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EXPERIMENTAL ANALYSIS OF THERMALLY STRATIFIED STORAGE TANK

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ABSTRACT

With use of thermally stratified storage tank in solar water heating system, the stored heat can be utilized more effectively. A inlet SBCD and internal obstacle for thermal storage tank can maintain thermal stratification better by reducing mixing process of cold and hot water and improves thermal storage efficiency. Experiment are carried out for investigation of the discharging performance of thermally stratified storage tank with three inlet and outlet configurations with three flow rates. The results shows using inlet sintered bronze conical diffuser and internal obstacle improves the thermal stratification. It increases outlet hot water temperature, energy extracted by water and also the volume of hot water. Further it is concluded that configuration of two inlets and two outlets placed opposite to each other provides better thermal stratification compared to configuration of one inlet and one outlet.

Keywords: Internal obstacle, Sintered Bronze Conical Diffuser (SBCD), Thermal Energy Storage (TES) tank, Thermal stratification

Introduction

The principle of stratified TES tank operation is based on thermal stratification process. It means lower temperature cold water flows at the bottom of the tank and higher temperature hot water flows at the top of the tank driven by buoyancy. This produces the thermal stratification in hot water storage tank, thus increases the thermal performance of a solar water heating system. A hot water tank is used for storing solar energy collected by solar collector to use later. When the hot water is taken out of the tank the cold water flows in the tank and mixes with the remaining hot water lowering its temperature. It is an undesirable phenomenon. In this study, solar tank having internal obstacle having gap in the center and inlet SBCD is considered for minimizing the mixing of cold and hot water so that water is availabble at higher temperature.

Experimental Setup

The tank is made of stainless steel (grade 304) of height 1 m having an internal diameter of 0.35m. Tank capacity is 100 litres. Internal obstacle made of stainless steel (thickness=0.75 mm) having hole at centre (d2=0.0699 m) is welded at a distance of 133 mm from the bottom end. Tank is having 2 inlets 20 mm from the bottom end and 2 outlets 20 mm from the top end of 20 mm diameter. At both the inlets SBCD is fitted inside the tank. The tank is insulated with 3mm glass wool insulation. The top end of the tank is kept detachable for placing thermocouples inside the tank.

V_H -Manual valve for hot water from solar collector T1 to T9- Thermocouples

V_C -Manual valve for cold water to solar collector V1 to v4- Manual valve

A-Hot water from solar collector B- Cold water to solar collector

D1 and D2-SBCD

Description of Cases

1. Single inlet diffuser and outlet on same side of tank (Case a).
2. Single inlet diffuser and outlet on opposite side of tank (Case b).
3. Two inlet diffusers and outlets on both sides of tank (Case c).

Experimental Procedure

1. Fill the tank with cold water by opening the inlet valve. So that the water from make-up water tank enters into TES tank.
2. After the tank becomes fully charged, circulates the cold water through the collector. Heat the water above 55ºC. Hot water from collector enters in the TES tank from the hot water inlet.
3. Make two processes of cold out and hot in simultaneous till the water is heated to the temp above 55°C. After this cut off the collector connection and wait for at least one hour so that stratification will occur. We can observe the temperature distribution in TES tank from the temperature reading indicated by data logger. When the temperature readings are stable, we can say that stratification is occurred.
4. After the stratification is occured, discharging of hot water start. Let the hot water pass through the outlet. 10 litre of hot water will be taken out from the respective outlet and 10 litre of cold water will be made to enter the tank from respective inlet simultaneously. The temperature of hot water will be measured using temperature sensors.
5. Take the readings of the removed hot water for every 10 liters.
6. Observe how the water removal process affects the stratification level in TES tank from variations in temperature reading at various instants of time.
7. Repeat the step 4 to step 6, till we can get useful hot water for bathing (at least at 40°C).
8. Measure how much amount of water we will get for this combination with useful energy extracted also.

Results

Analysis based on Heat Extraction Values

For 3 lpm Flow Rate

From figures it is observed that the heat extraction values are increasing with the draw off water volume. Initially all cases shows same trend but after some volume there is drop in heat extraction values for case a and case b as compared to case c. Due to high mass flow rate there is more momentum diffusion. Hence energy extracted for 3 lpm is more than 6 and 12 lpm and of 6 lpm is more than 12 lpm. Cold water jet penetrates more when flow rate increases.

For the comparison between 3 cases the energy extraction is calculated for each case. Cut-off temperature was set to 40°C (temperature of water at outlet becomes 40°C). Heat extraction values in above figures indicates that TES with arrangement like case c uses heat from the reservoir effectively than case a and case b.For case c cold water is entering from both inlets of tank. Due to this penetration depth of cold water jet is low as compared to other two cases. Hence mixing of cold water in hot water is less. Due to which discharge temperature obtained at outlet is more for case c as compared to case a and case b.

Analysis based on Temperature Curves on Central Plane

Fig. shows temperature distributions axially for different operation time period for case a, b, c respectively. The low flow rate will have longer discharge time. We can conclude that from these 3 cases, case c shows less mixing and greater stratification. The jet of cold water tends to move along axis and then radially towards the wall. Due to which eddies are formed which having more turbulent diffusion. We can see in case c forming of turbulent eddies for small height as compared to other two cases. We can observe that temperature decreases 1^{st} and then increases. This is due to jet of cold water 1^{st} tends to move downward and then move radially upward. For case c cold water is entering from both inlets of tank. Hence mixing of cold water in hot water is less. Due to which discharge temperature obtained at outlet is more for case c as compared to case a and case b. Growth of mass flow rate enhances mixing process of cold and hot water and deteriorates thermal stratification.

For 3 lpm Flow Rate

For case c maximum temperature is achieved at y=0.2 m for all operation time while the case a and case b reaches maximum temperature in y= 0.36m and y=0.4 m respectively. The minimum temperature is reached at the height of 0.05 m.

For 6 lpm Flow Rate

For case c maximum temperature is achieved at y=0.22 m for all operation time while the case a and case b reaches maximum temperature in y= 0.3 m and y=0.4m respectively. The minimum temperature is reached at the height of 0.05 m.

For 12 lpm Flow Rate

For case c maximum temperature is achieved at y=0.45 m for all the operation time and the case a and case b reaches maximum temperature in y= 0.3 m and y=0.36 m respectively. The minimum temperature is reached at the height of 0.05 m.

Conclusions

1. By using SBCD and internal obstacle the volume of hot water collected is increased by 30 to 40 litres.
2. The maximum uniform temperature attained in the tank is 67ºC due to less turbulence in the tank by using internal obstacle and SBCD.
3. The energy extracted by water with the use of internal obstacle and SBCD is increased by 8 to 10%.
4. Two inlet and two outlet configuration stores more energy than single inlet and outlet configuration. It shows better

stratification in two inlet and two outlet configuration.

5. The high mass flow rates causes more turbulent diffusion. Thus there is a considerable reduction in the thermal stratification levels.

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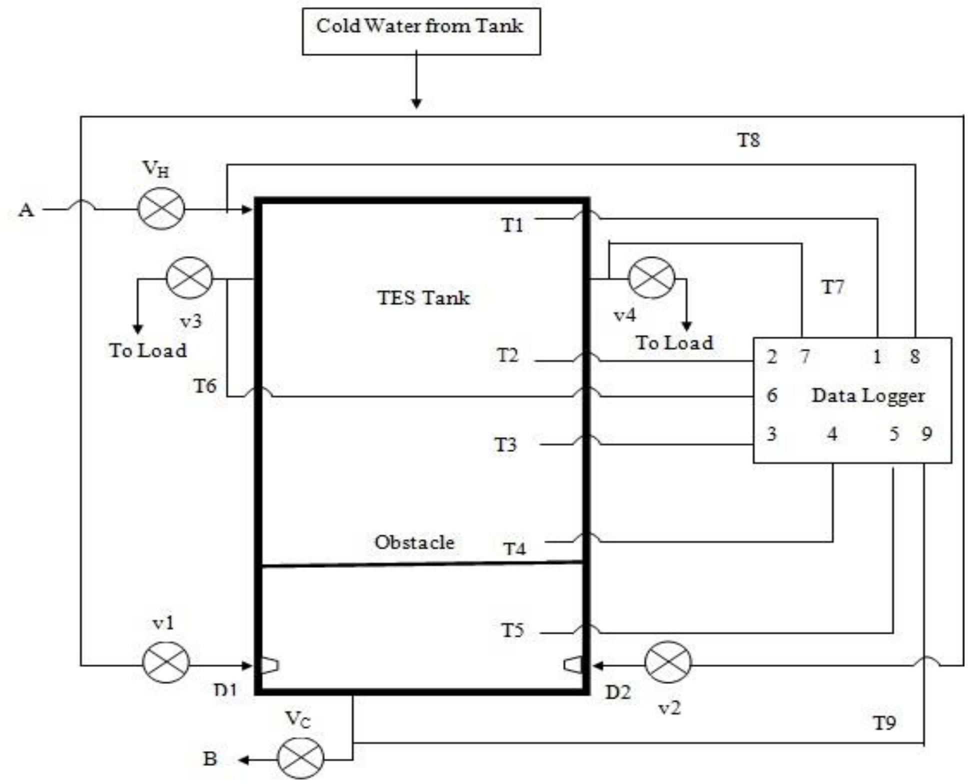


Fig 1: Experimental Setup

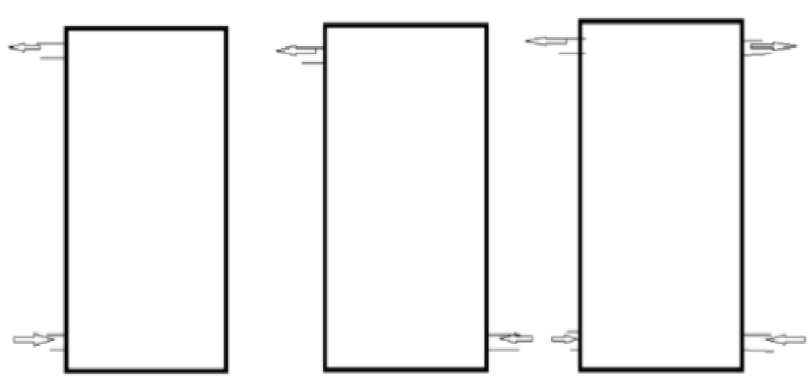


Fig 2: Different Inlet and Outlet Configurations of TES Tank

TABLE 1: Heat Extraction Values

Method used	Amount of Energy Extracted for Cases (kJ)		
	Case a	Case b	Case c
Experimental	7451.42	7362.40	9669.58

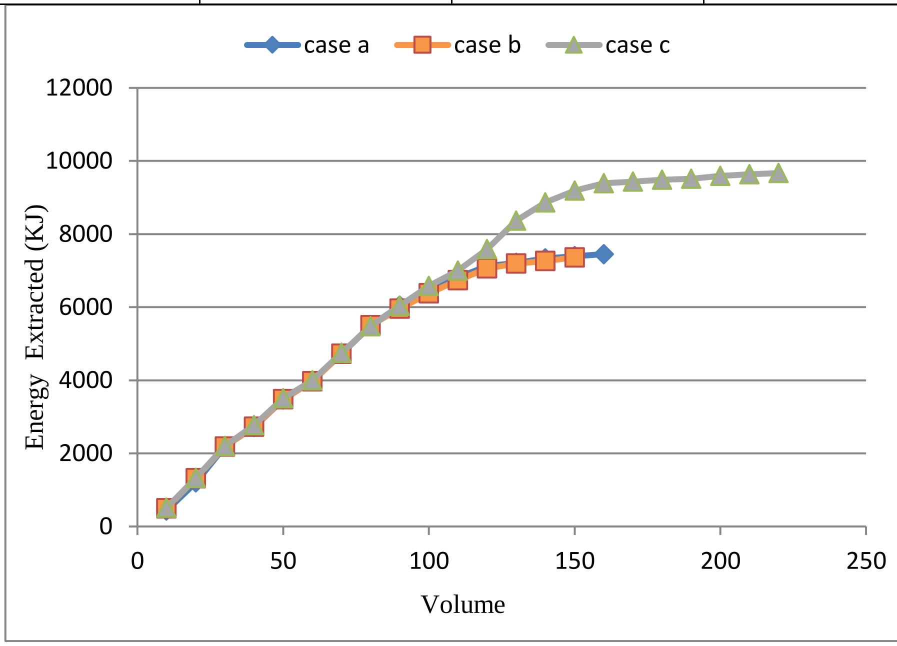


Fig 3: Extraction of energy vs Volume (cumulative)

For 6 lpm Flow Rate

TABLE 2: Heat Extraction Values

Method used	Amount of Energy Extracted for Cases (kJ)		
	Case a	Case b	Case c
Experimental	6914.51	7056.54	8758.64

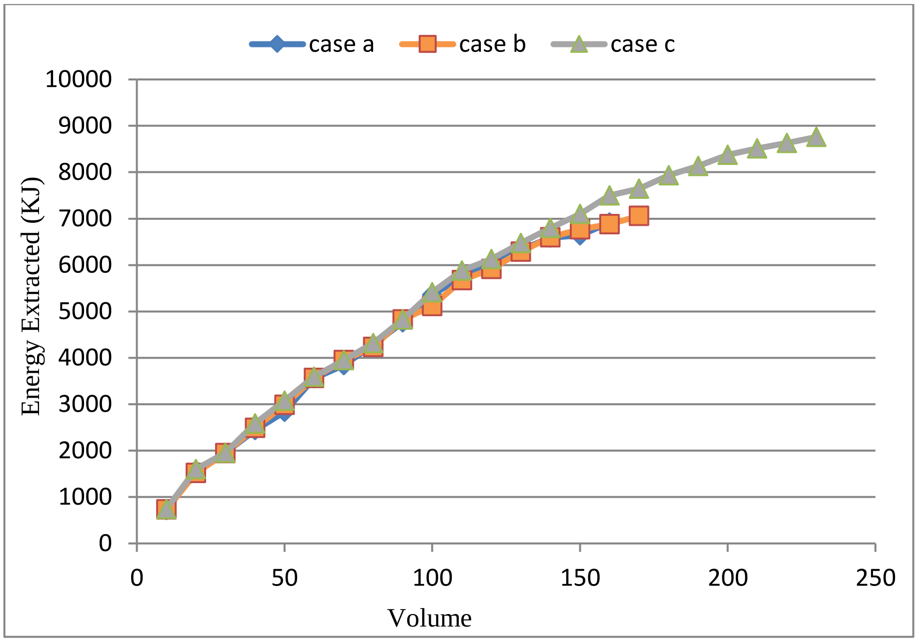


Fig 4 : Extraction of Energy vs Volume (cumulative)

For 12 lpm Flow Rate

TABLE 3: Heat Extraction Values

Method used	Amount of Energy Extracted for Cases (kJ)		
	Case a	Case b	Case c
Experimental	7391.25	7204.83	8391.10

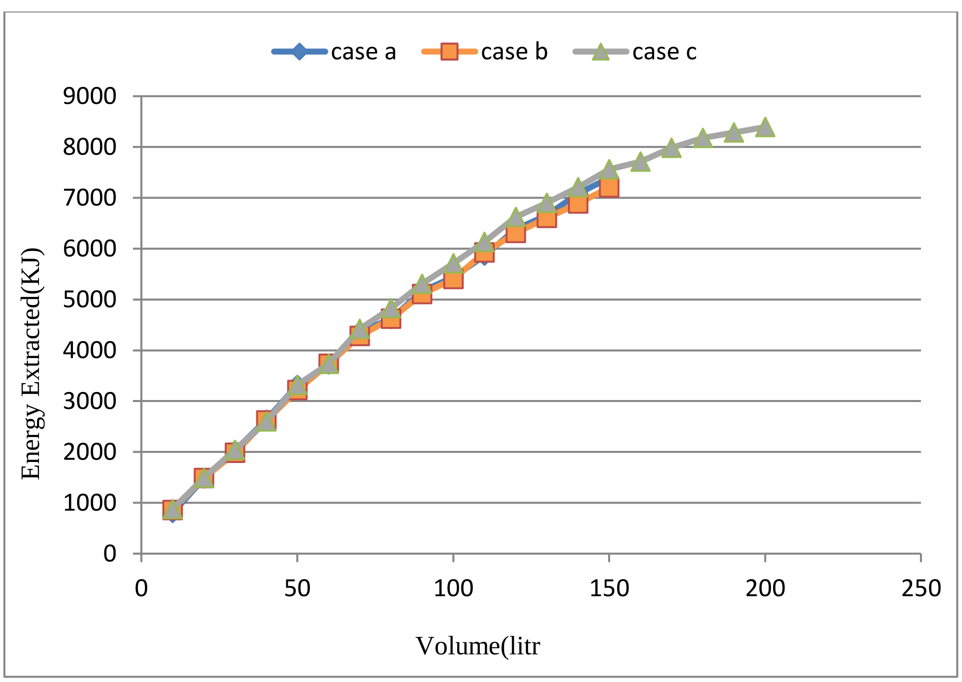
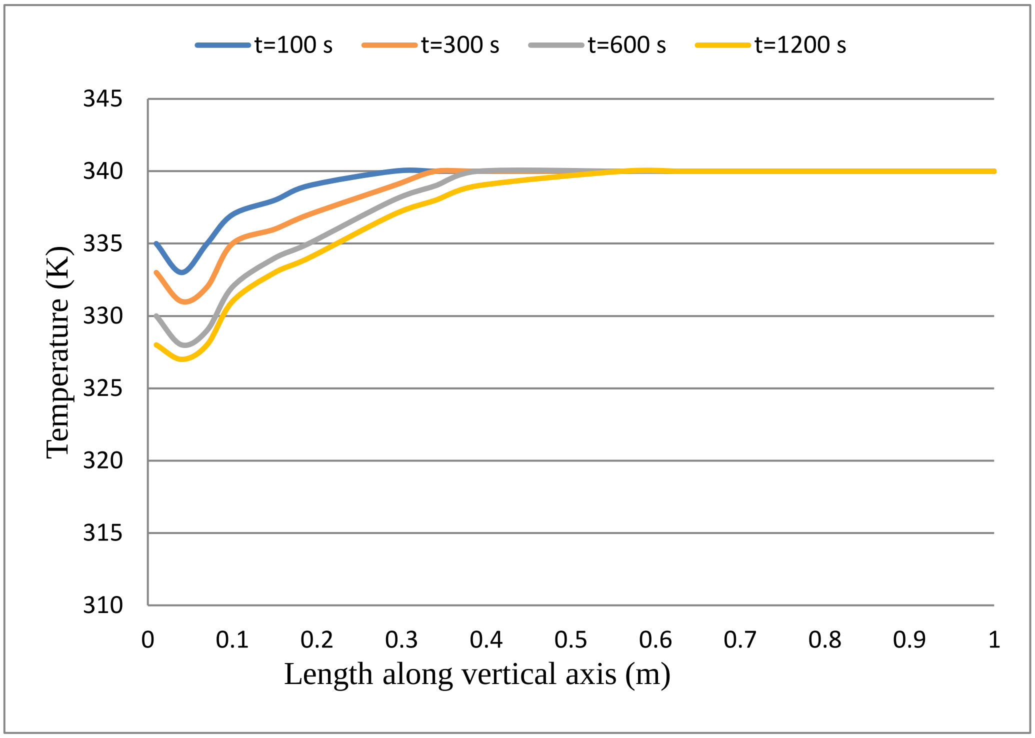
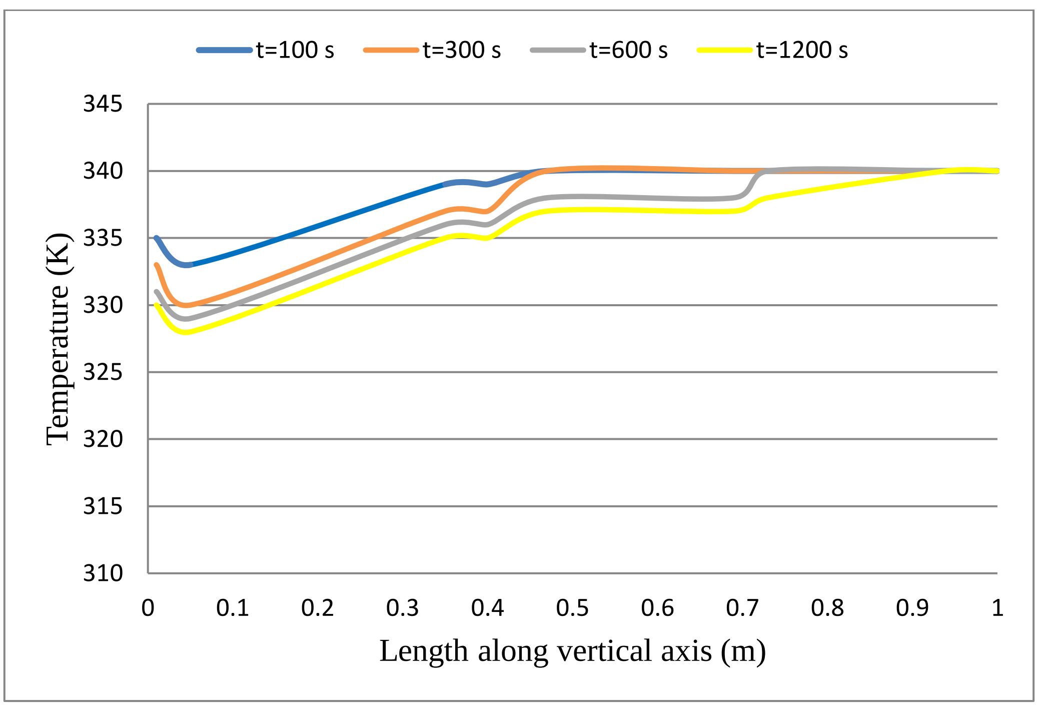


Fig 5 : Extraction of Energy vs Volume (Cumulative)





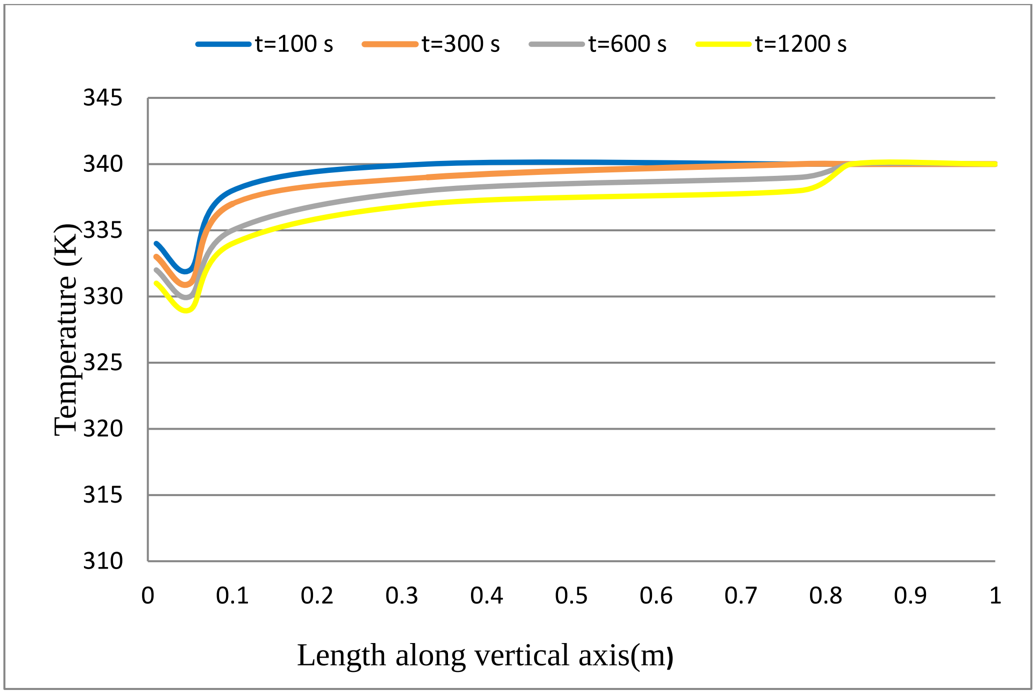
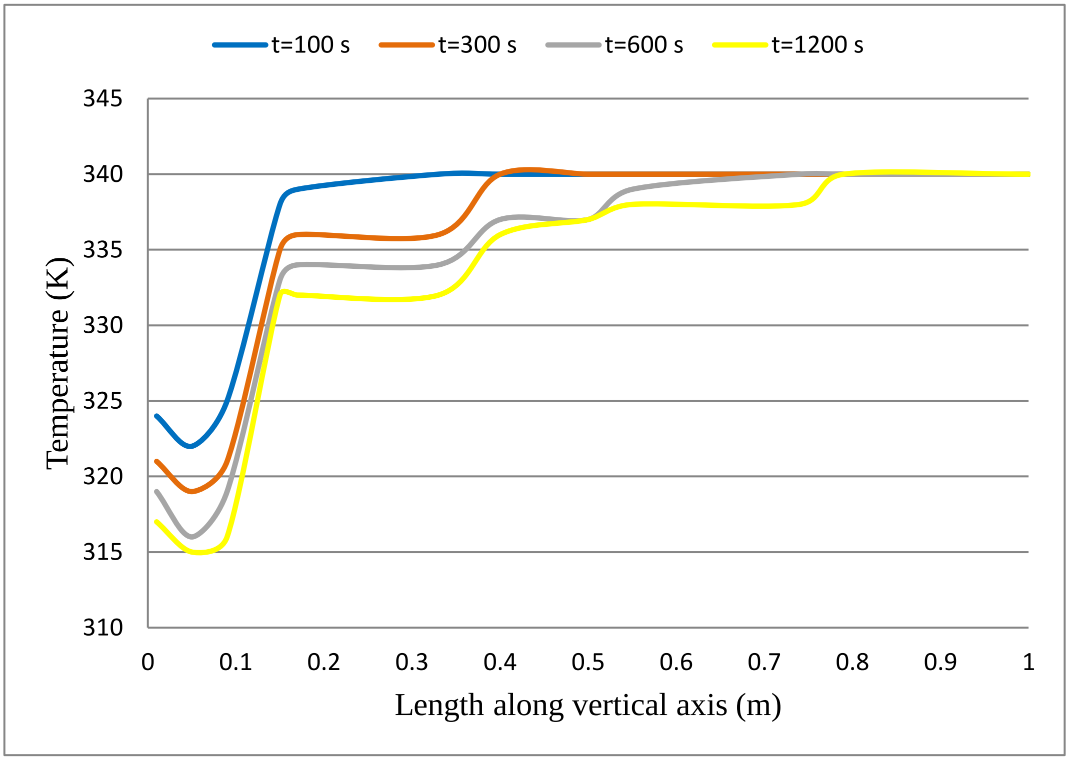
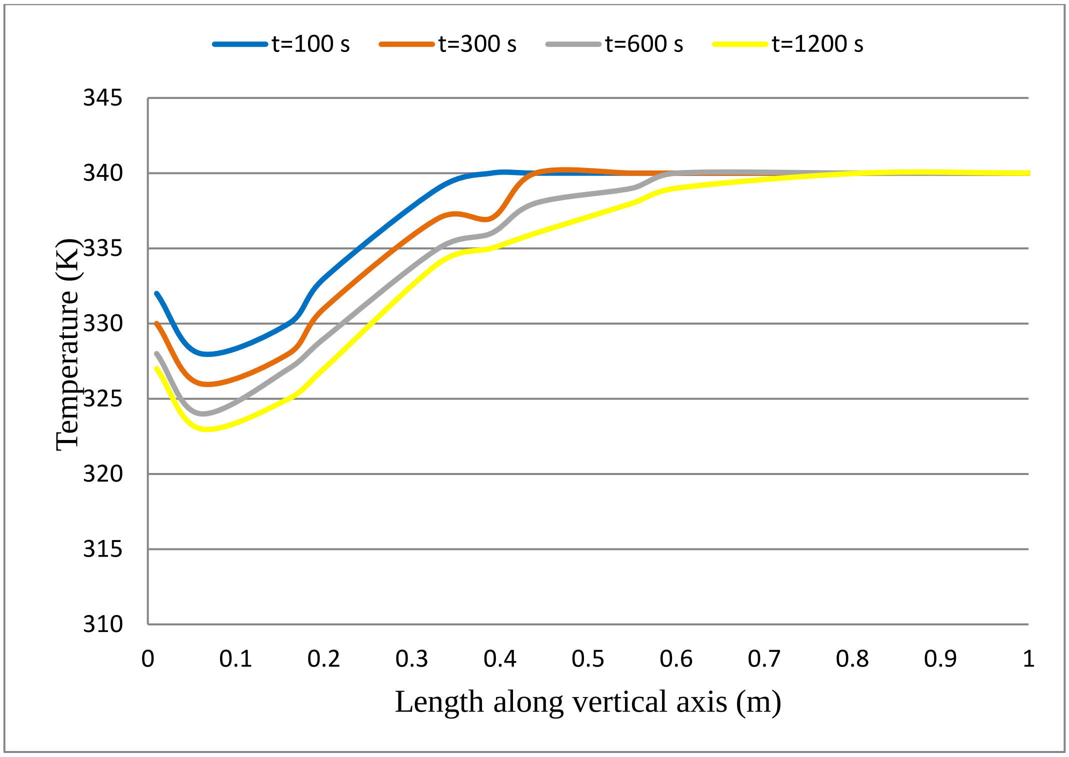


Fig 6 : Temperature Distribution in the Tank axially for Case a, b and c for 3 lpm flow rate





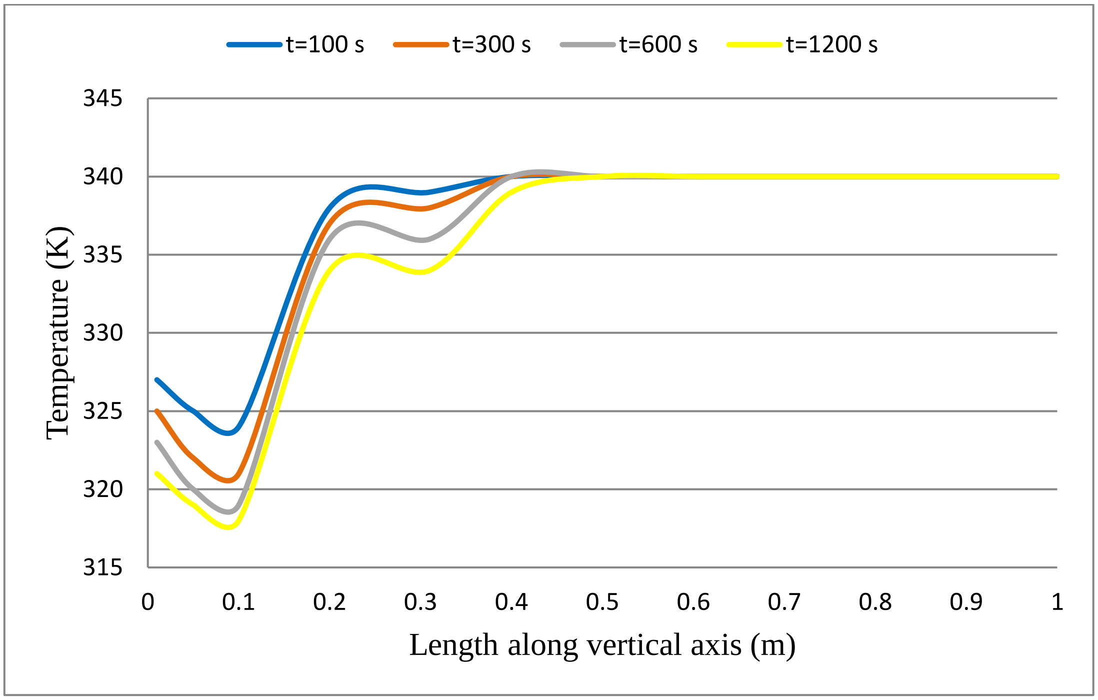
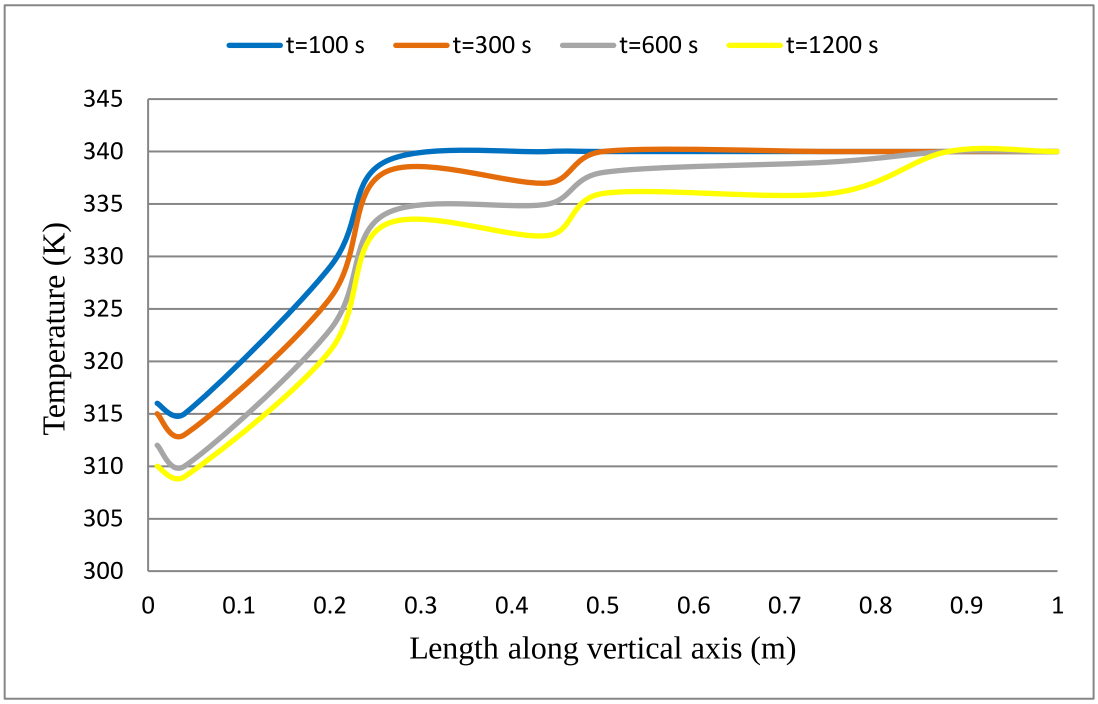


Fig 7 : Temperature Distribution in the Tank axially for Case a, b and c for 6 lpm flow rate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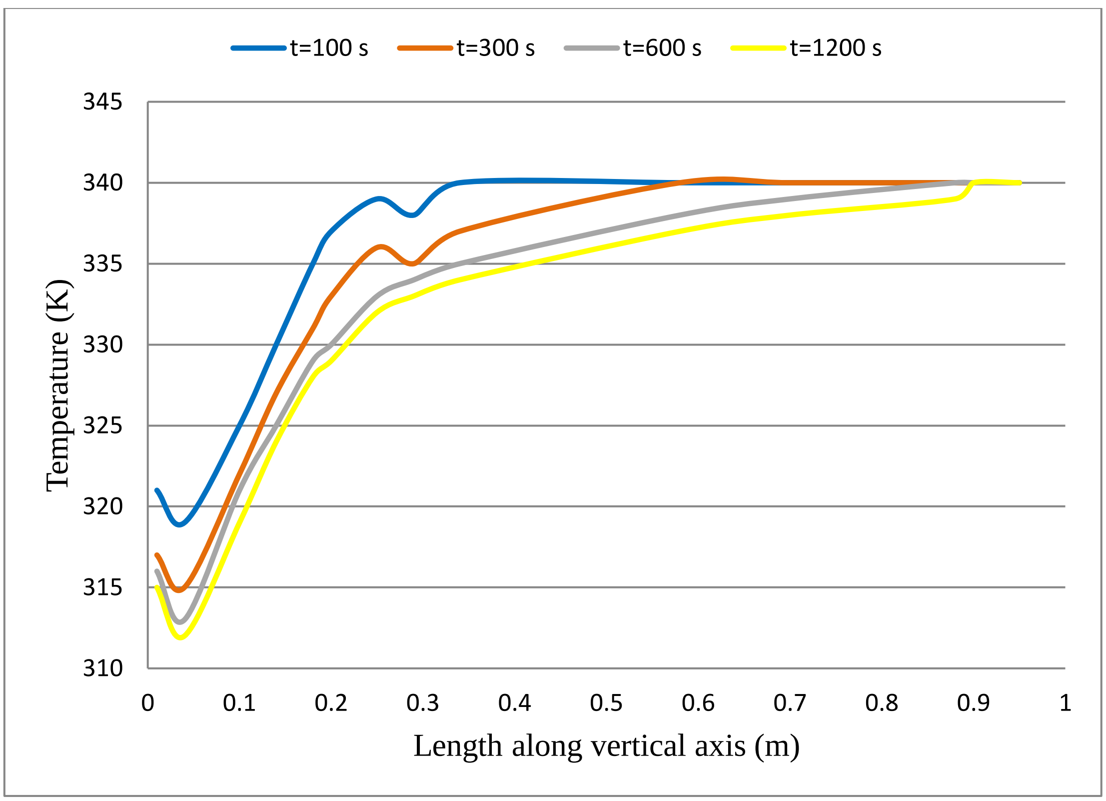
t=300 s
t=600 s
t=1200 s
Temperature (K)
345
340
335
330
325
320
315
310
305
300
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Length along vertical axis (m)


t=100 s
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Temperature (K)
345
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Length along vertical axis (m)

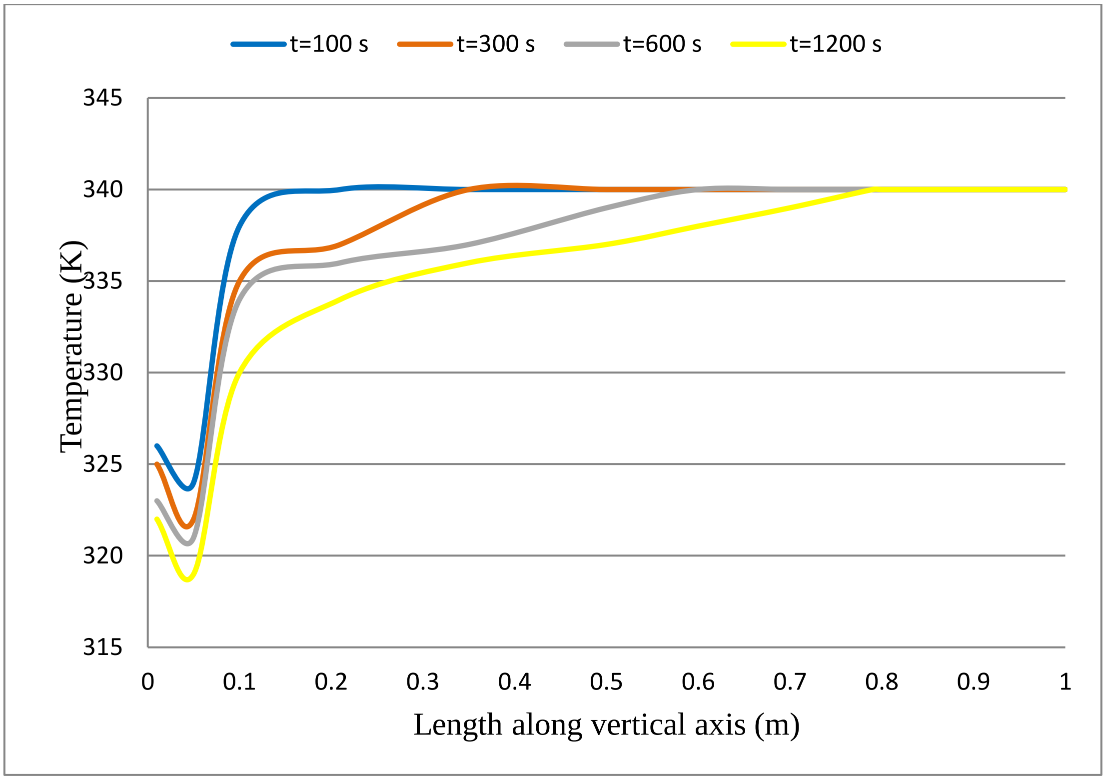

Fig 8 : Temperature Distribution in the Tank axially For Case a, b and c for 12 lpm flow rate