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Entropy and Exergy Analysis of Thermo cline Zone in the Solar Domestic Hot Water Storage Tank

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Abstract **--An Analytical analysis of entropy and exegry in the SDHW storage tank is studied. In the stratified solar domestic hot water (SDHW) storage tank there are three zones of water temperature. Due to buoyancy effect and highly stratification of water, hot water remains at the top of the tank, which is known as hot water zone. Cold water remains at the bottom of the tank, known as cold water zone. In between hot and cold water zone, the water temperature diffusion starts, which is called as thermocline zone. An imaginary initial partition line considered in between hot and cold zone known as thermocline line. The temperature in this thermocline line is calculated and the entropy generation in hot and cold zone. The heat diffusion starts from that imaginary line. Over a period of time the heat diffusing zone that is thermocline zone increases and heat gradient occurs. From the hot water entropy decreases while entropy increases in the cold water.**

Keywords: SDHW, entropy, exergy, thermal stratification, thermocline

1. Introduction

To store thermal energy in the storage tank using Sun heat and light is having greater potential at free of cost. The tank contained hot and cold water for energy storage and heating process should be thermally stratified enough.

Ideally hot water should maintain a constant hot water temperature at the top of the tank for a particular volume without mixing with the cold water.

Cold water will remain at the bottom of the tank for a particular volume without receiving temperature from the top stored hot water. The reason to maintain cold water at the bottom of the tank is to supply cold water to the solar collector where the cold atmospheric water should convert into hot water and to be supplied for storage at the top or top side of the tank for better stratification and storing hot thermal energy without loss of heat and temperature. But ideally we cannot maintain such thermal stratification without using any barrier in between hot and cold water. Always more heat diffusion and mixing occur from the partition of the hot and cold water level. Theoretically we can assume initially there is one partition line in between hot and cold water zone which is known as thermocline line. Heat diffusion starts from that line and a thermocline stiff thickness zone occurs with average gradient water temperature. We cannot avoid it. Only we can study the growth of thermocline thickness. As there is heat diffusion from the imaginary thermocline line so there is entropy decrease from the hot water and entropy increase to the cold water takes place. In this analytical investigation a solar domestic hot water storage tank is used to store thermal energy. A schematic diagram of SDHW storage tank is as shown in the Fig.1.

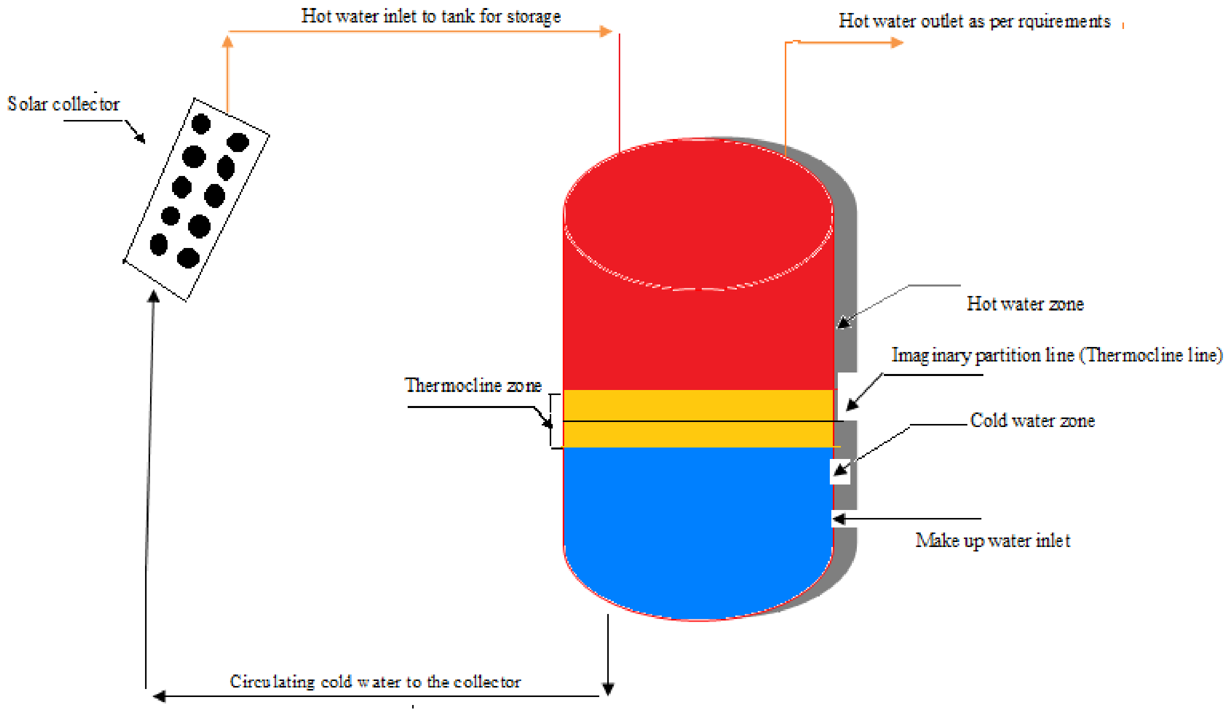

Fig.1: Schematic diagram of SDHW system without using heat exchanger.

Nomenclatures

SDHW : Solar domestic hot water

mwh : Mass of hot water

mwc : Mass of cold water

Symbols

t1 : Hot water temperature in the system 1

t2 : Cold water temperature in the system 2

m1 : Mass of water in the system 1

m2 : Mass of water in the system 2

c1 : Specific heat of water in the system 1

c2 : Specific heat of water in the system 2

tth : Partition thermocline temperature.

Sg1 : Entropy generation in the system 1

Sg2 : Entropy generation in the system 2

ΔSthg : Entropy generation in the thermocline zone.

ΔS : Entropy generation in the whole system

Xd1 : Exergy destroyed in the system 1

Xd2 : Exergy destroyed in the system 2

Xdes. : Exergy destroyed in the whole system.

2. Problem definition

The considered problem is of SDHW storage tank. The tank is vertical tank having dimensions of 360mm diameter and 1200mm height. It can store 122kgs of water. Initially top half portion of the tank is having hot water and bottom half of the tank is having normal atmospheric water. In between hot and cold water region one partition line is considered which is called as thermocline line. This thermocline line average temperature should be calculated using mass balance in between hot and cold water region. Also entropy generation and exergy destruction in the hot and cold water region should be calculated. Total entropy and exergy of the tank should be calculated. The calculations should be carried out by varying the hot water temperature from 40°C to 85°C at an interval of 5°C variations, while tank bottom water temperature considered as 25°C which is atmospheric temperature. For calculations the initial mass of hot water and cold atmospheric water is considered as equal which is taken as 61kgs (mwh=mwc=61kgs).
The walls of the tank are assumed as adiabatic walls and the tank inside system is isolated system. It has been explained with the schematic diagram as shown in Fig.2.

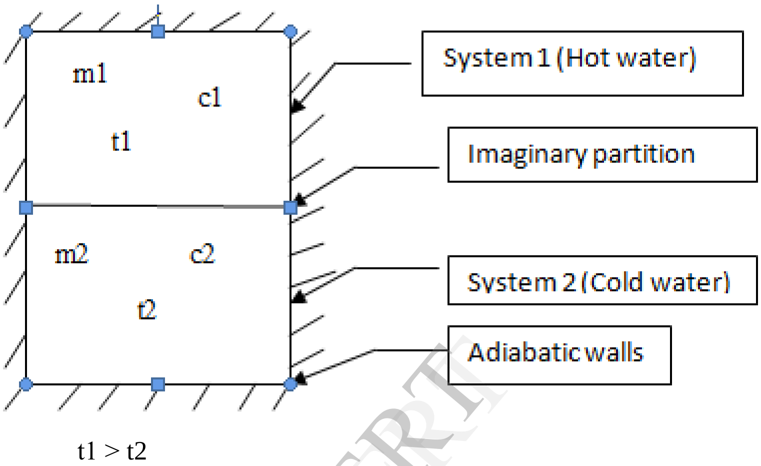

Fig. 2: schematic diagram of problem definition of SDHW storage tank.

Case 01

The tank water temperatures are divided into two parts. In between two different temperatures one imaginary partition is considered at the centre of the tank. Above the partition the temperature of water system1 is considered as 40°C which is hot and the temperature of water in the system 2 is considered as atmospheric temperature 25°C.

Case 02

System 1 temperature = 45°C and
System 2 temperature = 25°C.

Case 03

System 1 temperature = 50°C and
System 2 temperature = 25°C.

Case 04

System 1 temperature = 55°C and
System 2 temperature = 25°C.

Case 05

System 1 temperature = 60°C and
System 2 temperature = 25°C.

Case 06

System 1 temperature = 65°C and
System 2 temperature = 25°C.

Case 07

System 1 temperature = 70°C and
System 2 temperature = 25°C.

Case 08

System 1 temperature = 75°C and
System 2 temperature = 25°C.

Case 09

System 1 temperature = 80°C and
System 2 temperature = 25°C.

Case 10

System 1 temperature = 85°C and
System 2 temperature = 25°C.

Case 11

System 1 temperature = 90°C and
System 2 temperature = 25°C.

Case 12
System 1 temperature = 95°C and
System 2 temperature = 25°C.

3. Analytical Mathematical analysis

The basic equations of mass balance, entropy balance and exergy balance equations are used to analyze the problem mathematically and to investigate entropy and exergy in the partition thermocline line. The system 1 is having hot water of mass m1, specific heat c1 and t1 and system 2 consisting of cold fluid of mass m2, specific heat c2 and temperature t2, comprising a composite system in an adiabatic system. The temperatures, t1 is greater than t2 (t1 > t2). The two fluids, water starts mixing from the imaginary partition line and forms equilibrium temperature in the thermocline zone let assumed equilibrium thermocline temperature as tth.

3.1 Partition temperature calculations

Energy interaction is exclusively in the confined space of the tank which is a isolated system.
Therefore by applying mass balance equation in between system 1 and system 2 as,
By applying Mass balance principle,

$$m_1 c_1 (t_1 - t_{th}) = m_2 c_2 (t_{th} - t_2)$$

$$t_{th} = (m_1 c_1 t_1 + m_2 c_2 t_2) / (m_1 c_1 + m_2 c_2)$$

Since partition thermocline considered at the centre of the tank,

Therefore, $m_1 = m_2 = m$ and assuming $c = c_1 = c_2$,
Then, $t_{th.} = t_1 + t_2 /2$

3.2 Entropy and exergy balance

By applying Entropy balance principle,

The entropy generation in the system 1 is,

$$S_{g1} = m_1 c_1 \ln (t_{th}/t_1)$$

Therefore exergy destroyed in system 1 is,

$$X_{des.\ 1} = t_o \cdot S_{g1}$$

The entropy generation in the system 2 is,

$$S_{g2} = m_2 c_2 \ln (t_{th}/t_2)$$

Exergy destroyed in the system 2 is,

$$X_{des.\ 2} = t_o \cdot S_{g2}$$

Entropy generation in the thermocline zone is

$$\Delta S_{thg} = S_{g1} + S_{g2}$$

$$= m_1 c_1 \ln (t_{th}/t_1) + m_2 c_2 \ln (t_{th}/t_2)$$

When $m_1 = m_2 = m$ and $c_1 = c_2 = c$ at full mixing condition then,

$$\Delta S \text{ generation system} = m\, c \ln t_{th}^2 / t_1 . t_2$$

$$X_d \text{ system} = t_o \cdot \Delta S$$

4. Results and discussions

From the hot water zone the thermal energy is being transferred to the cold water zone. Due to this the entropy from the hot water zone decreases and the entropy in the cold water zone rises as entropy is the function of heat. Hot water is having more heat and temperature which in turn transferred to the cold water zone by conduction thermal diffusion in between hot and cold water zone starting from the imaginary separation layer of thermocline layer. Also exergy which is the function of temperature and entropy destroys from the hot water zone. For different hot water temperature calculated entropy values are plotted in the graph which is shown in Fig.03.

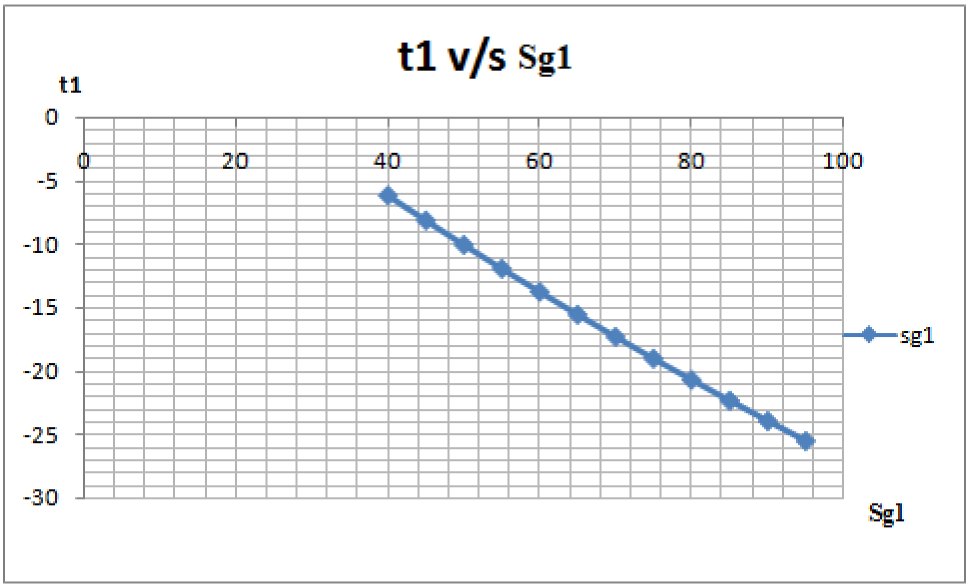

Fig.03: System 1 temperature v/s entropy

The constant cold atmospheric water temperature versus the entropy rise is plotted and shown in the Fig. 04. Considering exergy values of system 1 hot water versus hot water temperature is recorded in the graph as shown in Fig. 05. While the Fig.06 represents how the energy is getting received in the system 2 and energy increases. In case hot water both entropy and exergy line comes down in the graph as entropy reduces and exergy destroys. While in the system 2 cold water zone the graph rises as in heat transfer cold water receives energy from hot water that is from system 01.

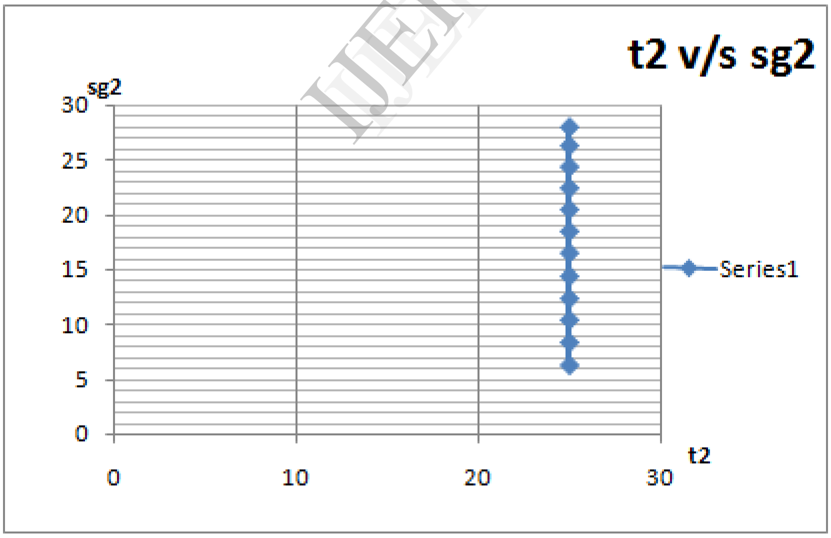

Fig. 04: System 2 temperature v/s entropy.

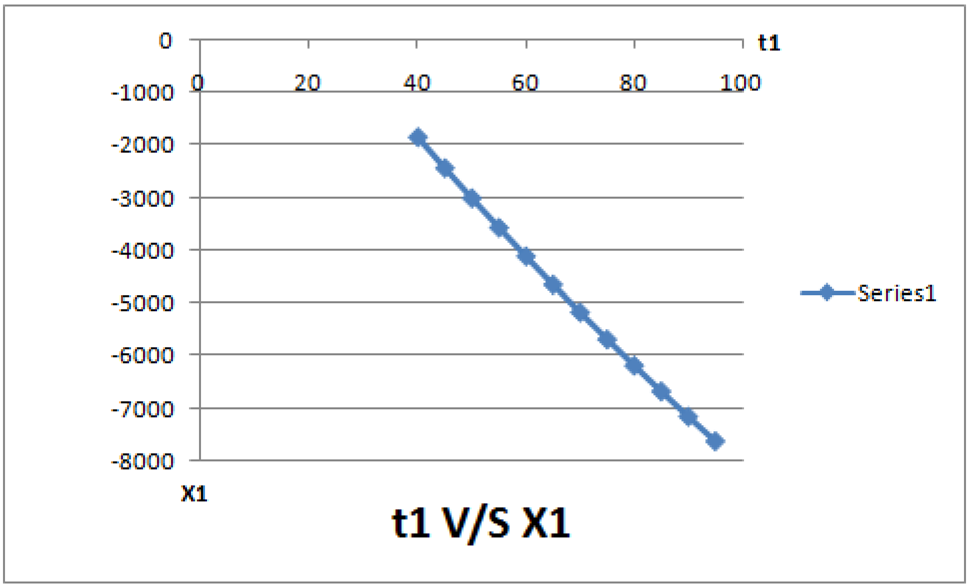

Fig.05: System 1 temperature v/s exergy destroyed.

It is observed that both entropy and exergy reduces from the hot water zone for different hot water temperature calculations starting from hot water temperature 40°C to 95°C. Thermal energy storage tank especially SDHW storage tank is to store constant hot water temperature for a longer period of time. But from the partition zone of hot and cold water the entropy and exergy transformation starts.

If the transformation of energy is not restricted then over a period of time when there is no supply of hot water in the SDHW storage tank especially during evening or night time or cloudy and rainy days the tank water temperature becomes in equilibrium temperature. At this equilibrium temperature the entropy and exergy is calculated and plotted in the graph which is shown in the Fig. 07 and Fig. 08 respectively.

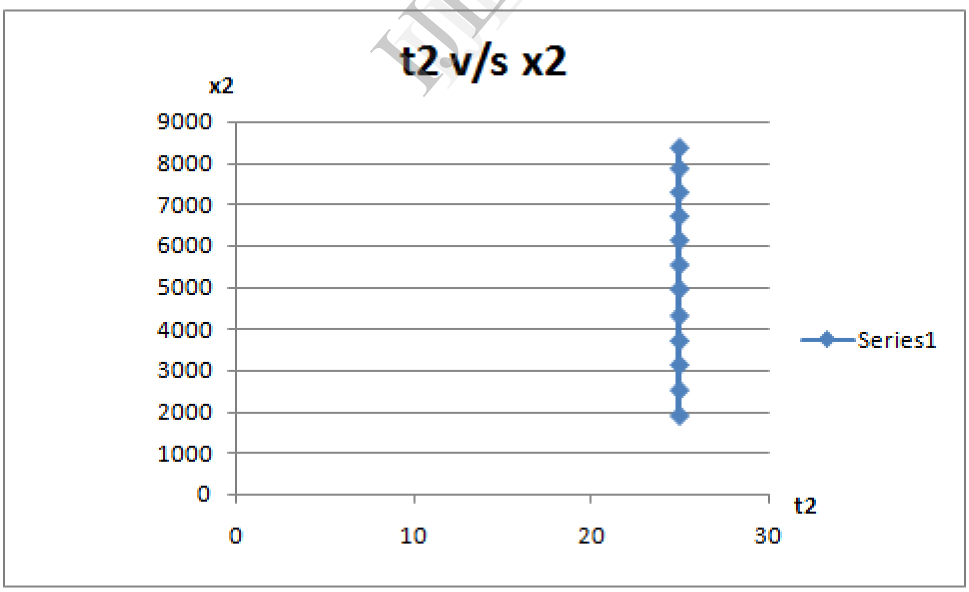

Fig. 06: system 2 temperature v/s exergy.

It is advisable to have a barrier partition in between hot and cold water zone as the energy destroys. Even the energy is being stored at a higher temperature then to energy destroy takes place and that energy destroy takes place at a higher rate than the lower hot water temperatures.

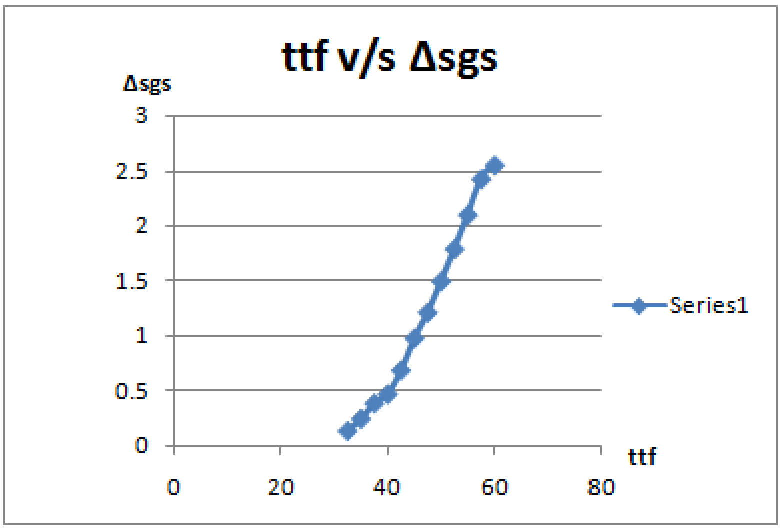

Fig. 07: System mixing average temperature v/s entropy plot.

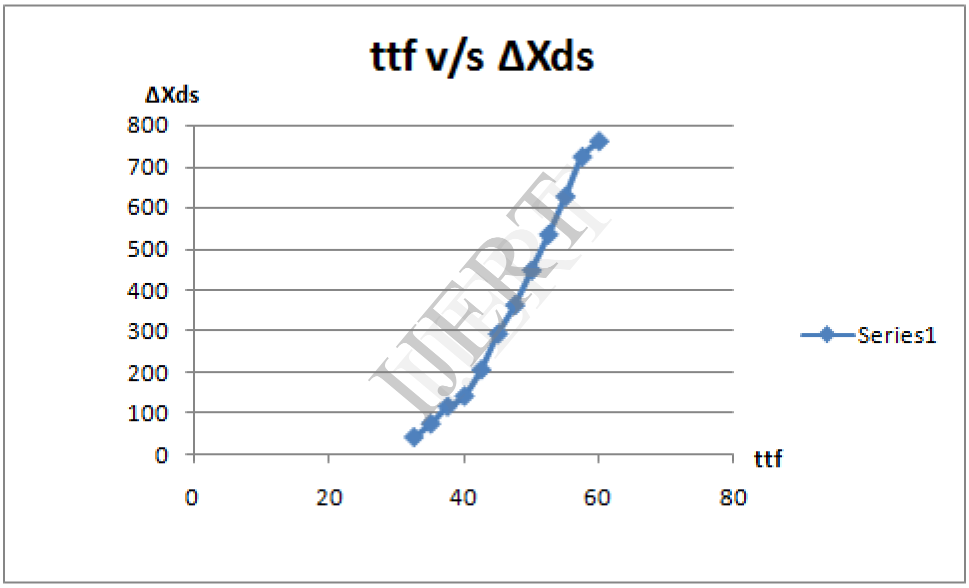

Fig. 08: System mixing average temperature v/s exergy plot.

5. Conclusion

The entropy generation and exergy destroyed in the SDHW storage tank has been calculated analytically from the imaginary thermocline line for different temperatures. Due to heat diffusion from the thermocline line and mixing of hot and atmospheric cold water the entropy decreases from hot water and entropy increases in cold water. Due to this available required stored hot water thermal energy is destroyed and exergy also destroyed. To preserve and conserve energy and exergy it is necessary to create one artificial barrier or separator in between hot and cold water. It can be done by installing one separator steel plate at the centre of the tank. Also separator plate can be provided with minor clearance to move up and down by that extra generated hot water can be stored by lowering the separator plate. This plate can be guided using tie rods for up and down movements.

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