Assignment: Thermal Energy Storage

By: Rajnesh Kumar

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TES assessment exercises:

Exercise 1: Evaluate how much time is needed to heat a 200 L of water tank (cp=4,186kJ/kgK; r=1000 kg/m3) from 40ºC to 60ºC if inlet heat flux is 1,5 kW, considering a (UA) = 2W/K under an external ambient temperature of 20ºC.

Given data:

Volume of tank = V = 200 L = 0.2 m^3
Specific heat capacity of water = Cp = 4.186 kJ/kg.K
Density of water = r = 1000 kg/m^3
Water initial temperature = $T_{initial}$ = 40 °C
Water final temperature = T_{final} = 60 °C
Ambient temperature = $T_{ambient}$ = 20 °C
Inlet heat flux = Q_{in} = 1.5 kW
UA = 2 W/K = 0.002 kW/K

Required: how much time it takes to heat the water from 40 °C to 60 °C.

Applying the energy balance, we have:

$$\dot{E_{in}} - \dot{E_{out}} = \Delta E/\Delta t$$

$$\Delta t = \frac{\Delta E}{\dot{E_{in}} - \dot{E_{out}}}$$

$$\Delta t = \frac{r * V * Cp * (T_{final} - T_{initial})}{Q_{in} - UA * (T_{initial} - T_{ambient})}$$

$$\Delta t = \frac{1000 * 0.2 * 4.186 * (60 - 40)}{1.5 - 0.002 * (40 - 20)} = 11468.5\ seconds = 3\ hours\ 11\ minutes$$

It takes around 3 hours and 11 minutes to heat the given volume of water in a tank from 40 °C to 60 °C.

Exercise 2: A 200 L of water tank at 60ºC is completely stopped during one full day. Considering an (UA) = 2W/K under an external ambient temperature of 20ºC, evaluate the final mean temperature of the water at the end of the day.

Given data:

Volume of tank = V = 200 L = 0.2 m^3
Specific heat capacity of water = Cp = 4.186 kJ/kg.K
Density of water = r = 1000 kg/m^3
Water initial temperature = $T_{initial}$ = 60 °C
Ambient temperature = $T_{ambient}$ = 20 °C

UA = 2 W/K = 0.002 kW/K
Δt = 1 day = 86400 seconds

Required: final mean temperature of the water at the end of the day.

Applying the energy balance, we have:

$$\dot{E_{in}} - \dot{E_{out}} = \Delta E/\Delta t$$

$$-UA * (T_{initial} - T_{ambient}) = \frac{r * V * Cp * (T_{final} - T_{initial})}{\Delta t}$$

$$T_{final} = T_{initial} - \frac{UA * (T_{initial} - T_{ambient}) * \Delta t}{r * V * Cp}$$

$$T_{final} = 60 - \frac{0.002 * (60 - 20) * 86400}{1000 * 0.2 * 4.186} = 51.74\ °C$$

At the end of one day, the final mean temperature of water will reach 51.74 °C, that is, it will cool down by 8.26 °C.

Exercise 3: An organic acid lauric PCM (melting temperature 44,2ºC; heat of fusion 211,6kJ/kg; density 1007 kg/m3 and heat capacity 2270 J/kgK) is compared against water (cp=4,186kJ/kgK; r=1000 kg/m3) for LTES vs STES applications. Evaluate the water temperature difference needed in STES system for the same equivalent heat storage volume capacity of LTES system.

Given data:

Latent heat stored by per kg of PCM = $\Delta h_{fusion,\ PCM}$ = 211.6 kJ/kg
Specific heat capacity of water = Cp = 4.186 kJ/kg.K
Density of water = r = 1000 kg/m^3

Required: change in temperature difference needed in STES system for same equivalent heat storage volume capacity of LTES system.

Latent heat stored by per kg of PCM = Sensible heat stored by per kg of water

$$\Delta h_{fusion,PCM} = Cp * \Delta T$$

$$\Delta T = \frac{\Delta h_{latent,PCM}}{Cp} = \frac{211.6}{4.186} = 50.5\ K = 50.5\ °C$$

Water temperature must be increased by 50.5 °C in STES system for same equivalent heat storage volume capacity of LTES system.

Exercise 4: Calculate the PCM melting point for an LTES tank if 5kg/s waste-water discharges heat at 50ºC, while 2kg/s of cooled water charges at 20ºC.

Given data:

Charging PCM using waste water.	Discharging PCM using cooled water.
Mass flowrate of waste water = m_{waste} = 5 kg/s Temperature of waste water = T_{waste} = 50 °C = 323.15 K	Mass flowrate of cooled water = m_{cooled} = 2 kg/s Temperature of cooled water = T_{cooled} = 20 °C = 293.15 K

Required: melting point of PCM (T_{PCM}).

Estimated maximum heat provided by waste water to PCM during charging is given as:

$$\dot{Q}_{max,charging} = \dot{m}_{waste} * Cp * (T_{waste} - T_{PCM})$$

Estimated maximum heat gained by cooled water from PCM during discharging is given as:

$$\dot{Q}_{max,discharging} = \dot{m}_{cooled} * Cp * (T_{PCM} - T_{cooled})$$

While selecting a PCM, it is desirable to choose PCM with melting point that can store and release the same amount of energy during charging and discharging, respectively.

$$\dot{Q}_{max,charging} = \dot{Q}_{max,discharging}$$

$$\dot{m}_{waste} * Cp * (T_{waste} - T_{PCM}) = \dot{m}_{cooled} * Cp * (T_{PCM} - T_{cooled})$$

$$T_{PCM} = \frac{\dot{m}_{waste} * T_{waste} + \dot{m}_{cooled} * T_{cooled}}{\dot{m}_{waste} + \dot{m}_{cooled}}$$

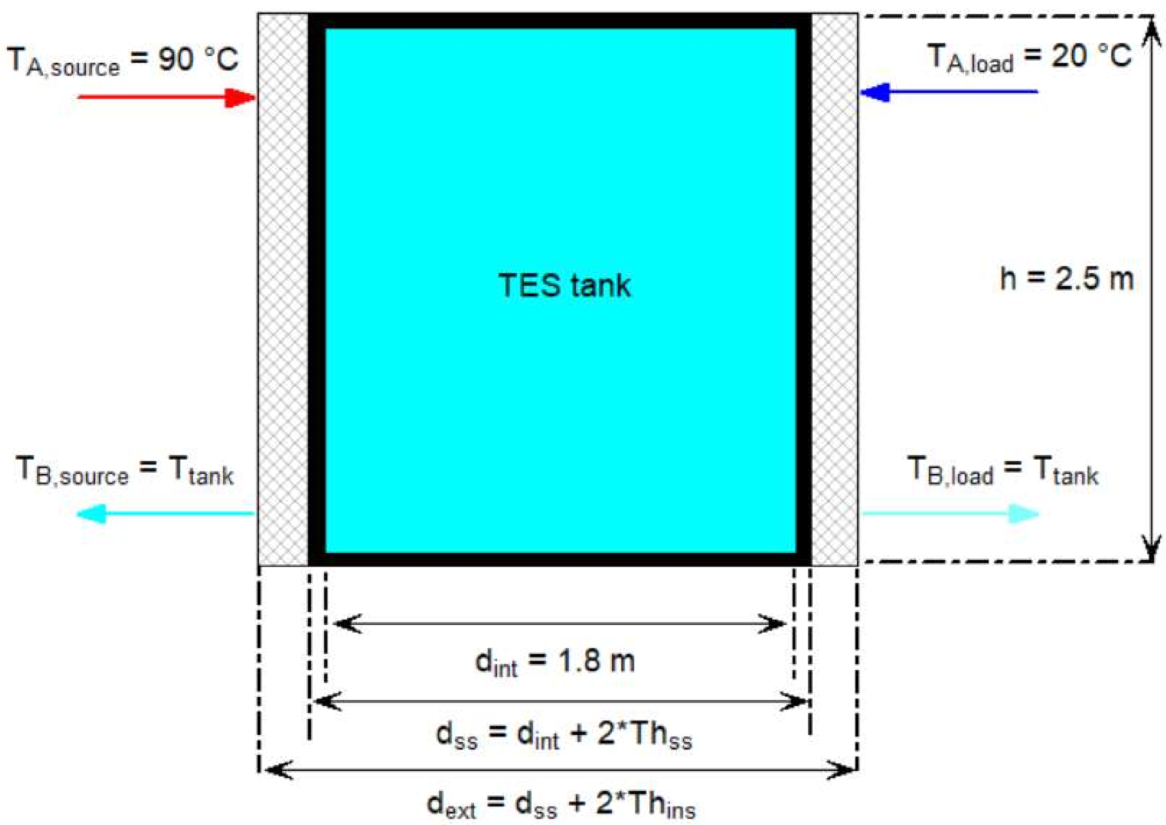
$$T_{PCM} = \frac{5 * 323.15 + 2 * 293.15}{5 + 2} = 314.57\ K = 41.3\ °C$$

The melting point of PCM selected should be 41.3 °C to store and release the same amount of energy during charging and discharging, respectively.

Micro Project: Case # 1

General input data: consider a tank of 1.8 m in diameter and 2.5 m tall. The tank material is stainless steel (ρ = 7900 kg/m^3 Cp = 510 J/kg/K, λ = 17 W/m/K) of 6 mm of thickness. It is insulated with mineral wool (λ = 0.035 W/m/K) of 10 cm and 25 cm of thickness in cases 1 (or 2) and 3 respectively. Ambient temperature is kept constant and equal to T_{ext} = 20°C. For all cases α_{int} = 23 W/m^{2}K and α_{ext} = 12 W/m^{2}K. Energy losses across both bottom and top sections can be neglected.

Case 1 specific input data: hot water is stored in the above-mentioned tank. Initially, 0 h (midnight) of the first day, the water in the tank is at uniform temperature, $T^{initial}$ = 20°C. Charging period is from 8 h to 16 h at constant conditions: $\dot{m}_S$ = 0.6 kg/s, T_A^S = 90°C. Discharging is from 13 h to 24 h, at also constant. conditions: $\dot{m}_L$ = 0.4 kg/s, T_A^L = 20°C. Evaluate the temperature evolution in the tank and the energy extracted from the source and delivered to the load for 5 days.
Apart from solving case for the specific input data, analyze the influence of at least two selected parameters (e.g., charging or discharging period, mass flow rates, inlet temperatures, etc.), and discuss the results.



Thermal Energy Storage Tank Schematic View

1a) System description

As shown in the figure, water is stored in a stainless-steel tank that is insulated using mineral wool. Tank is installed with two piping networks. The network on the left is used for circulation of hot water stream to store the heat in the tank-water (charging). On the other hand, the network on the right is used for utilization of stored heat when required (discharging).
The hot water is circulated through the tank from 8-16h while stored heat is utilized from 13-24h. This charging and discharging of heat cause the variation in temperature of tank-water. Initially (0h), both tank-water and environment are at equilibrium (20°C), but when the tank-water temperature is above ambient temperature, heat loss due to conduction and convection also plays role in variation in temperature of tank-water.

1b) Mathematical modelling

Assumptions:

1. The temperature of the water in the tank is uniform.
2. Loss of heat from top and bottom of the tank are neglected.
3. The temperature of water going towards the source and the load is equal to the temperature of water inside the tank at that instant.

Formulation:

Let $\dot{Q}_{source}$ is the energy per unit time supplied by the source, and it is given as:

$$\boxed{\dot{Q}_{source} = \dot{m}_s * Cp * (T_A^S - T_B^S) = \dot{m}_s * Cp * (T_A^S - T_{tank}^n)}$$

Where $\dot{m}_s$ is the mass flowrate of source circulated through the tank, Cp is the specific heat capacity of water, T_A^S is the source inlet temperature, T_B^S is the temperature of water flowing back to the source and T_{tank}^n is the temperature of water in the tank at any instant.

Let $\dot{Q}_{Load}$ is the energy per unit time supplied to the load, and it is given as:

$$\boxed{\dot{Q}_{Load} = \dot{m}_L * Cp * (T_B^L - T_A^L) = \dot{m}_L * Cp * (T_{tank}^n - T_A^L)}$$

Where $\dot{m}_L$ is the mass flowrate of load circulated through the tank, T_A^L is the temperature of water entering back inside the tank after supplying heat to the load and T_B^L is the temperature of water at which heat is supplied to the load.

Let $\dot{Q}_{Conv}$ is the energy loss per unit time due to conduction and convection, and it is given as:

$$\boxed{\dot{Q}_{loss} = UA * (T_{tank}^n - T_{ext})}$$

Where T_{ext} is the ambient temperature and UA is the overall conductivity. UA can be also written in terms of total resistance as $\frac{1}{R_{total}}$ and the total resistance can be calculated as:

$$\boxed{R_{total} = R_{int} + R_{ss} + R_{ins} + R_{ext}}$$

Internal convection resistance (R_{int})	Resistance of stainless steel (R_{ss})	Resistance of mineral wool (R_{ins})	External convection resistance (R_{ext})
$\frac{1}{\alpha_{int} * (pi * d_{int} * h)}$	$\frac{\ln\left({}^{d_{ss}}/{}_{d_{int}}\right)}{2 * pi * Th_{ss} * \lambda_{ss})}$	$\frac{\ln\left({}^{d_{ext}}/{}_{d_{ss}}\right)}{2 * pi * Th_{ins} * \lambda_{ins})}$	$\frac{1}{\alpha_{ext} * (pi * d_{ext} * h)}$

Where α_{int} and α_{ext} are the internal and external convection coefficients, respectively; λ_{ss} *and* λ_{ins} are conductivities of stainless steel and mineral wool; Th_{ss} and Th_{ins} are the thicknesses of the stainless steel and mineral wool insulation; and $d_{int}, d_{ss}, d_{ext}, and\ h$ are the tank dimensions as shown in the figure.

Let T_{tank}^{n} and T_{tank}^{n+1} are the temperatures of water in the tank observed at time instants t^{n} and t^{n+1}, respectively. Hence, the variation in the temperature of water inside the tank can be determined by applying energy balance on tank as following:

$$E_{in} - E_{out} = \frac{\Delta E}{\Delta t}$$

$$\dot{Q}_{source} - (\dot{Q}_{Load} + \dot{Q}_{loss}) = \frac{r * V * Cp * (T_{tank}^{n+1} - T_{tank}^{n})}{(t^{n+1} - t^{n})}$$

$$\boxed{T_{tank}^{n+1} = = T_{tank}^{n} + \frac{(\dot{Q}_{source} - \dot{Q}_{Load} - \dot{Q}_{loss}) * (t^{n+1} - t^{n})}{r * V * Cp}}$$

Where r is the density of water and V is the volume of water inside the tank. The volume can be calculated as:

$$V = pi * \frac{{d_{int}}^{2}}{4} * h$$

2a) Code description

The above system of equations is modelled using MATLAB to calculate the temperature of tank at any instant and to evaluate the temperature profile for 5 days. The code can be divided into five major segments.

1. Known Data

First, the known data in the problem statement has been written in the code and the data is categorized based on its type.

2. Initialization of Matrix

New matrices of proper rows and columns are initialized to record the unknown data.

3. Defining Initial conditions

After initializing the matrices, the initial conditions and assumptions are defined to make the program be able to run for the first time and become self-sustaining afterwards.

4. For loops

Two "For loops" are used in the code to produce the temperature profile over five days:
One child "For loop" to reiterate the code for 0 to 24h with step size of 0.1 hour (6 minutes) to determine the temperature profile over 24 hours.
One parent "For loop" to reiterate the child loop five times to determine temperature profile over 5 days.

5. If Conditions

Four "If conditions" are used inside the child "for loop" to justify the charging and discharging periods, which in results decides which factors in the energy balance will affect the temperature profile at any instant.

a) If t^n < 8h

$\dot{m}_S$ = 0 and $\dot{m}_L$ = 0
It implies that only conduction and convection heat loss will affect the water temperature inside tank, except the case of first day and initial 8 hours because in that specific case conduction and convection heat losses are also zero because of equilibrium with environment.

b) If t^n <= 8h and t^n < 13h

$\dot{m}_S$ = 0.6 kg/s and $\dot{m}_L$ = 0
It implies that at 8 O'clock, the water circulation of source through tank is turned on and now in addition to conduction and convection heat losses, source heat will affect the temperature profile of tank.

c) If t^n <= 13h and t^n <= 16h

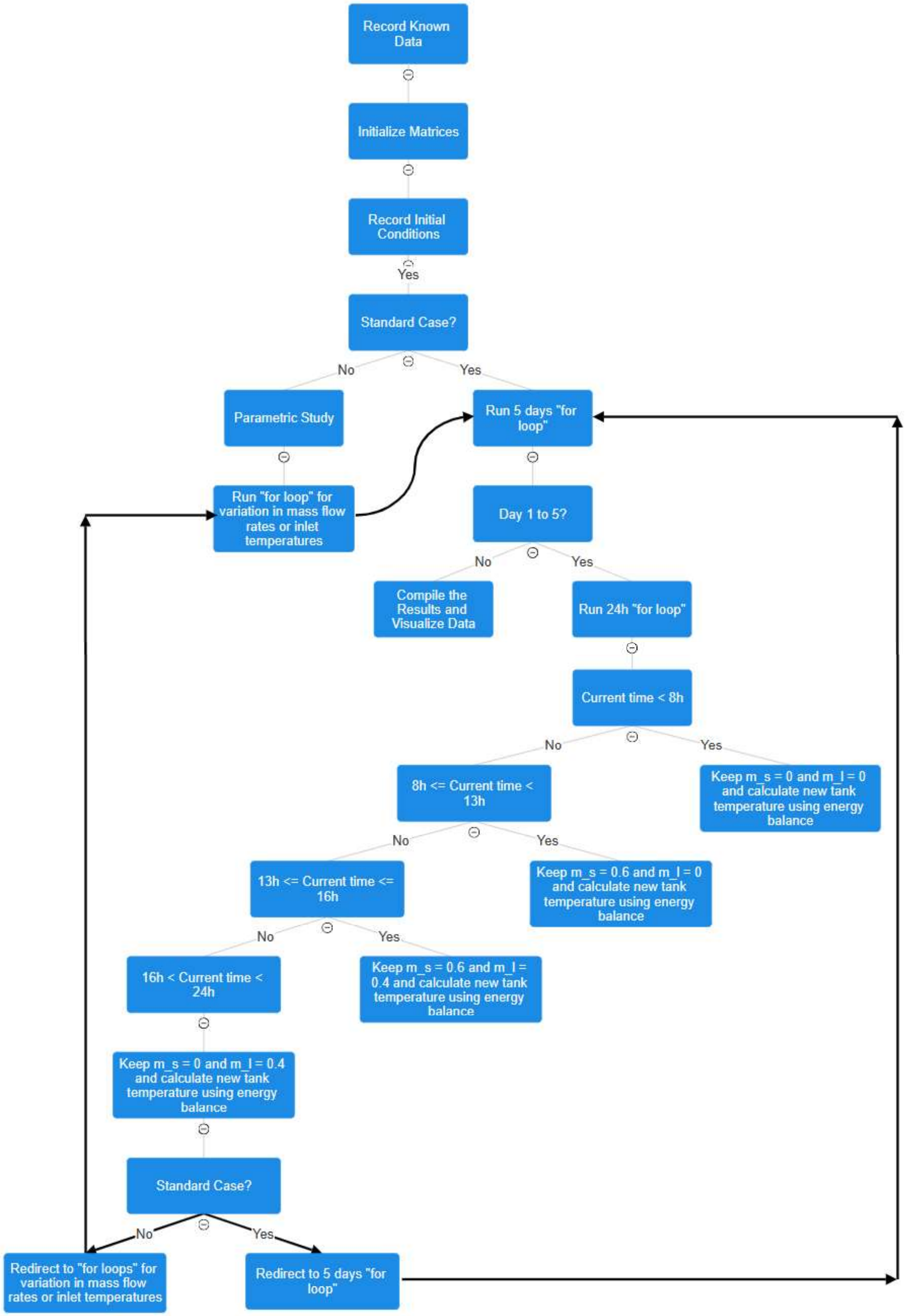
$\dot{m}_S$ = 0.6 kg/s and $\dot{m}_L$ = 0.4 kg/s
It implies that at 13 O'clock, the water circulation towards load is also turned on and the temperature profile of the water in the tank is also being affected by the load in addition to source water and heat losses from the tank.

d) If t^n < 16h and t^n <= 24h

$\dot{m}_S$ = 0 and $\dot{m}_L$ = 0.4 kg/s
It implies that at 16 O'clock, the source water circulation is turned off and only load water and heat losses from tank are factors that contribute to the variation in temperature of the water inside the tank. And at 24 O'clock, water circulation towards the load is also turned off.

6. Parametric Study

For parametric study, additional "super-parent for loop" is introduced over "parent for loop" to introduce variation in mass flowrate and inlet temperature of source and load.


Record Known Data
Initialize Matrices
Record Initial Conditions
Yes
Standard Case?
No
Yes
Parametric Study
Run "for loop" for variation in mass flow rates or inlet temperatures
Run 5 days "for loop"
Day 1 to 5?
No
Yes
Compile the Results and Visualize Data
Run 24h "for loop"
Current time < 8h
No
Yes
Keep m_s = 0 and m_l = 0 and calculate new tank temperature using energy balance
8h <= Current time < 13h
No
Yes
Keep m_s = 0.6 and m_l = 0 and calculate new tank temperature using energy balance
13h <= Current time <= 16h
No
Yes
Keep m_s = 0.6 and m_l = 0.4 and calculate new tank temperature using energy balance
16h < Current time < 24h
Keep m_s = 0 and m_l = 0.4 and calculate new tank temperature using energy balance
Standard Case?
No
Yes
Redirect to "for loops" for variation in mass flow rates or inlet temperatures
Redirect to 5 days "for loop"

2b) Code Verification

The following table shows the results obtained using the code. The step size of 0.1 hour (360 seconds) is considered to generate the results.

Day Count	Time of the Day (Hour)	Accumulative Time (Hour)	Tank-water Temperature (Kelvin)	Energy extracted from Source (kJ)	Energy Supplied to the Load (kJ)	Energy losses (kJ)
1	7.9	7.9	293.15	0.00	0	0.00
1	8	8	293.15	63201.60	0	0.00
1	8.1	8.1	295.53	61055.71	0	0.18
2	15.4	39.4	339.30	21530.27	27780.88	3.48
2	15.5	39.5	339.07	21742.62	27639.32	3.46
2	15.6	39.6	338.85	21942.95	27505.77	3.44

To verify the accuracy of code, we will do manual calculation using mathematical modelling in section 1b and compare the results from program and manual calculation.

1. Trail # 1

Let's consider the case of day one at 8h and calculate the temperature of water inside the tank at 8.1h.

Data:

t^{n+1} = 8.1h, t^{n} = 8h and Δt = 0.1h = 360 seconds.

T^{n}_{tank} = 293.15 K

T_{ext} = 293.15 K

T^{S}_{A} = 363.15 K

r = 1000 kg/m^3

d_{int} = 1.8 m and h = 2.5 m

Cp = 4.18 kJ/kg.K

$V = pi * \frac{{d_{int}}^{2}}{4} * h = 3.14 * \frac{1.8^{2}}{4} * 2.5 = 6.36$ m^3

As we know that

$$T^{n+1}_{tank} = = T^{n}_{tank} + \frac{(\dot{Q}_{source} - \dot{Q}_{Load} - \dot{Q}_{loss}) * (t^{n+1} - t^{n})}{\text{r} * \text{V} * \text{Cp}}$$

On the first day at 8h, only the source-water circulation is turned on, while load-water circulation is turned off. Also, the tank water temperature is equal to external temperature.
Therefore, $\dot{Q}_{Load}$ and $\dot{Q}_{Conv}$ are equal to zero. While $\dot{Q}_{Source}$ can be given as:

$$\dot{Q}_{source} = \dot{m}_{s} * Cp * (T^{S}_{A} - T^{S}_{B}) = 0.6 * 4.18 * (363.15 - 293.15) = 175.56\ kW$$

Energy extracted from the source = $\dot{Q}_{source} * \Delta\text{t} = 175.56 * 360 = 63201.6\ kJ$

$$T_{tank}^{n+1} = = 293.15 + \frac{63201.6}{1000 * 6.36 * 4.186} = 295.53\ K$$

Since the value of T_{tank}^{n+1} calculated both manually and using the MATLAB exactly match with each other, therefore, it can be concluded that the MATLAB code is correct.

2. Trail # 2

Let's consider the case of day two at 15.4h and calculate the temperature of water inside the tank at 15.5h.

Data:
t^{n+1} = 15.5h, t^{n} = 15.4h and Δt = 0.1h = 360 seconds.
T_{tank}^{n} = 339.30 K
T_{ext} = 293.15 K
T_A^S = 363.15 K
T_A^L = 293.15 K
r = 1000 kg/m^3
d_{int} = 1.8 m and h = 2.5 m
Cp = 4.18 kJ/kg.K
$V = pi * \frac{{d_{int}}^2}{4} * h$ = 3.14 * $\frac{1.8^2}{4}$ * 2.5 = 6.36 m^3
UA = 0.0002092 kW/K (calculated using formula of UA mentioned in mathematical modelling).

As we know that

$$T_{tank}^{n+1} = = T_{tank}^{n} + \frac{(\dot{Q}_{source} - \dot{Q}_{Load} - \dot{Q}_{loss}) * (t^{n+1} - t^{n})}{\mathrm{r} * \mathrm{V} * \mathrm{Cp}}$$

On the second day at 15.4h, since both hot source-water and cool load-water are circulating through tank and also the tank water temperature is also above external temperature; therefore, all the factors, $\dot{Q}_{source}, \dot{Q}_{Load}$ *and* $\dot{Q}_{loss}$, are playing role in variation of tank water temperature.
$\dot{Q}_{Source}$ can be given as:

$$\dot{Q}_{source} = \dot{m}_s * Cp * (T_A^S - T_B^S) = 0.6 * 4.18 * (363.15 - 339.30) = 59.81\ kW$$

Energy extracted from the source = $\dot{Q}_{source} * \Delta t = 59.81 * 360 = 21533.69\ kJ$

$\dot{Q}_{Load}$ can be given as:

$$\dot{Q}_{Load} = \dot{m}_L * Cp * (T_B^L - T_A^L) = 0.4 * 4.18 * (339.30 - 293.15) = 77.16\ kW$$

Energy supplied to the load = $\dot{Q}_{Load} * \Delta t = 77.16 * 360 = 27778.61\ kJ$

$\dot{Q}_{loss}$ can be given as:

$$Q_{loss}^{\cdot} = UA * (T_{tank}^{n} - T_{ext}) = 0.0002092 * (339.30 - 293.15) = 0.0096\ kW$$

Energy loss from the tank = $Q_{loss}^{\cdot} * \Delta t = 0.0146 * 360 = 3.48\ kJ$

$$T_{tank}^{n+1} = = 339.30 + \frac{21533.69 - 27778.61 - 3.48}{1000 * 6.36 * 4.186} = 339.06\ K$$

Since the value of T_{tank}^{n+1} calculated both manually and using the MATLAB exactly match with each other, therefore, it can be concluded that the MATLAB code is correct.

3) Results and Discussion

1- Standard case

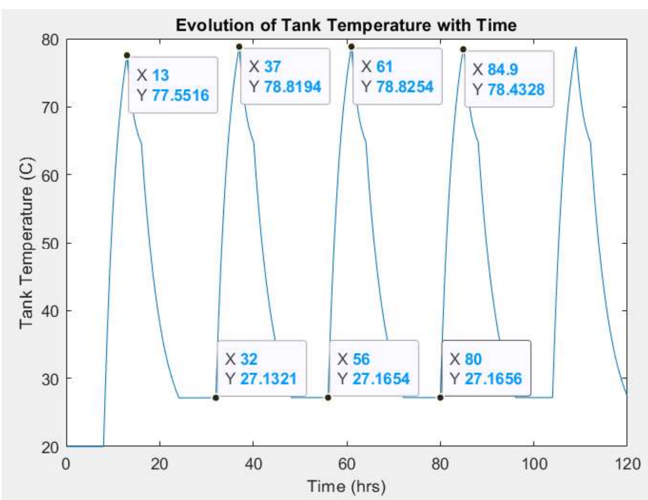


Figure 1a

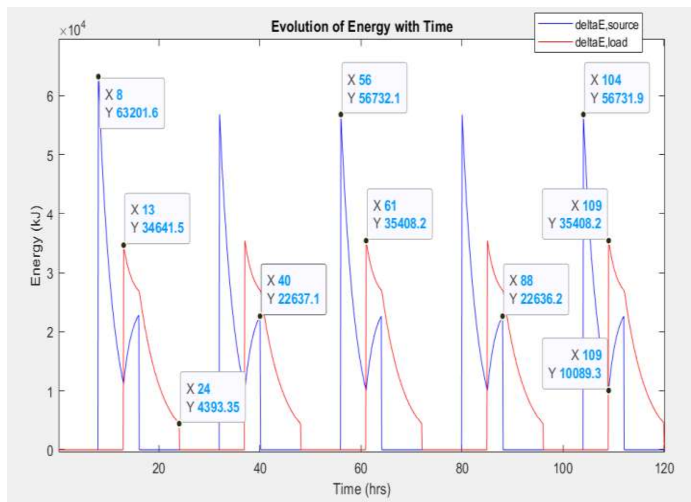


Figure 1b

Figure 1a shows the variation in temperature of water inside the tank with time over the course of 5 days (120 hours). Maximum temperatures are observed at the 13th hour of the day. On the other hand, minimum temperatures are observed at the 8th hour of the day. This can be explained by the charging and discharging periods. From 8 to 13th hour of the day, only source water circulation is turned on which causes the increase in temperature of tank water. However, at 13th hour, water circulation towards load is also turned on so the temperature starts decreasing and the temperature at 13th hour is recorded as peak temperature. At 16th hour, source water circulation is turned off, therefore a sharp decrease in temperature is observed until 24th hour of the day. Afterwards, from 0 to 8th hour of the day, only minor decrease in temperature is observed because of the loss of the heat from the tank due to conduction and convection. Thus, on the 8th hour of the day the tank temperature is recorded as a minimum.

In addition, it can also be observed that tank steady state maximum temperature reaches around 78 °C (difference of 12°C with source). This implies that we can store more energy if we can either increase the charging period or mass flowrate of the source. Similarly, the tank minimum temperature reaches around 27°C (7°C temperature difference with load inlet temperature limit).

This implies that we can utilize more energy if can increase the discharging period or load mass flowrate.

Figure 1b shows the variation in energy extracted by the source and supplied to the load with time over the course of 5 days. It can be observed that energy extracted from the source is inversely proportional to the tank temperature while the energy supplied to the load is directly proportional to the tank temperature. That is the main reason why the maximum values of energy extracted from the source are observed at the 8th hour of the day when the temperature of the tank is minimum. On the other hand, peaks of energy supplied to load align with the peaks of tank temperature.

2- Parametric study

a) Impact of source mass flowrate

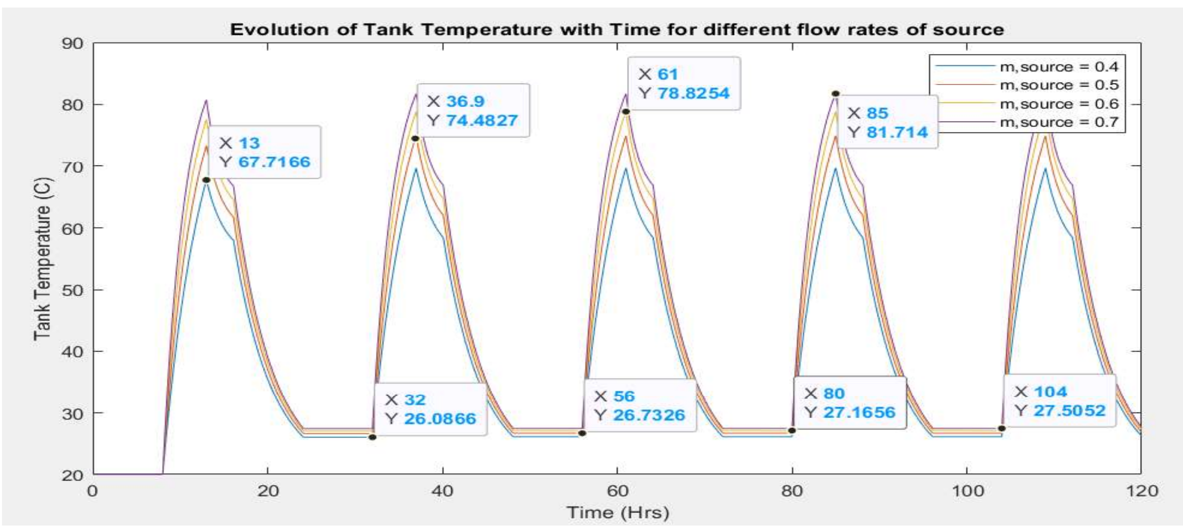


Figure 2a

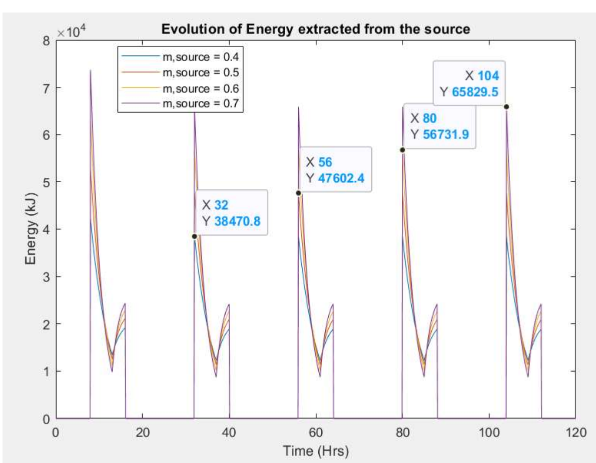


Figure 2b

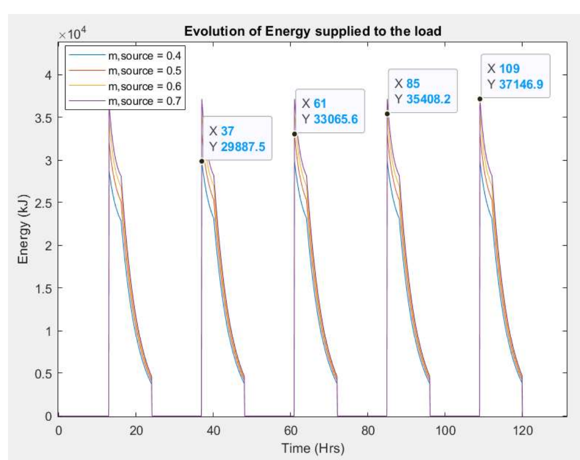


Figure 2c

Figure 2a shows the impact of mass flowrate of the source on temperature profile of the tank. It can be observed that as the source mass flowrate is increased, the maximum temperature that is achieved also increases. This can be explained using figure 2b. Increasing the mass flowrate of the source increases the rate of heating of water inside tank for same charging period. However, even though a significant change in maximum temperatures is observed, there is not a major difference between the minimum temperatures of the tank for different mass flowrates of the source. This can be explained using figure 2c. By increasing the tank temperature, we are also increasing the rate of heat transfer towards load and heat loss from the tank, and as the result, the minimum temperatures of the tank do not change significantly as compared to the maximum temperatures. However, it must be noted that the source flowrate can only be increased up to a certain limit. As source temperature is limited to 90 °C, increasing the source mass flowrate above a certain limit will require decreasing the charging period, else there will be no impact of increasing the source mass flowrate on tank temperature due to thermodynamic equilibrium between source and tank water.

b) Impact of load mass flowrate

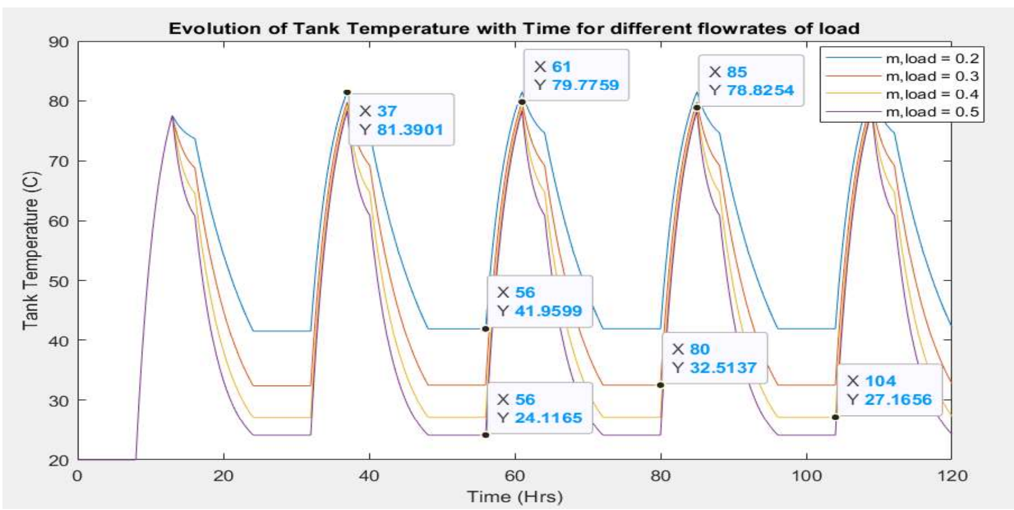


Figure 3a

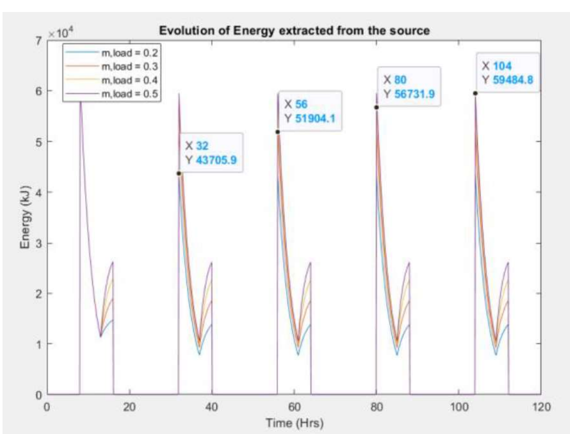


Figure 3b

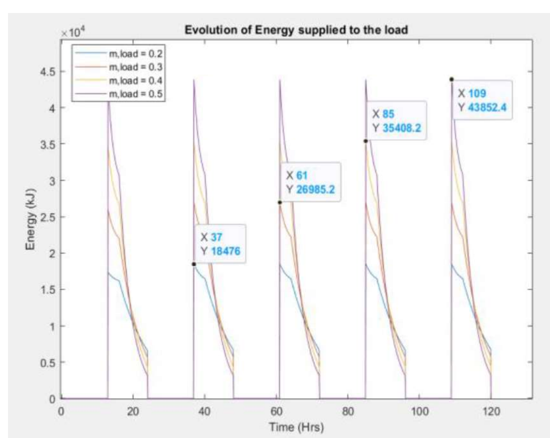


Figure 3c

Figure 3a shows the impact of mass flowrate circulation towards load on temperature profile of the tank with time over the course of 5 days. It can be observed that increasing the load mass flowrate significantly decreases the minimum temperature of the tank. On the other hand, the maximum temperature also decreases but not as significantly as minimum temperature. This can be explained using figure 3c. Increasing the mass flowrate of load increases the rate of heat extraction from tank for same discharging period, as the result the minimum temperatures also decrease. However, as shown in figure 3b, these reduced temperatures cause increased temperature difference for the source and the heat extraction from the source increases for same charging period. This explains the smaller change in maximum temperature compared to minimum temperature. However, it must be noted that the load flowrate can only be increased up to a certain limit. As load inlet temperature is limited to 20 °C, increasing the load mass flowrate above a certain limit will require decreasing the discharging period, else there will be no impact of increasing the load mass flowrate on tank temperature due to thermodynamic equilibrium between load and tank water.

c) Impact of source inlet temperature

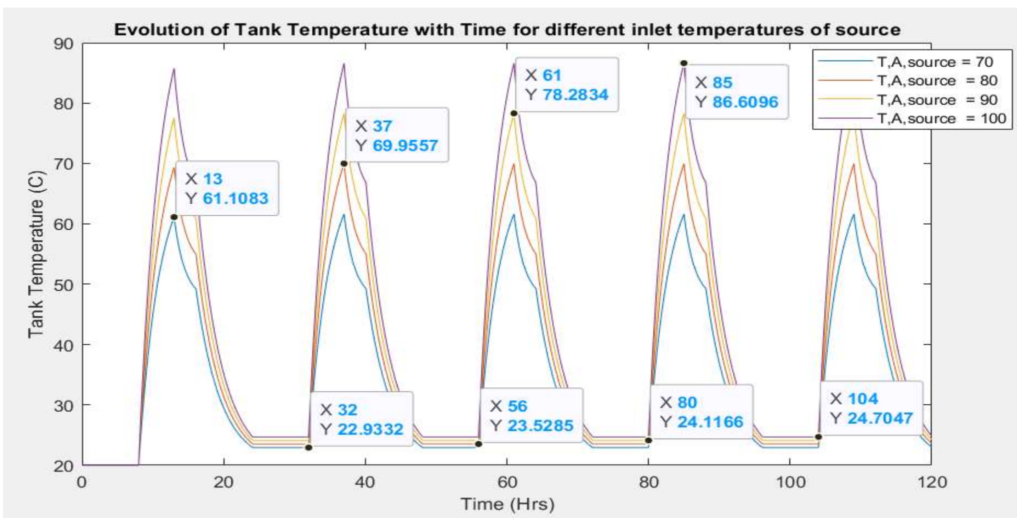


Figure 4a

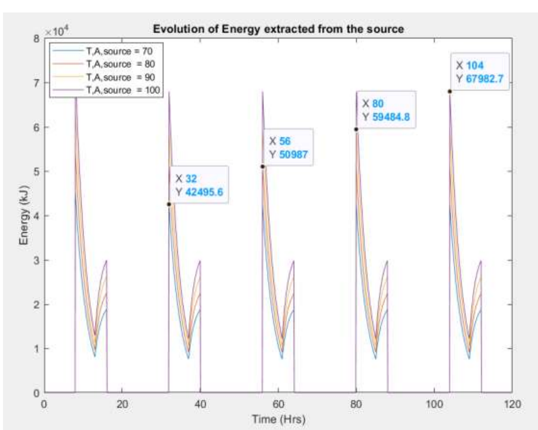


Figure 4b

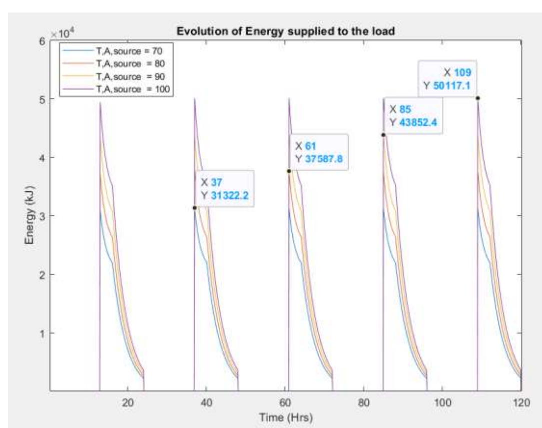


Figure 4c

Figure 4a shows the impact of source inlet temperature on temperature profile of tank water. It can be observed that increasing the source inlet temperature increases the maximum and minimum temperatures of tank water achieved. However, it can also be observed that it has more significant on maximum temperatures compared to the minimum temperatures. This can be explained using figure 4b. By increasing the source inlet temperature, we are increasing the rate of heat being extracted from the source for the same charging periods which results in increased maximum temperature. However, as shown in figure 4c, this also results in an increase in the rate of heat being supplied to the load for the same discharging period and the rate of heat loss from the tank which results in a sharp decrease in the tank temperature, making the increase in minimum temperatures relatively insignificant.

d) Impact of load inlet temperature

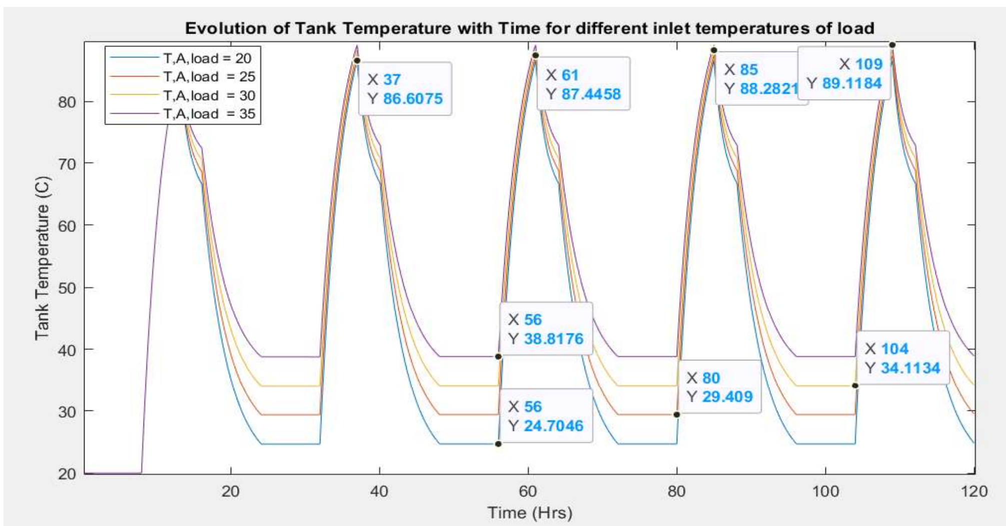


Figure 5a

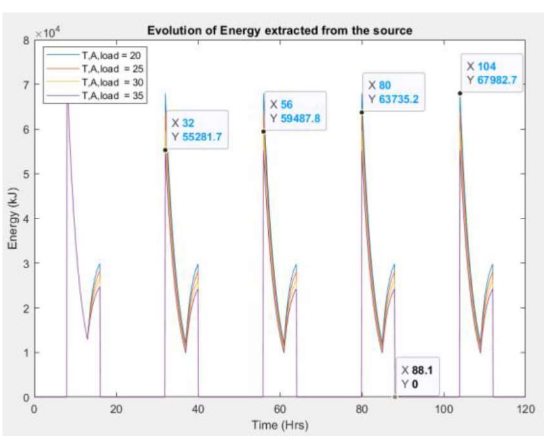


Figure 5b

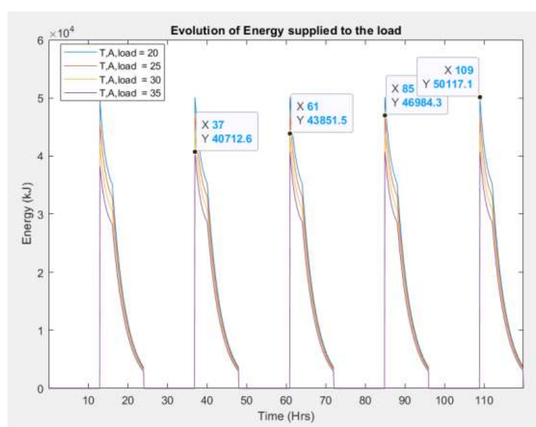


Figure 5c

Figure 5a shows the impact of load inlet temperature on the temperature profile of the tank water. It can be observed that increasing the load inlet temperature increases both maximum and minimum temperature of the tank. However, the impact is significant on minimum temperature compared to the maximum temperature. This can be explained using figure 5c. By increasing load inlet temperature, we are reducing the heat being supplied to the load which results in increased minimum temperature of tank. On the other hand, as shown in figure 5b, these increased temperatures result in reduction of heat being extracted from the source which results in less impact on maximum temperature of the tank.

4) Conclusion

In this report, the analysis of well mixed TES tank has been carried out. The system is modelled using MATLAB and the impact of source & load mass flowrate and inlet temperature on the temperature profile of the tank and the energy extracted from the source and energy supplied to the load has been studied.

From the analysis, it has been observed that increasing the source mass flowrate and inlet temperature has similar impact on the temperature profile. For same charging and discharging period, increasing both the parameters increases the maximum temperature and minimum temperature of the tank. However, the impact is significant on maximum temperature compared to the minimum temperature. Even though both methods allow us to increase the energy extracted from the source, the method with increasing the source mass flowrate is limited by source inlet temperature. Therefore, after increasing the source mass flowrate to a certain limit, charging period must be decreased. Otherwise, increasing the mass flowrate will have no impact due to thermodynamic equilibrium between source and tank water.

In addition, it has been observed that load parameters increase the maximum and minimum tank temperature when load mass flowrate is decreased, and load inlet temperature is increased, and unlike source parameters, they have significant impact on minimum temperature of tank temperature profile compared to the maximum temperature. Even though both methods can be used to increase the energy supplied to the load, the method where load mass flow rate is increased can only be applied to a certain limit, as it is limited by load inlet temperature. Therefore, after increasing the load mass flowrate to a certain limit, the discharging period must be decreased. Otherwise, increasing the load mass flowrate will have no impact due to thermodynamic equilibrium.