RESEARCH ARTICLE OPEN ACCESS

Experimental studies on PCM filled Flat Plate Solar Water Heater without and with Fresnel lens glazing

R. Sivakumar *, V. Varun Prabu**
**Mechanical Engg. Dept., Addis Ababa Science and Technology University, Addis Ababa, Ethiopia,*
***Jai Sai Ram Mech. And Tech. India Pvt. Ltd., Orissa,*

ABSTRACT
Flat Plate Solar Water Heater (FPSWH) is commonly used to harvest solar energy. Solar concentration techniques help to achieve higher temperatures of energy. The aim of this article is to compare the performance of a Fresnel lens glazed Flat Plate Solar Water Heater with Phase Change Material (PCM) with that provided with an ordinary glazing. The effect of solar concentration using Fresnel lens on energy storage in PCM and heat gained by water are studied and compared with that having an ordinary glazing. Experiments showed 47% improvements in the heat gained by water.
Keywords**:** Flat Plate Solar Water Heater, Fresnel lens, Phase Change Material, Solar Concentrator.

I. INTRODUCTION

Sun is the ultimate source of all forms of energy on earth. Harvesting solar energy for domestic and industrial uses is in practice for a long time. Solar energy is clean, non-polluting and freely available in nature with the only constraint that it is diurnal and seasonal. Several models of solar water heaters are available in market. Using Fresnel Lens in a Flat Plate Solar Water Heater (FPSWH) can concentrate the energy on to a small area and thereby enables achieving higher temperature.

A Fresnel lens is a cheap and light weight optical component. In a Fresnel lens, as much possible optical material is removed from the non-optical interface since the power of lens is available only in the optical interface. Focal length of the lens is the distance from the lens where the beam light converges to a point.

Udawant et al [1] studied the performance of a Fresnel Lens Solar Concentrator and reported that the overall efficiency of the Fresnel Lens solar concentrator is 51% and it has a good potential to generate low pressure steam.

Gaurav A. Madhugiri and S.R. Karale [2] reviewed the research works carried out on high concentration solar energy using Fresnel lens and reported that Fresnel lenses are conducive and have a breakthrough in commercial applications in near future.

Rajesh et al [3] evaluated the performance of a solar desalination system with a Fresnel Lens and reported that the performance improved with Fresnel lens concentration and a temperature of 64^{o}C was achieved in the water pre-heater tank.

Patil Divyesh Sakharam et al [4] studied a Solar Water Heater with Fresnel lens and two axis tracking system for design optimization, and reported that energy consumed by the electronic tracking system is very small when compared to the gain in energy achieved with tracking and using Fresnel lens.

Mohamed Salah Mahmoud et al [5] reported that losses due to radiation are more practically than those calculated theoretically for heating water.

W.T. Xie et al [6] reviewed the usage of Fresnel lens in concentrated Solar energy applications, and reported that Polymethylmetacrylate (PMMA) has good sunlight resistance and transmisivity. Non-Imaging Fresnel lens solar concentrators are suitable for collection of solar energy while imaging Fresnel lens solar concentrators reproduce the accurate image of the sun. Arumugam and Seeralan [7] experimentally studied the usage of Fresnel lens in Hybrid solar steam generators for desalination and small laundry system application. Radiation losses were reported to be more because of increased temperature due to energy concentration. Desalination yield depends on mass flow rate. Efficiency of the system was reported to be 25 % which could be further improved by additional condensation steps. Heat recovered was used for laundry system.

Valmiki et al [8] used a large Fresnel lens with sun tracking system for concentrating sunlight onto a solar cooker with a fixed heat receiving area. The stove top temperature achieved was about 300^{o}C. The system was easy to use and efficient.

Christina Sierra et al [9] studied the use of Fresnel lens for concentrating solar energy to achieve temperatures as high as 1500 to 2000 K for material treatment which could be completed in few minutes.

Y. Tripanagnostopoulos et al [10] studied the use of Fresnel lens for temperature control in buildings within comfort range and illumination.

Aadesh Rajkrishna [11] studied the performance of a conventional FPSWH by placing Fresnel lenses over a conventional glazing and reported an improvement of instantaneous efficiency by 20%. However comparison was not done simultaneously with two different models. Thermal analysis and cost analysis were done to show that the system designed was low cost and efficient. It was also recommended that Fresnel lens FPSWH can be used in places where solar radiation is low.

From literature review on usage of Fresnel lens in Solar Water Heaters, it is observed that different studies on usage of Fresnel lens to improve performance of water heating, desalination, cooking etc have been carried out. However comparison of Fresnel lens and ordinary glazing with same solar radiation input and ambient conditions was not observed. In this paper, the authors report the comparison of performance using Fresnel lens and an ordinary glazing in a FPSWH with PCM.

II. EXPERIMENTAL SET UP

Figure 1 shows the schematic diagram of the experimental setup used. The two FPSWH models are of dimensions 0.3 m x 0.3 m. Mild steel box of 0.14 m depth is inserted and fitted into a box of 0.16 m depth which is filled with 1 kg paraffin wax PCM in pellet form and serpentine water tubes immersed in PCM. The absorber box and absorber surface are completely painted black. The absorber box is provided with Styrofoam insulation of 0.02 m thickness and an outer wooden frame cover. Water is passed through the serpentine copper tube of ¾ inch inner diameter with a spacing of 0.03 m pitch. The whole assembly is kept inclined at an angle of 21^{o} to ensure circulation of water by natural convection.

The Fresnel lens used is made of 80% Si. It has a deformation temperature of 520^{o}C, annealing temperature of 560^{o}C, melting temperature of 820^{o}C, refractive index of 1.47, luminousity of 92%, elasticity modulus of 76 kNmm^{-2}, tensile strength of 40 to 120 Nmm^{-2}, processing temperature of 1220^{o}C, coefficient of linear expansion of 3.3 x 10^{-6} K^{-1} and level 1 water resistance.

PT100 thermal sensors were used to sense the temperature of absorber plate, paraffin wax, inlet and outlet water temperatures. Radiation sensor and RTD sensors were connected to a 16 channel data logger shown in Figure 4. Holes were drilled at suitable locations in the header tube to insert the RTD sensors to measure the inlet and outlet temperatures of flowing water. Experiments were conducted with both the models simultaneously on different days and results of data recorded on a particular day is presented.

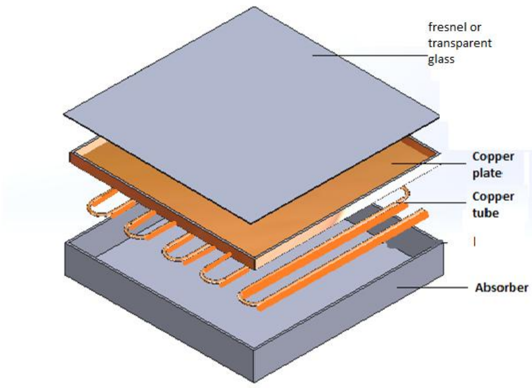

Figure 1 Schematic diagram of FPSWH

Figure 2 Photograph of FPSWH model with Fresnel lens glazing

Figure 3 Photograph of FPSWH model with ordinary glazing

Figure 4 Solarimeter and Universal data logger

III. RESULTS AND DISCUSSION

Figure 5 shows the variations in water temperature rise achieved with time by water circulated through the FPSWH models with Fresnel lens and that with ordinary glazing.

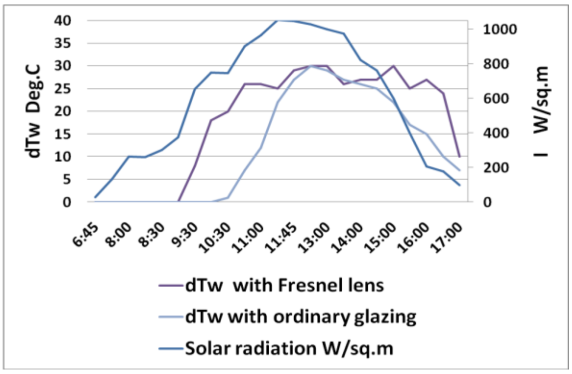

Figure 5 Variations in water temperature rise with time

Figure 6 shows the variations in wax temperature achieved with time in FPSWH models with Fresnel lens and that with ordinary glazing. It is observed that the model with Fresnel lens glazing achieved quick rise in wax temperature to it melting point and remains for a longer duration of time thereby acquiring latent heat of fusion and transferring more heat to water. The region where concentration of solar energy was more is observed to have quick melting of PCM. On the other hand, the model with ordinary glazing takes more time to reach its melting point and remains only for a shorter duration of time acquiring latent heat of fusion and hence less heat to water. The melting of PCM is observed to be slow and uniform. The average value of PCM recorded with Fresnel lens is 6^{o}C higher than that with ordinary glazing.

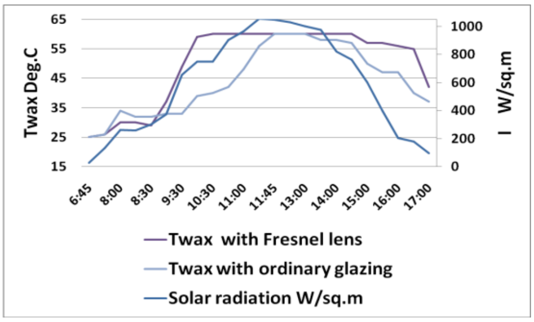

Figure 6 Variations in wax temperature with time

Figure 7 shows the variations in absorber surface temperature achieved with time in FPSWH models with Fresnel lens and that with ordinary glazing. The rise in absorber surface temperature is rapid because of solar energy concentration. Because of melting of Paraffin wax taking place at a constant temperature, the absorber temperature does not rise much beyond melting temperature. Maximum absorber temperature achieved sustains for a longer duration of time. On the other hand, the model with ordinary glazing takes more time to reach its maximum temperature. The maximum temperature achieved prolongs only for a short duration of time.

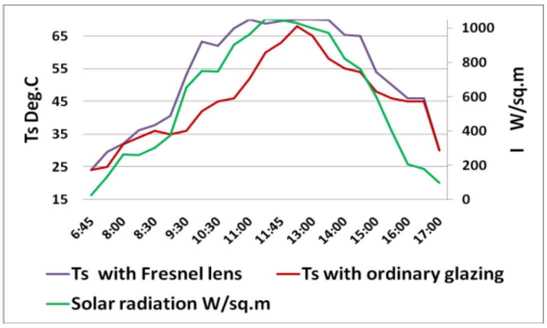

Figure 7 Variations in absorber surface temperature with time

Figure 8 shows the variations in Average Mean Temperature Difference in FPSWH models with Fresnel lens and that with ordinary glazing. The variation pattern is similar.

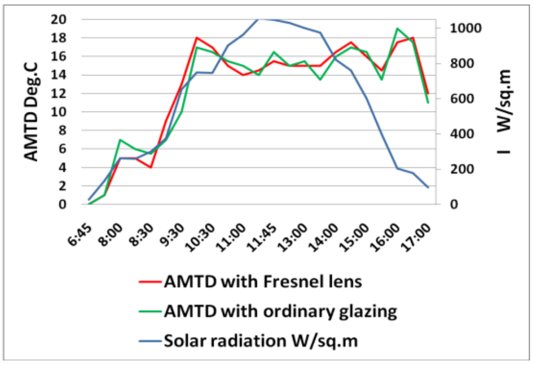

Figure 8 Variations in Average Mean Temperature Difference with time

IV. CONCLUSION

Latent heat storage type Flat Plate Solar Water Heater Models with Fresnel lens glazing and ordinary glazing were experimentally studied and compared. For same solar insolation on a given day, the model with Fresnel lens glazing showed maximum absorber temperature and sustained for longer duration of time than that with ordinary glazing. Similarly, maximum wax temperature was sustained for a longer duration of time than that with ordinary glazing. Heat gain by water is 47% more and average PCM temperature was 6^0C more in FPSWH using Fresnel lens glazing when compared to that with ordinary glazing.

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NOMENCLATURE

I	Solar Radiation	(Wm^{-2})
dTw	Water temperature rise	(^oC)
Tw	Wax temperature	(^oC)
Ts	Absorber Surface Temperature	(^oC)
AMTD	Average Mean Temperature Difference	(^oC)