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Thermal Stratification in Vertical Solar Water Heater Tank

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Abstract: The present paper deals with temperature distributions at different water levels inside the solar vertical storage tank and collector efficiency are analyzed with respect to transient behavior of vertical storage tank. The hot water zone, thermo cline zone and cold zone constitute the thermal stratification zones in the vertical tank that were investigated as part of the study on the 100 liters capacity Solar water heating system with vertical storage tank for the climatic conditions of Hubli **(**latitude 15.3° N). The parameters considered at various operating conditions include uniform hot water withdrawal and metered hot water withdrawal at specified time interval from storage tank. The experimental results indicted overall efficiency of 54 percent for the water withdrawal at a rate of 20 liters per hour and 60 percent for 30 liters per hour.

Key words: Thermal stratification, Collector efficiency, Water withdrawal.

1.0 INTRODUCTION

The present world is facing the huge energy crisis due to over-consumption, aging infrastructure which is a great bottleneck in the supply of energy resource to an economy. This is the time to switch ourselves to energy source which is inexhaustible in nature. Some of the renewable energy sources are wind energy, tidal energy, ocean thermal energy, solar energy. India strategically located in tropical region receives about 4-7 kWh/m^2 of average daily solar radiation for about 300 days a year that accounts to over 5,000 trillion kWh of energy. The fossil fuel (mainly coal) based power generation contributes 76 GW while renewable power inclusive of hydro-power comprises 48.6 GW indicates among all renewable energy source solar energy is the prominent one.

In last few decades solar hot water systems gaining more importance to meet domestic thermal energy demand of millions of households, due abundant availability of solar radiation and low maintenance. In solar water heating systems water is heated only during day time and stored thought night. Thermal stratification is a simple and economical way improving thermal efficiency of solar collector and maintaining temperature of hot water inside the tank. Maintaining thermal stratification is very crucial. It depends on geometry of hot water tank, inlet velocity of water, inlet temperature of water, the rate and amount of hot water withdrawal from the tank. The present study deals with effect of thermal stratification process on thermal efficiency of water heater at different amount of water withdrawal.

2.0 LITERATURE SURVEY

Several theoretical and experimental studies were reported on Thermal stratification process conventional hot tank, solar hot water tank in horizontal and vertical tanks. The relevant research studies of thermal stratification process are discussed in this section.

Ghajar et al., (1991) compared weighted upwind difference scheme and second order upstream difference scheme at different inlet geometries through numerical model. It was indicated that second order upstream difference scheme shows better results compared to weighted pwind difference scheme. The inlet geometry had negligible effect on thermal stratification process for Richardson number above 10 and had significant effect between 3.6 to 5.

Khorasanizadeh et al., (1993) analyzed the flow visualization in thermally stratified vertical tank constructed from Perspex. It was concluded that the momentum of the plume (buoyancy induced or resulting from inlet momentum) plays an important role in forcing the jet to the upper layers in the tank.

Shin et al., (2004) investigated the effect of design and operating parameters on the thermal stratification mechanism of a storage tank. The parameters like storage tank size, loading time, shape of diffuser, turbulence model and inlet velocity and the effects of flow recirculation and mixing by turbulence on thermal efficiency of storage tank were considered for the study to optimize the design. It was observed that large scale system had better storage performance than the small system, increase of loading time leads to decrease in degree of stratification due to the increased effect of heat transfer by convection and diffusion via thermal stratification region, curved diffusers exhibited better performance than flat diffusers and the effect of inlet velocity was negligible in thermal stratification if large- scale tank and it was significant in small scale tanks.

Madhlopa et al., (2006) experimented on integrated collector – storage solar water heater with two horizontal cylindrical tanks. The tests were conducted in three different operational modes viz: tanks are in parallel in series connections and cold water outlet of storage was connected with cold water inlet of lower tank, cold and hot water zones of lower and upper tanks were interconnected and out let of hot water from upper tank was connected with hot water inlet of storage tank. It was found that in first mode of operation during heat charging process there was no stratification in the upper tank but it was occurred in lower tank. However second modes and third modes exhibited satisfactory temperature stratification in both tanks during solar collection and hot water draw-offs. *David* (2007): investigated factors affecting thermal stratification process using CFD model. The results showed that thermal stratification was increases for H/D ratio of 3 to 4. The results were validated through experimentation.

Dr. G K Abdulsada el al., (2008) discussed degradation of heat in stratified thermocline liquid tank during relaxation periods for both cold and hot storage tanks through 1D transient model. The model was used to analyze the conduction and convection heat transfer process inside the tank. It was found that the walls of the container have a strong effect on destroy of thermocline and thermal stratification could be improved by increasing number of baffles and flattens. The initial temperature distribution plays a vital role in subsequent decay of stratification and when the system operated with 2 baffles showed optimum performance.

Dwivedi (2009) analyzed thermal behavior of solar resource and Solar Hot Water (SDHW) system and twin cylinder for the cold weather conditions. It was observed position of auxiliary heat plays important role in thermal stratification process along with other design parameters. The low flow SDHW configuration performs better in terms of building thermal stratification and enhances solar fraction utilization compared to twin cylinder configuration and it was easily modified in to single storage tank to attain thermal stratification inside the tank.

Rao et al.,(2010) studied heat transfer at the mantle wall and at the tank wall of mantle heat exchanger. The results showed heat transfer coefficient inside the tank was initially decreased up and steadily increased between 30 minutes and 150 minutes. It was concluded that, higher mantle fluid inlet temperature transfers more heat to the tank contents.

Karim (2011): developed stratified storage tank with for air conditioning systems. The factors affecting the performance of chilled-water storage tanks were considered for investigation. The results indicated that the increase in flow rate of water leads to decrease in storage efficiency due to increase in mixing of warm and chilled water in the stratified storage tank and by using proper load management techniques the thermal efficiency of stratified storage tanks can be increased up to 90 percent.

Rodríguez et al., (2012*)*: optimized the size of the domestic solar water heater for different ratio of volume. It was observed that the performance of solar water heating system was degraded for the tank to collector area (V/A) of less than 0.05m and 0.08 m. Hence it was concluded that V/A of 0.05 m was considered as optimum value for the design of hot water tank.

3.0 Experimental Set-up:

The experimental setup for studies on solar hot water system shown in figure 3.1a consists of collector along with a solar tank of 100 liters capacity used to heat the water used for daily purposes. The experimental set-up adequately equipped with the measurement of different parameters like solar insolation, water temperature inside the tank, inlet temperature, outlet temperature and also the tank wall temperature. The experiments were performed in passive mode from 10:00 to 16:00 hours recording hourly solar radiation, ambient temperature, water temperatures at different points and mass flow rate of water. The K type thermocouples were placed inside the solar tank at three different regions namely hot, thermocline and cold regions. In each region the thermocouples are placed at a distance of 5, 10 and 15 cm with an angel of 120^0 respectively. Figure 3.1b shows the model of placement of thermocouples inside the tank, which helped to study the variation of temperature along the horizontal plane as well as in three different regions for variable mass flow rates.

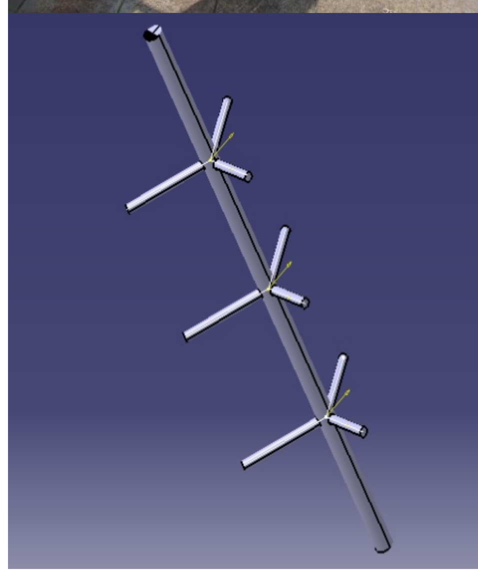

Fig. 3.1a: Pictorial view of Experimental set up
Fig 3.1b Position of thermocouples inside the tank

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4.0 Experimental Results:

The study of different parameters were done for two different mass flow rates of 20 kg/h and 30kg/h hence the obtained results are made known for two mass flow rates respectively.

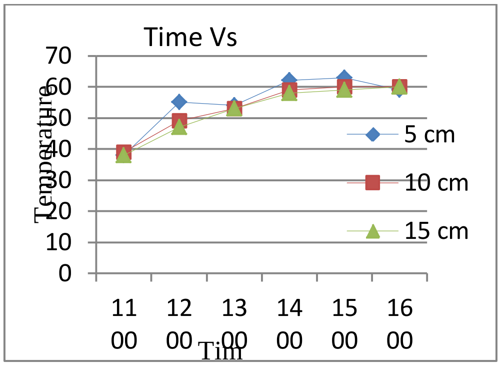

Fig 4.1 Variation of temperature along time(14 cm,20kg/h)

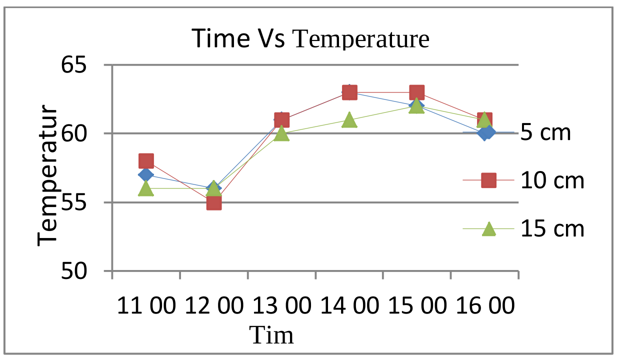

Fig 4.2 Variation of temperature along time(28 cm, 20kg/h)

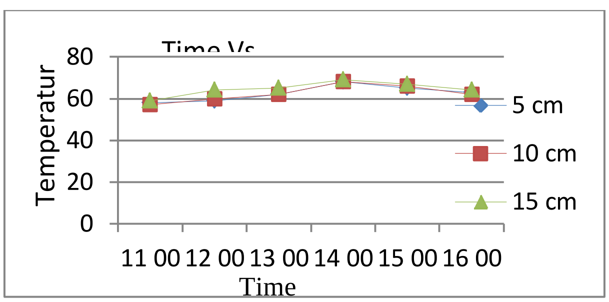

Fig 4.3 Variation of temperature along time (42 cm, 20kg/h)

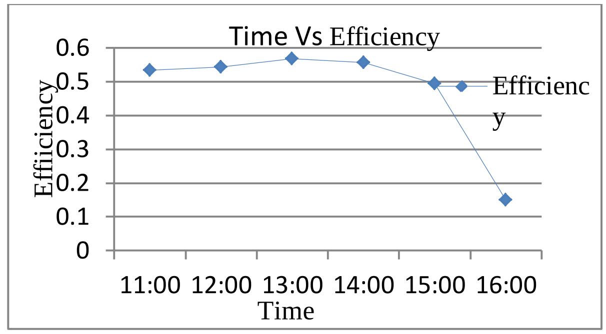

Fig 4.4 Deviation of efficieny along time(20kg/h)

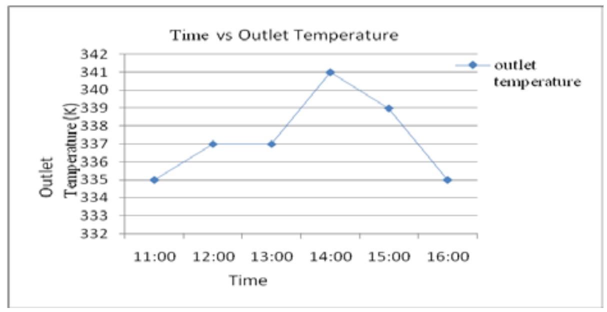

Fig 4.5 Deviation of outlet temperature along time (20kg/h)

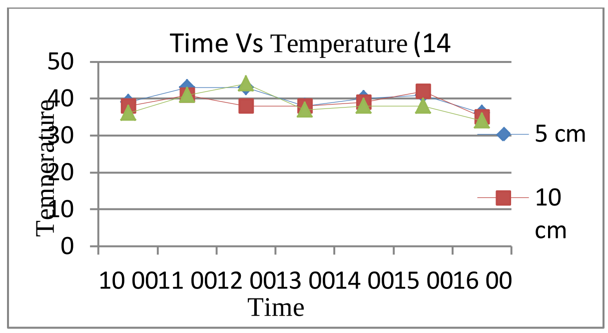

Fig 4.6 Variation of temperature along time(14 cm,30kg/h)

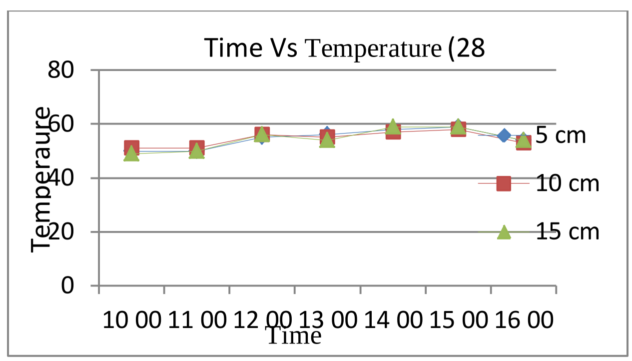

Fig 4.7 Variation of temperature along time(28 cm, 30kg/h)

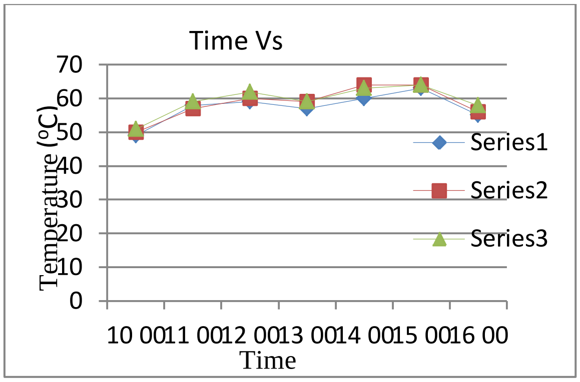

Fig 4.8 Variation of temperature along time (42 cm, 30kg/h)

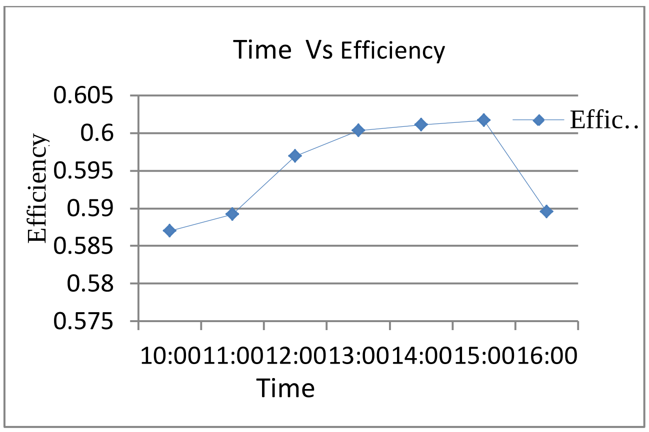

Fig 4.9 Deviation of efficiency along time(30kg/h)

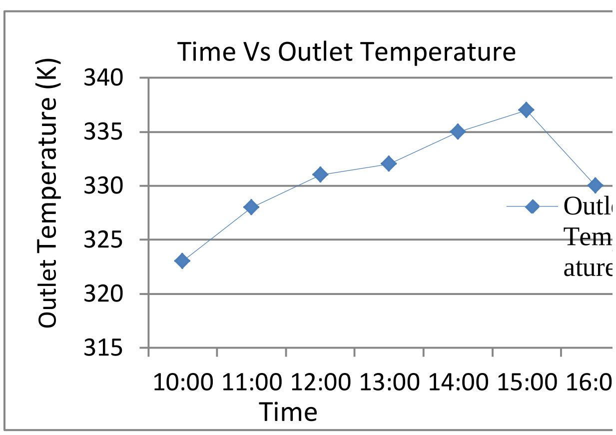

Fig 4.10 Deviation of outlet temperature along time(30kg/h)

The experiments were conducted to investigate the variation of the temperature inside the tank with different mass flow rates, also to study the variation of the thermocline region and the deviation of efficiency.For a mass flow rate of 20 kg/h the variation of the temperature in the tank at a distance of 14cm from base is represented in figure 4.1 which depicts that the temperature in that horizonatl plane varies radially along the distance from the centarl axis where the temperature at the distance of 5cm from the central axis is maximum throught the day similarly figure 4.2 shows the variation of temperature at a distance of 28cm from the base which shows that the temperature at a distance of 10 and 15cm from the central axis almost reached the same temperature where as the temperature at 5 cm from axis declined gradullay compared to the other two. Likewise figure 4.3 depicts the vatriation of temperature along time at a distance of 42cm from base where the temperature was higher at a distance of 15cm from base until 1300 hrs and later reached the same temperature as that of the other two. Figure 4.4 shows the deviation of the efficiency along the time where a maximum of 56% efficiency was reached at 1300 hrs and gradually decreased along the day. The efficiency was almost in steady state at a time interval from 1100 to 1300 hrs. Figure 4.5 represents the variation of the outlet temperature along time which shows that the highest temperature of 341^{o}K is reached at a time of 1400 hrs and then decreses.

As well in the same process the readings were noted and studied on next day for the mass flow rate of 30kg/h. The variation of the temperature at 14cm from base had a region of high temperature at 5 and 10cm when compared to that of 15cm distance from the axis which is depicted in figure 4.6. Similarly at 28cm from base all the three thermocouples almost had a same range of temperature as shown in figure 4.7. Where as in 42cm from base the highest temperature was reached in the 15cm distance from axis and the thermocouple at 5cm from axis had less temperature when compared to that of the others which can be seen in figure 4.8.The efficiency plot in figure 4.9 states that the highest efficiency of 60% is reached at 1500 hours and the highest outlet temperature of was reached during the same time as in figure 4.10.

CONCLUSION

The experiments were conducted at constant flow rate of water at 20kg/h and 30kg/h on consecutive days during testing time. At the flow rate of 20kg/h, the results indicate that at the initial stage of the temperature of water inside the solar tank is recorded as lowest average temperature as 38^{o}C at cold zone i.e. near the cold water inlet. The average temperature of 58^{o}C is recorded near the thermocline region and an average of 64^{o}C is measured at the hot zone. Similarly for mass flow rate of 30kg/h the average temperature of the water in the cold zone was recorded as 38^{o}C. The average temperature of 57^{o}C near the thermocline region and average of 62^{o}C was reached at hot water zone. The highest thermal efficiency of collector was reported as 60 percent for the mass flow rate of 30 kg/hr.

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