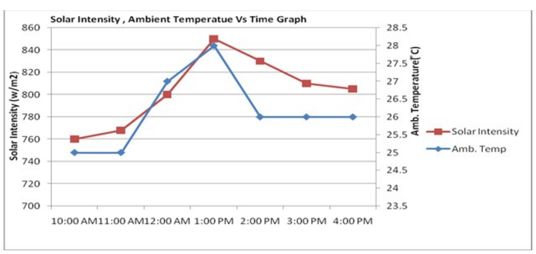

***Fig.6**. Solar Intensity, Ambient Temperature Vs Time Graph*

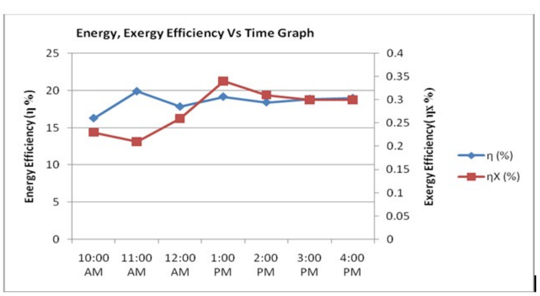

***Fig.**7.Energy, Exergy Efficiency Vs Time Graph*

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Energy & Exergy Calculation:

Overall Energy Efficiency-

$\eta = E_E/E_U$

$E_E = mcp\ (T_{fo} - T_O)$

$E_U = A \times I_T$

$\eta_{max} = 19.92\%$

$\eta_{avg} = 18.5\%$

Overall Average Exergy Efficiency-

$\eta_X = E_{XE}/E_{XU}$

$E_{XE} = m\ cp\ [\ \{T_{TOP} + T_{BOTTOM}\}/2 - T_O] - m\ cp\ T_O\ [\ \{\ln(T_{TOP}/T_O)\ -1] - [\ \{T_{BOTTOM} \times T_O\}/\{T_{TOP} - T_{BOTTOM}\}]\ m\ cp\ \ln(T_{TOP}/T_{BOTTOM})$

$E_{XU} = A \times I_T \times (\ 1 - T_O/T_S)$

$\eta_{Xmax} = .32\%$

$\eta_{Xavg} = .27\%$

Collector Average Exergy Efficiency-

$\eta_{XC} = E_{XO}/E_{XU}$

$E_{XO} = mcp\ (T_{fo} - T_O) - m\ T_O\ cp\ \ln(T_{fO}/T_O)$

$E_{XU} = A \times I_T \times (\ 1 - T_O/T_S)$

$\eta_{XC} = .31\%$