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Integrated with Solar Flat Plate Collector

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Abstract

Thermal stratification of water occurs in a storage tank when cold water with high density accumulates at the lowest part of the tank, and less dense hot water rises to the top due to gravity effect. As water heats and cools, it expands and contracts leading to a change in its density. Each layer of water in the tank is stacked above or below the others with the hottest water on top and the coldest water at the bottom. It is important to study the temperature distribution in hot water tanks in order to identify the factors which enhance or decline stratification within the tank. By enhancing the thermal stratification, hot water at a temperature suitable for domestic usage can be provided. Some of the factors that determine the rate at which cooling of hot water occurs in a storage tank is the volume of the tank, the time that is waited before the discharging of water takes place after heating, the quantity of hot water being drawn for consumption and the initial the cold water temperature that charges in through the bottom of the tank. This project investigates the effect of solar Flat Plate Collector on the temperature distribution in a thermos-cline tank. An experimental set up is prepared in order to study the thermal distribution in the tank.

Keywords:*Stratification, Thermal Energy Storage Tank, Solar Flat Plate collectors.*

1. Introduction

Thermal energy storage system is essential part of solar energy application because of its nature of intermittent radiations. Also, when there is no load condition, excess amount of energy generated by system must be stored. In that case storage is required to increase the efficiency and capacity of the system.. Thermal energy storage systems (TES) play a crucial part in the success of concentrated solar power as reliable thermal energy storage. Using stratified tanks is one of the well-known methods to store the solar thermal energy. The stratified thermal energy storage tanks play vital role in increasing the efficiency. Those are beneficial in following ways:

1. Stratified tanks increase utilization of collectors
2. Heat loss from the equipment is reduced when stratified tanks are used
3. Less lime scaling
4. Smaller tank is needed
5. Only one tank is required to store both hot and cold water

TES will enable the plant to run throughout the evening and it increases its production rate. The objectives of such systems are to store solar heat collected in summer for space heating in winter. These systems contribute significantly to improve the energy efficiency. Developing efficient and low cost energy storage devices is as essential as developing new sources of energy.

Thermal energy storage (TES) systems include numerous technologies. Thermal energy can be stored at temperature range starting from -40°C to 400°C as sensible heat, latent heat and chemical energy (i.e. energy storage by using thermo-chemical) using chemical reactions. Thermal energy storage in the form of sensible heat is based on the specific heat of a storage medium. The storage medium is usually kept in storage tanks and the tanks are highly thermal insulated. The most popular and commercial heat storage medium is water, which has a number of residential and industrial applications. Therefore it is most important to study the thermal energy storage system which uses water as a working fluid and increase the efficiency of such systems. Stratified thermal energy storage tank is one of the effective way to store solar thermal energy. The efficiency of stratified tank depends on the thickness of the thermocline layer present in the tank. Lesser the thickness of the layer, higher is the efficiency of the tank. Therefore it is important to investigate the temperature distribution in the thermocline tank so that efficiency of the tank and result of stratification can be studied.

This paper investigates the temperature distribution in a thermocline storage tank which is integrated with solar flat plate collectors. Also, it presents a review of thermal energy storage system and methodologies with the parameters to be considered at different levels in order to study the temperature distribution in thermocline tank. Thermal energy storage casts a vital component of any solar system for betterment of its dispatch ability. Though there are many reviews of storage media, there are not many which focus on storage system design along with thermocline/ stratified tank and the temperature distribution in it.

The experimental set up is made to study the thermocline temperature distribution in the tank when integrated with a solar flat plate collector. The temperature distribution is studied against the parameters listed below:

1. Charging characteristics: Time required to charge the tank and maximum temperature reached
2. Heat retention: heat retention over the period of 14 hours. (Evening 6pm to morning8 am)
3. Effect of fluid flow rate on simultaneous charging and discharging behavior: it has been proven that, low flow rate gives maximum thermocline effect. But low flow rate leads to high charging time of the tank hence we have to determine optimum flow rate in order to find best suitable situation.

2. Literature Survey

Thermal stratification occurs within a TES tanks as a result of temperature gradients and buoyancy effects during charging (as the temperature of water increases, the density of the fluid decreases, causing hot water to rise to the top of a TES tank while cold water falls to the bottom). This effect produces regions of hot and cold water (i.e., thermal layers), separated by a temperature gradient commonly referred to as a thermocline. Three storage tanks are shown in Fig. 1.1 which shows different levels of stratification. Figure 1.1(a) is representative of a highly stratified storage tank, due to its large temperature gradient (dT/dx) and small thermocline. Figure 1.1(b) is representative of a moderately stratified storage tank, due to its smaller temperature gradient and larger thermocline. Finally, Fig. 1.1(c) illustrates a fully mixed tank with uniform temperature, and experiences no stratification:

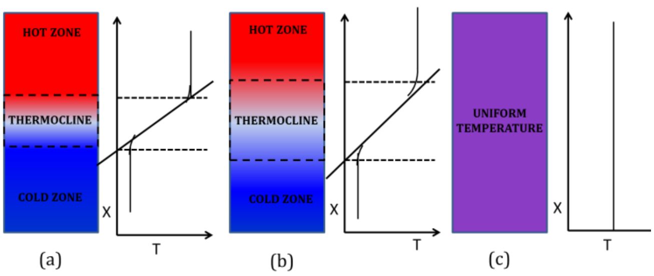


Fig. 1.1 varying stratification levels within a storage tank for cases of (a) highly stratified storage; (b) moderately stratified storage; and (c) fully mixed or un-stratified storage.

Tambrallimath and Shekhar K, in their paper, Thermal Stratification in Vertical Solar Water Heater Tank, ISSN 2348 – 7968, May-2014[1],discussed the thermocline storage tank integrated with flat plate collector. They have used 2m²areas of collector for 100 lit capacity tanks. Which shows that for around 100 to 150 lit tank, 2m²FPC area is enough to heat up the water at required temperature. Apart from this, the conclusion of the paper is keeping the storage tank vertical compared to horizontal placement gives better stratification. Which means, greater is the H/D ratio, good is the stratification.

C. Cristofari, G. Notton, P. Poggi, A. Louche in their paper, Influence of the flow rate and the tank stratification degree on the performances of a solar flat-plate collector, 8 July 2002[2] discussed the influence of flow rate on the stratification of the tank. In this experiment, single plat plate collector of area 2m² is connected to the thermocline storage tank. Different flow rates are studied and optimized flow rate is decided. The stratifier is used in the tank to achieve stratification.

NesreenGhaddar in Stratified storage tank influence on performance of solar water heating system tested in Beirut, Nov1994 paper,[3] discussed parameters to design thermocline tank inlet geometry. This inlet geometry is then validated in CFD analysis and experimental study is also carried out and results are plotted.

There are many papers available which study the parameters regarding design of the thermocline tank. But very few papers are available in which the tank is integrated with solar system and parameters like flow rate, heat retention, simultaneous charging discharging behavior, temperature distribution in the tank with day time variation, peak temperature achieved with solar radiation at particular place etc. are studied and experimental results are plotted. Therefore in this paper, these parameters are studied.

APPLICATIONS OF STRATIFIED THERMAL STORAGE TANK:

1. The Space Heating System

The collector and storage components are coupled with a heat exchanger, circulating pump, and auxiliary heat source to form the space heating system (Fig.1.2) the heating load to be supplied either by solar or auxiliary or by combination of two. In fig 1.2, the auxiliary heating source is boiler

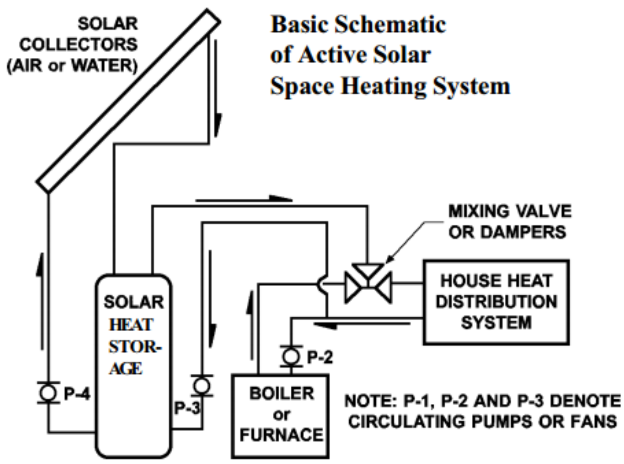


Fig 1.2 – Space heating Schematic with solar and auxiliary heating source

2. Solar domestic hot water systems

Many countries are promoting use of solar energy and usage of this technology for domestic water heating is implemented. The technology is grown a lot and has been made commercially available in numerous countries for more than 30 years. Typical solar domestic hot water systems used for many apartments, buildings or single houses homes in India has hot water storage with volumes of approximately 300-500 liter. A collector area between 4-6 m2 and can supply 60-90% of the annual hot water demand based on the type of collector being used and local solar radiation conditions. In sunny days/summer, thermo-syphon systems are widely used with a collector area of around 2-4 m^2 and a 100-300 liter storage tank.

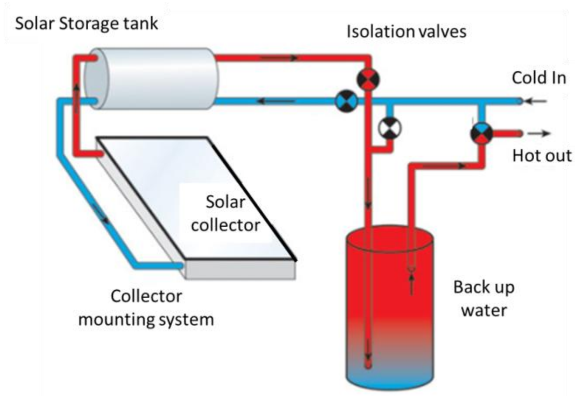


Fig. 1.3 –Typical solar water heater system for domestic use

3. Solar water heater in Dairy Industry

Dairy Industry is are really very fast growing industries these days. Similarly food industry is also growing rapidly. Every day, they are introducing advanced technologies to get better food quality in such industries. Solar energy usage has great scope for its commercial use in the dairy processing operations. Solar heaters and eventually Solar thermal can be applied in milk cooked meats (sausage and salami) and brewery industries at medium temperature for washing, cleaning, sterilizing, pasteurizing, drying, cooking, hydrolyzing, distillation, evaporation, and extraction.

4. Textile Industry

Bleaching application in textile industry requires temperature range of 60-80° C. Bleaching is a process of removing pigmentation, natural dyes etc. that are there in fibers and give sort of coloration. This process can be carried out in single way or in combination with other treatments. There is strong correlation between water and energy use in this industry, since a high proportion of the energy is used for heating water that is used to wash the fabric. Therefore by reducing the water consumption of bleach range significant savings in energy can also be observed.

5. Pharmaceutical Industry

Pharmaceutical industries need 60-90° C hot water for sterilization of different instruments. Hot water is the most commonly used as a substance, raw material or starting material in the production, processing and formulation of pharmaceutical products. Water has unique chemical properties because of its polarity and hydrogen bonds. This means it is able to dissolve, absorb, adsorb or suspend many compounds. Different degree of water quality are required depending on the purpose of use needed for the administration of the pharmaceutical products. Solar water heaters play an important role when used effectively for the hot water usage in pharmaceutical industries.

3. Experimental Set –up and Methodology

Asstated earlier, this paper investigates the temperature distribution in thermocline tank integrated with solar flat plate collector.

Charging Loop:

1. Storage tank is initially filled with cold water completely.
2. Flat plate collectors of 2m2 area are chosen and collected in series
3. The hot water outlet of the second flat plate collector is connected to stratified storage tank
4. Simultaneously the cold water from the bottom of the tank is supplied to the inlet of the first flat plate collector.
5. Fig. 2.1 shows the experimental setup block diagram created for the study
6. A pump is provided to suck the hot water from second flat plate collector which is then supplied to the tank Hot water inlet
7. Hot water is so charged in the tank that it will form thermocline layer in the tank and hot and cold fluids remain separated

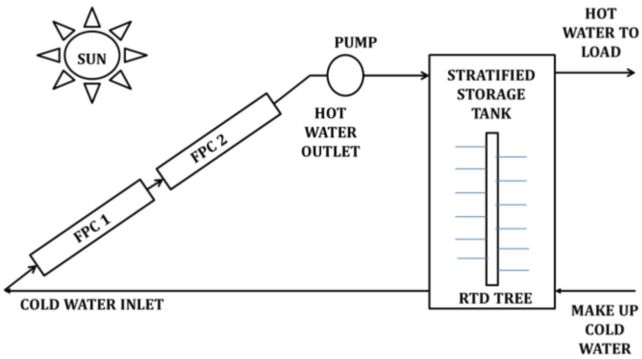


Fig. 2.1 –Block diagram of the experimental setup created

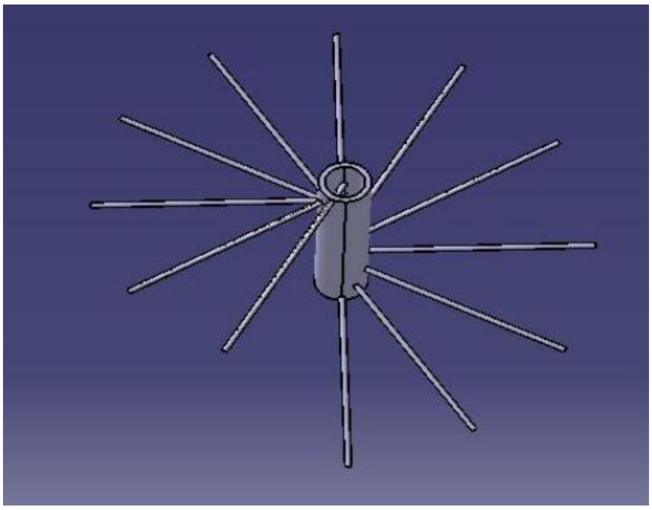


Fig. 2.2 –RTD tree model

Fig. 2.3 – Thermocline storage tank

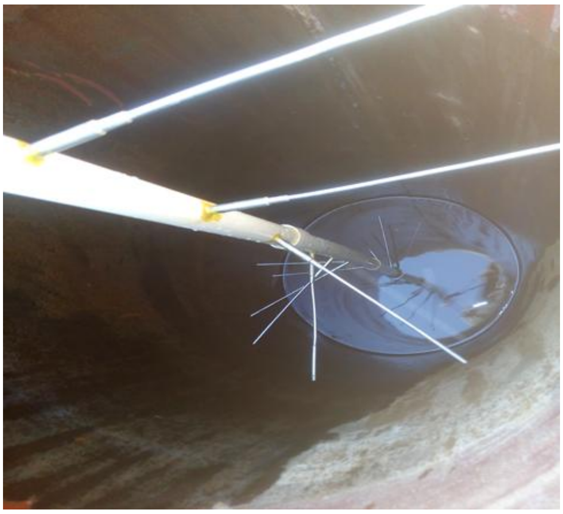


Fig. 2.4 –RTD tree in the tank

Fig. 2.5 –flat plate collectors used

8. Then this hot water can be supplied to load and cold water again charged in the tank at the bottom inlet. That extra cold water is called as make up water which would be added in case of loss. And this is how charging of the tank takes place

In this paper the parameters studied are,

1. Total time required to charge tank completely. (charging time)
2. Heat retention capacity of the tank over the span of 14 hours (evening 6pm to morning 8am.)
3. Optimum flow rate at which tank is charged for simultaneous charge –discharge operation.

Through this experiment, above said phenomenon is studied and readings are taken. There are total 12 RTDs are mounted in the tank at different height. These RTDs record temperature of the water inside the tank at certain height. Which is thendisplayed on the device called temperature indicator. The readings are taken and graphs are plotted accordingly. A valve is mounted there at the hot water inlet of the tank to monitor the low rate. Second set of readings are taken by varying flow rate.

4. Experimental Set-up and Graphs

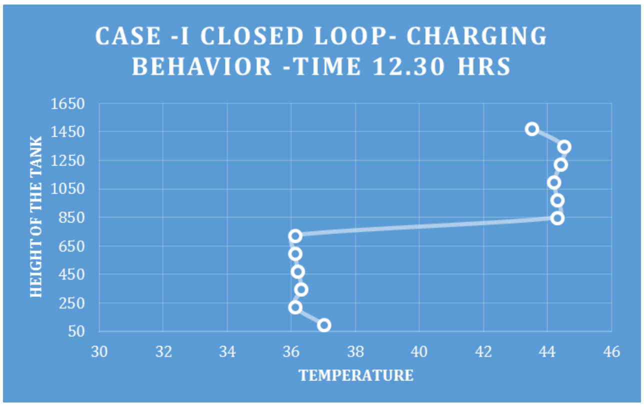
Case-1:- Height of the tank versus temperature-

In first case, the temperature distribution in the tank is studied. The closed loop charging circuit is kept operation for 1 hour and the readings are taken

Tank charged: **-50%**
Time at which readings are taken – **12.30pm**
Time required for charging 50% of the tank**- 1 hour**
Maximum temperature observed in 1 hour**- 44.5°C**
Initial temperature of water**- 30°C**
Operating hours – **1 hour (11.30 Hrs. to 12.30 Hrs.)**
Operating style –**Closed loop**
Minimum temperature of fluid in the tank **– 36°C**

Table-1. Readings for Case-I

Time	RTD No.	Temp	Height
12.30 Hrs	1	43.5	1475
	2	44.5	1350
	3	44.4	1225
	4	44.2	1100
	5	44.3	975
	6	44.3	850
	7	36.1	725
	8	36.1	600
	9	36.2	475
	10	36.3	350
	11	36.1	225
	12	37	100



Graph -1. - Temperature distribution in tank

OBSERVATIONS:

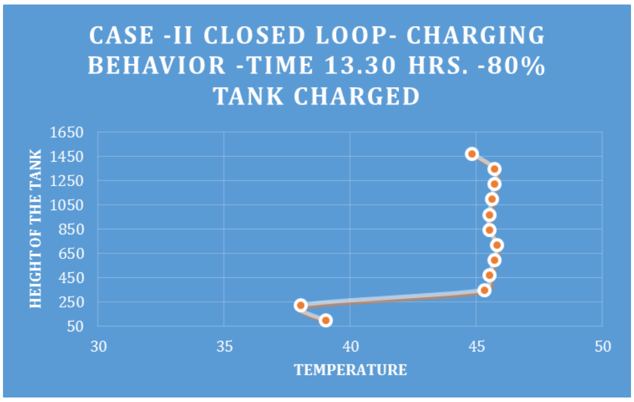
1. Well-developed thermocline region is observed in the tank between RTD 6 and 7
2. Initial time required to charge 50% of the tank is 1 hour and it is observed that, once it starts charging after some time, the time required to charge the tank reduces. Eg-1 hour is required to charge 50% of the tank, rest of the tank can be charged in less than 1 hour.

Case II: - Flow rate versus Time required for charging 80% of the tank

Flow rate- **25% valve open**
Tank charged- **80%**
Time required **-40 min (from 50% charged to 80% charged tank)**
Operating hours **- 1hour 40min.**
Operating style-**Closed loop**
Minimum temperature of fluid in the tank-**38°C**

Table 2- Readings for Case II

Time	RTD No.	Temp	Height
13.30 Hrs	1	44.8	1475
	2	45.7	1350
	3	45.7	1225
	4	45.6	1100
	5	45.5	975
	6	45.5	850
	7	45.8	725
	8	45.7	600
	9	45.5	475
	10	45.3	350
	11	38	225
	12	39	100



Graph -2. - 80% charged tank with 25% valve open

OBSERVATIONS:

1. Time required to charge 80% of tank is 1 hour 40 min.
2. By varying flow rate, this charging time is studied. Also it is observed that when there is low flow rate, maximum high temperature can be achieved.
3. Optimum flow rate can be decided in order to achieve optimum temperature and flow rate

Conclusion

Connecting two solar flat plate collectors in series gives maximum temperature of 57oC at 15.30hours. Hot water of 57oC is collected in stratified tank of 300lit capacity. The tank shows good stratification behavior when readings are taken. In first case, Well-developed thermocline region is observed in the tank between RTD 6 and 7 Initial time required to charge 50% of the tank is 1 hour and it is observed that, once it starts charging after some time, the time required to charge the tank reduces. Eg-1 hour is required to charge 50% of the tank, rest of the tank can be charged in less than 1 hour. Case II is studies by varying flow rate and it is observed that, time required to charge 80% of tank is 1 hour 40 min. By varying flow rate, this charging time is studied. Also it is observed that when there is low flow rate, maximum high temperature can be achieved. Optimum flow rate can be decided in order to achieve optimum temperature and flow rate hence it can be concluded that, use of stratified tank provides more hot water than mixed tank as stratification does not allow waters to get mixed and energy loss can be restricted. This is studied and results are plotted.

References

[1] Tambrallimath and Shekhar K,(May-2014), Thermal Stratification in Vertical Solar Water Heater Tank, ISSN 2348 – 7968, May-2014

[2] C. Cristofari, G. Notton, P.Poggi,(2002) A. Louche Influence of the flow rate and the tank stratification degree on the performances of a solar flat-plate collector, 8 July 2002

[3] NesreenGhaddar, (1994) Stratified storage tank influence on performance of solar water heating system tested in Beirut, Nov1994

[4] Abodoly M. and Rapp D., (1982) “Theoretical and experiment studies of stratified thermocline storage of hot water”, Energy Conversion, Vol. 51, 275-285

[5] Han Y. ,Wang R. and Dai Y.(2009) , “Thermal stratification within the water tank”,Renewable and Sustainable En-ergy Reviews, Vol. 13,1014-1026.

[6] Lavan Z. and Thompson J.,(1977) “Experimental study of thermally stratified hot water storage tanks.”,solar en-ergy, Vol. 19,519-524.

[7] Zurighat Y.,Liche P. and Ghajar A.(1991) Influence of in-let geometry on mixing in thermocline thermal energy storage. Heat and mass transfer 34 , 115-134.

[8] ZurighatY. ,GhajarA.andMoretti P. (1988) Stratified Ther-mal Storage Tank Inlet Mixing Characterization. Ap-plied energy, vol.30 , 99-111

[9] Shah L.,Furbo S.,(2003) Entrance effect in solar storage tank, Solar energy, vol.75 , 337-348,

[10] Yang Z. Chen H.,WangL.,shengY.and Wang Y.(2015) , Com-parative study of the influences of different water tank shapes on thermal energy storage capacity and thermal stratification Renewable energy , vol.31 , 31-44