CFD Analysis Of Thermocline Thermal Energy Storage Tank

Objective Of The Case Study

❑ The primary objective of this study is to simulate the formation of thermocline in thermal energy storage tank using ANSYS Fluent.

❑ The secondary objective is to study the de-stratification of thermal layers when fluid at relatively lower temperature is entrained into the storage tank.

What is thermocline?

❑ It is the region in water bodies where abrupt temperature gradient is observed.

❑ The water above and below this thermocline layers are at different temperatures.

Thermocline Thermal Energy Storage Tank

1. High Temperature Fluid

2. Thermocline Region

3. Low Temperature Fluid

High Temperature

High To Low Temperature Gradient
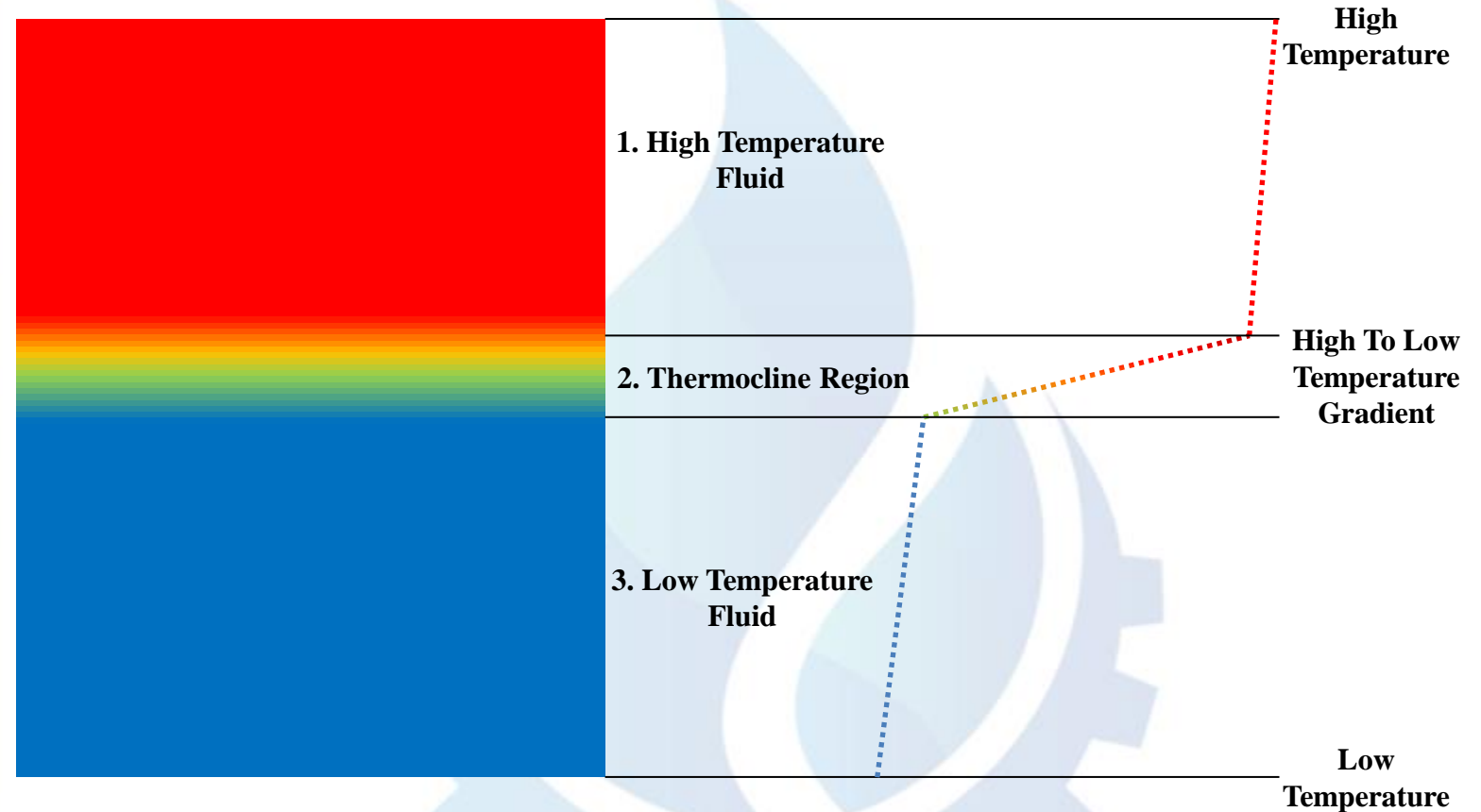
Low Temperature

This concept of thermocline formation in water bodies is used in the thermal energy storage tanks to store water at different temperatures in a one single tank as shown in the figure above.

Operation Of Thermal Energy Storage Tank?

Its operation involves two processes:-

1. Charging Process:- Hot fluid from the solar collection field enters at the top of storage tank & the cold fluid exits from the bottom to be heated.

2. Discharging Process:- Hot fluid exits from the top to electricity generation power block and after being cold enters from the bottom of the storage tank.

Charging Process

Hot Fluid Enters At Top

Solar Collection Field

Cold Fluid Exits From The Bottom

Discharging Process

Hot Fluid Exits From Top

Power Block Of Electricity Generation

Cold Fluid Enters From The Bottom
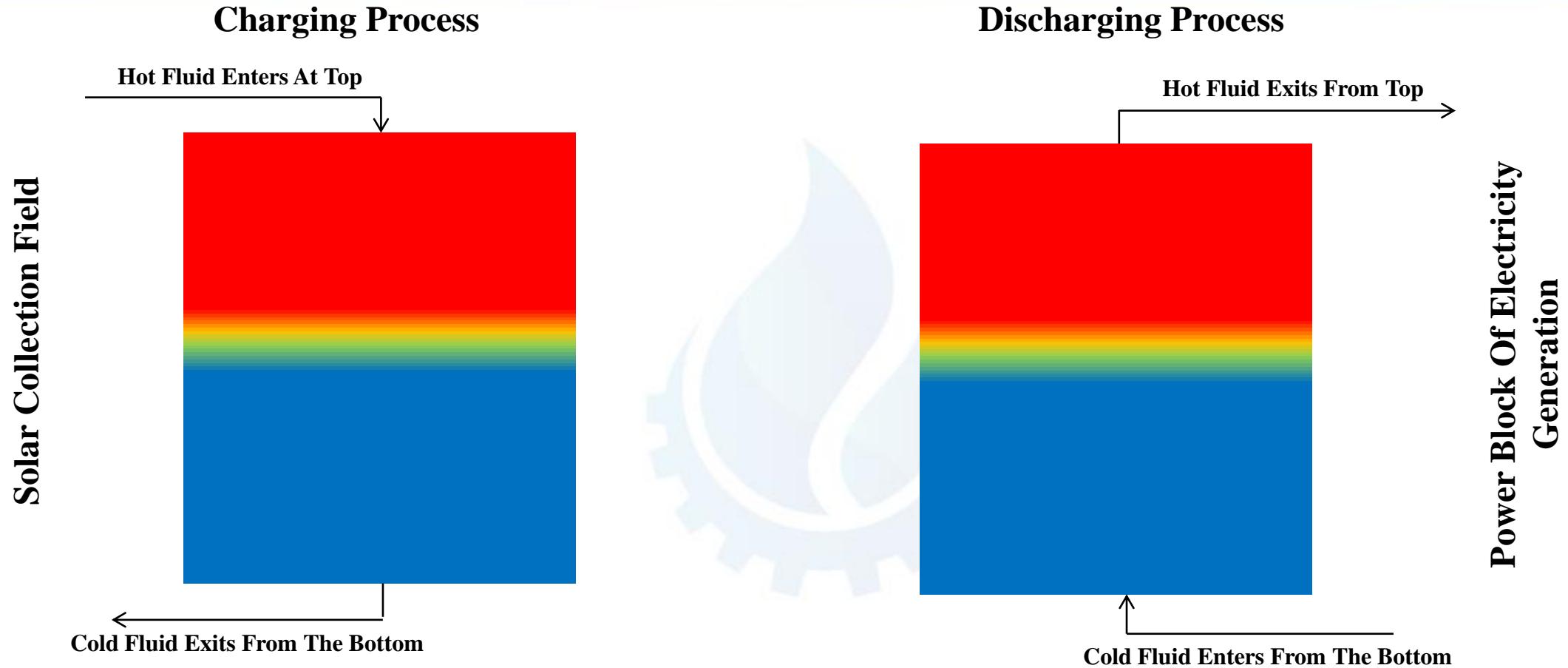
Factors Affecting The Efficiency Of Thermocline Storage Tank

❏ The thickness of the thermocline region can be used to quantify the efficiency of thermal stratification which in turn quantifies the storage efficiency of the thermocline tank.

❏ Tank with thin thermocline displays superior thermal storage efficiency as compared to a tank with a thicker thermocline.
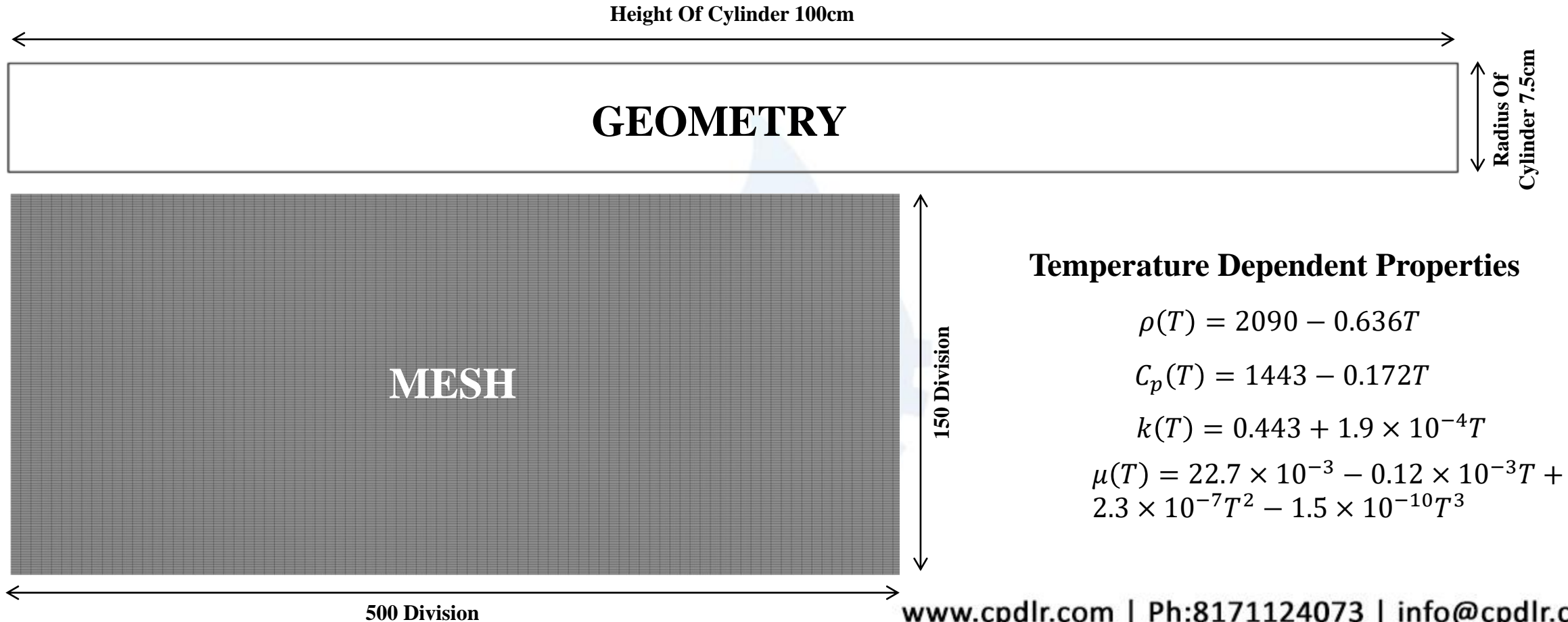
During Charging Process

Hot Fluid Entering At Relatively Low Temperature

Solar Collection Field

Cold Fluid Exits From The Bottom
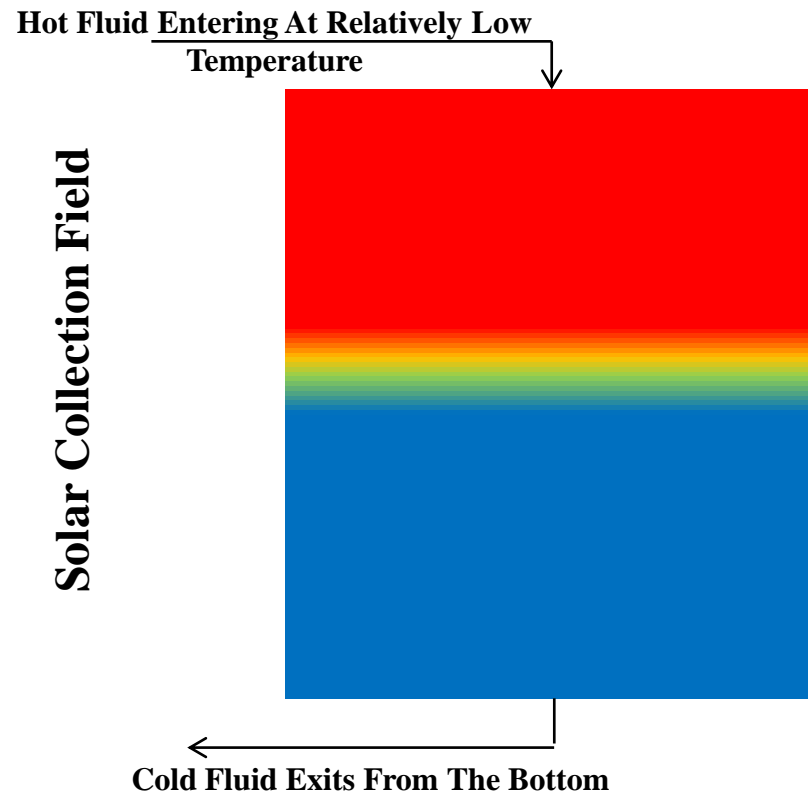
❏ Thermal stratification in thermocline tank can be affected by various flow instabilities that causes undesirable mixing of hot and cold fluid inside the tank.

❏ One of the instability in flow can be due to fluid entering at relatively low temperature at top when coming from the solar collection field.

❏ The instability caused in thermocline stratification during charging process is discussed in this case study.

Geometry & Mesh Details

❑ The storage tank simulated is cylindrical in shape with diameter 15cm and height 100cm.
❑ To reduce computational time, 2D axis-symmetric assumption was taken to reduce the 3D model to 2D.
❑ Structured mesh was created using ANSYS meshing application with 500 divisions in axial direction and 150 divisions in radial direction.

Height Of Cylinder 100cm

GEOMETRY

Radius Of Cylinder 7.5cm

MESH

150 Division

500 Division

Temperature Dependent Properties

$$\rho(T) = 2090 - 0.636T$$

$$C_p(T) = 1443 - 0.172T$$

$$k(T) = 0.443 + 1.9 \times 10^{-4}T$$

$$\mu(T) = 22.7 \times 10^{-3} - 0.12 \times 10^{-3}T + 2.3 \times 10^{-7}T^2 - 1.5 \times 10^{-10}T^3$$

Case Details

- ❑ The case was simulated in transient mode.
- ❑ The complete charging process was simulated in four steps as explained below.
- ❑ The continuity, momentum and energy equations were the three main governing equations.
- ❑ Flow was taken as laminar.

| **Transient Step 1** T1=66.2s	**Transient Step 2** T1=134.0s	**Transient Step 3** T1=25.0s	**Transient Step 4** T1=775.0s
Hot Fluid (350°C) Enters At 0.00755m/s	Fluid Entrainment Stopped	Relatively Cold Fluid (345°C) Enters At 0.00755m/s	Fluid Entrainment Stopped
During this period, the fluid entering from top at 8l/min will fills the tank half	During this period, the buoyancy forces removes radial temperature gradients.	In this duration, the induced flow disturbance destratify the thermocline region.	In this duration, the fluid in the thermal storage tank will stratified again.

Results & Discussion

❑ Temperature contours are shown below in which the hot fluid entering the thermal energy storage tank can be seen clearly.

❑ At t=66s, the fluid has filled the tank half and after additional 134sec (transient step 2), the thermocline has settled at the mid-height of the tank.

❑ The temperature plot shows the temperature gradient in the thermocline region of the storage tank.

At t=0s   At t=33s   At t=66s   At t=200s
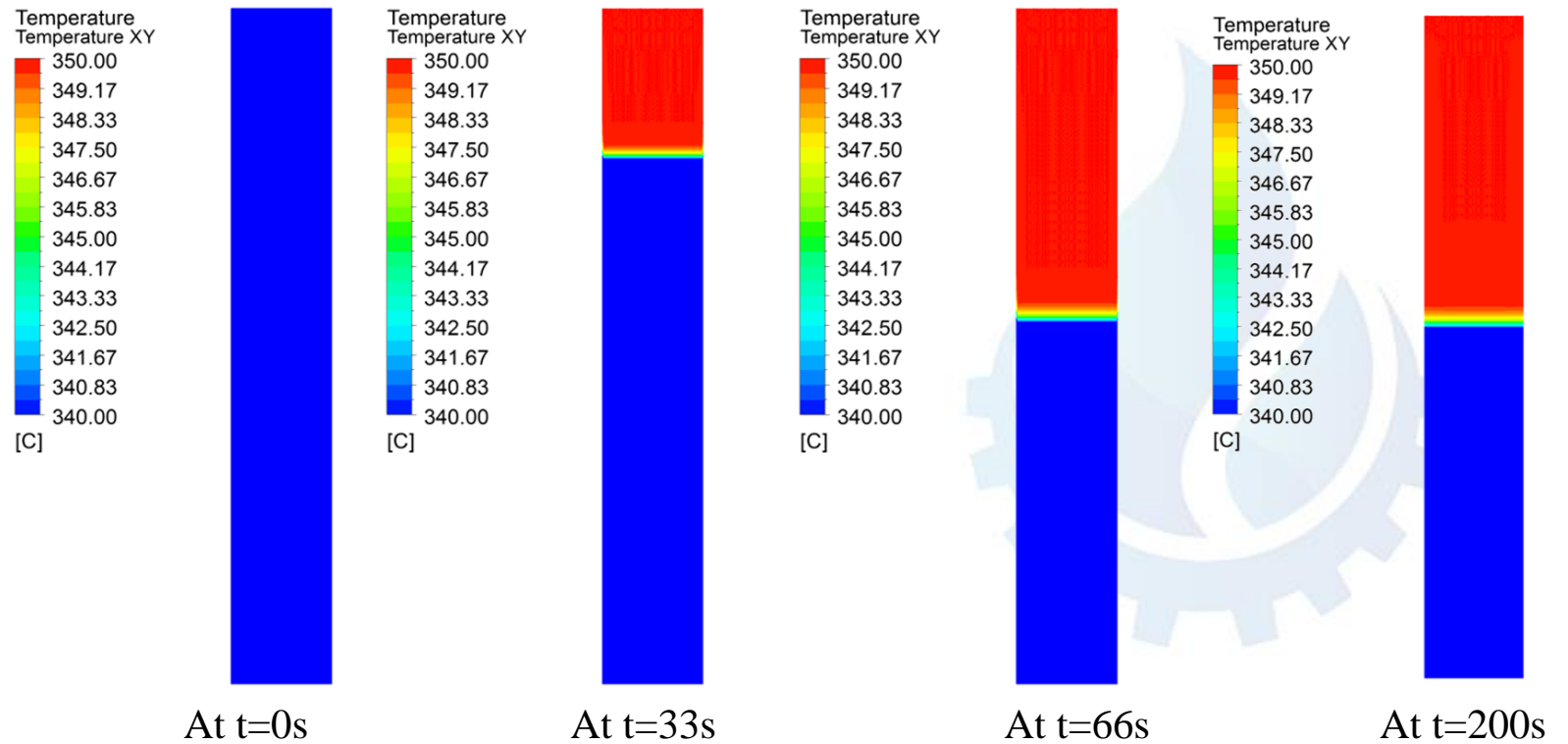
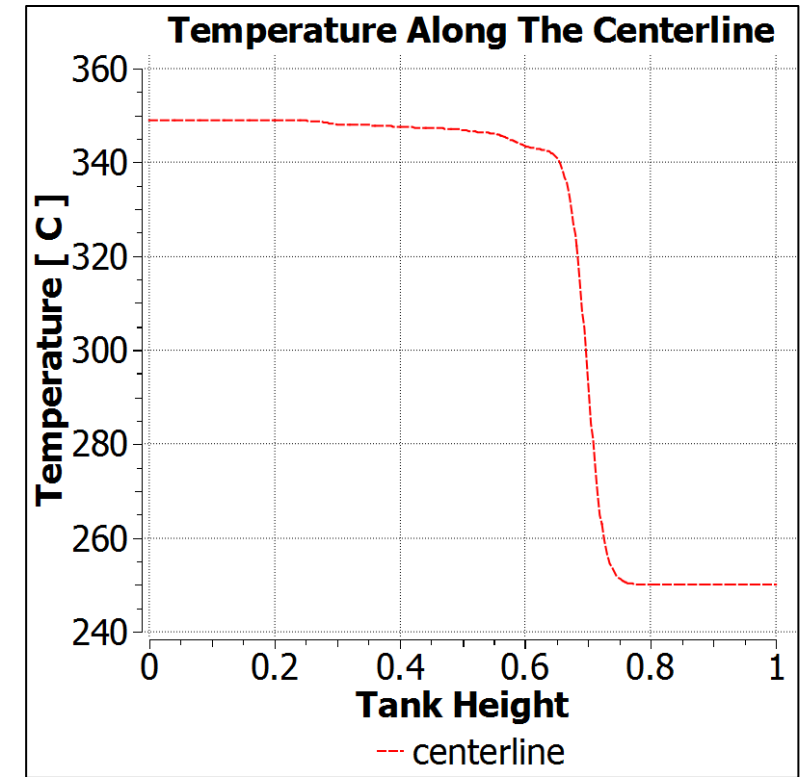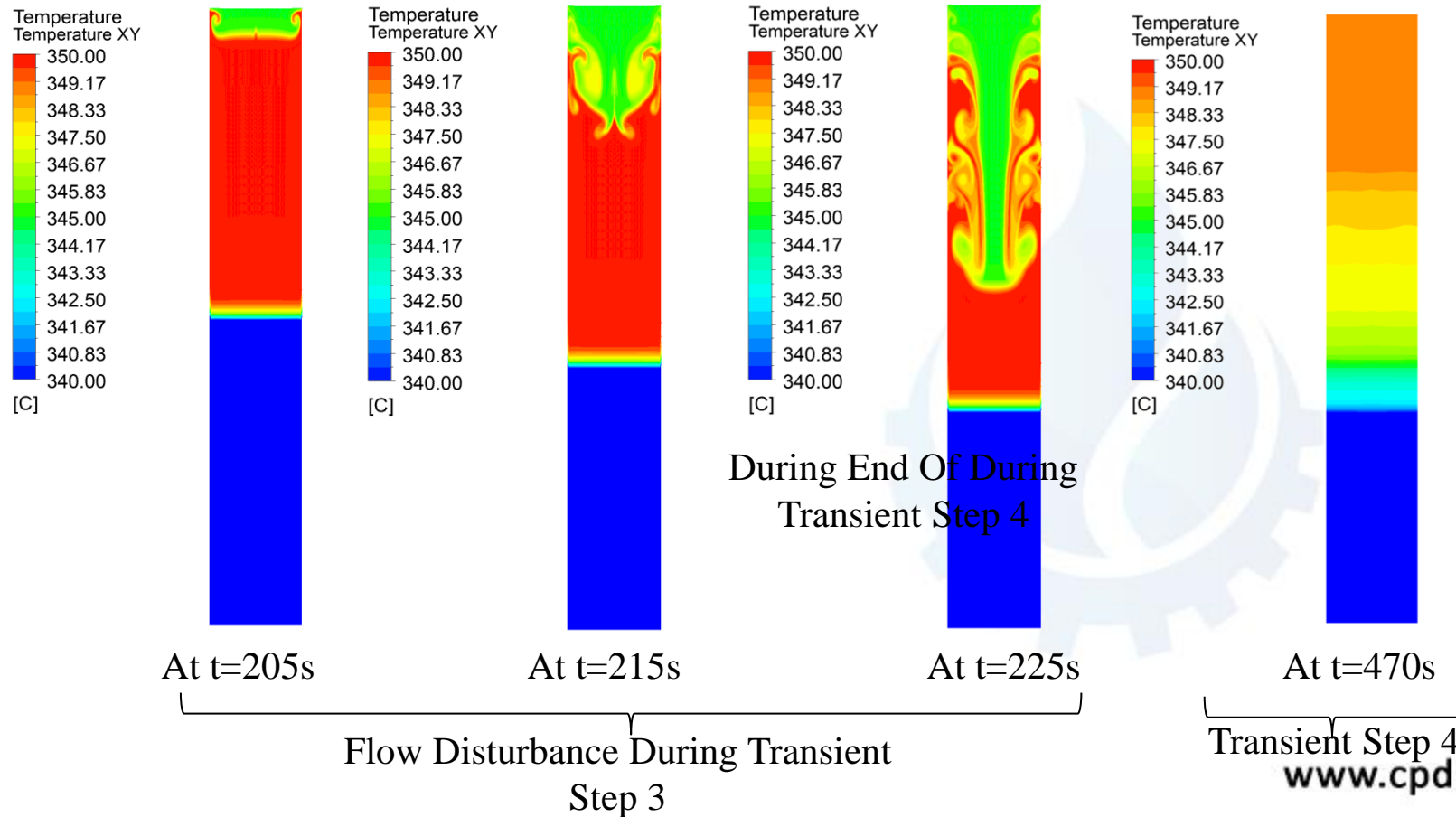Formation Of Thermocline During Transient Step 1

During End Of During Transient Step 2
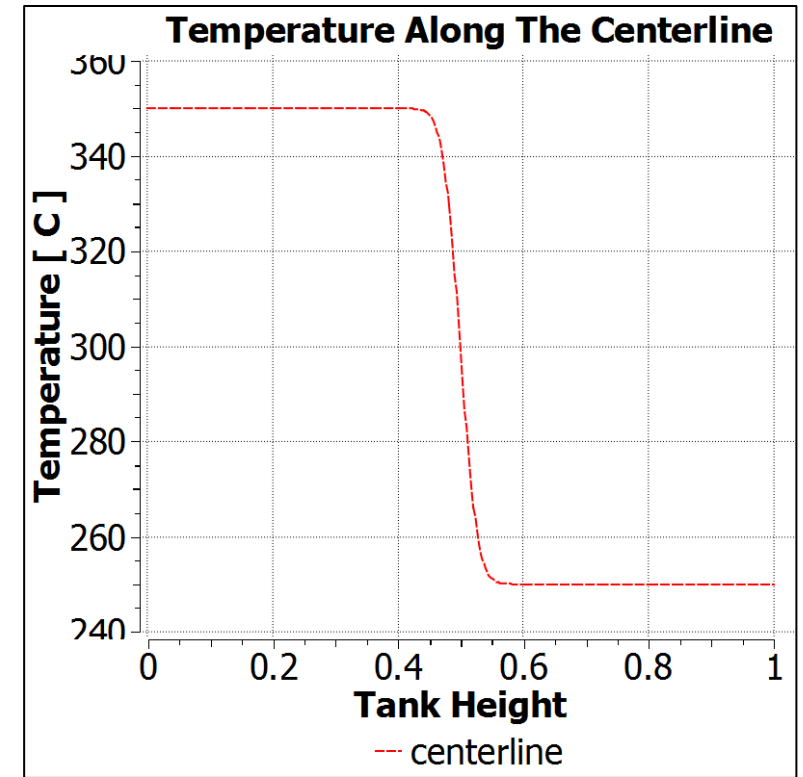
Abrupt Temperature Gradient Can Be Seen In The Thermocline Region

Results & Discussions

- ❑ Solidworks model of shell & tube heat exchanger was imported in ANSYS DM, and then the fluid volume was extracted.
- ❑ Due to symmetry in the CFD model, symmetry assumption was taken and the computational time was reduced to half.
- ❑ The model was then meshed in the ANSYS mesh software. Inflation layer was applied at the walls to capture the boundary layer.

At t=205s   At t=215s   At t=225s   At t=470s

During End Of During Transient Step 4

Flow Disturbance During Transient Step 3

Transient Step 4

Conclusion

❑ In the present case study, the formation of thermocline was simulated using ANSYS Fluent software in transient mode.

❑ Effect of flow disturbance on thermal stratification process was studied by introducing hot fluid at relatively lower temperature.

❑ The 4th transient step, required for re-stratification after flow disturbance was not run completely due to time restrictions, but still it can be seen that the thickness of thermocline was affected by the flow disturbances which will give rise to reduction in the thermal storage efficiency of the tank.

Temperature Along The Centerline