AL-MUSTAQBAL UNIVERSITY
Iraq - Babylon

RENEWABLE ENERGY TECHNOLOGY
Sustainable Path For a Carbon Free Future

Refrigeration and Air conditioning Techniques Engineering Department

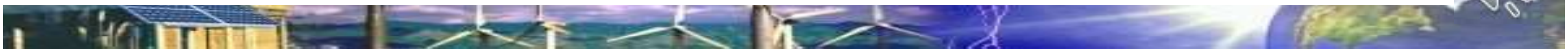
Subject : Renewable Energy

Grade: 4th Class First semester

Lecture: 9 Solar Thermal Storage

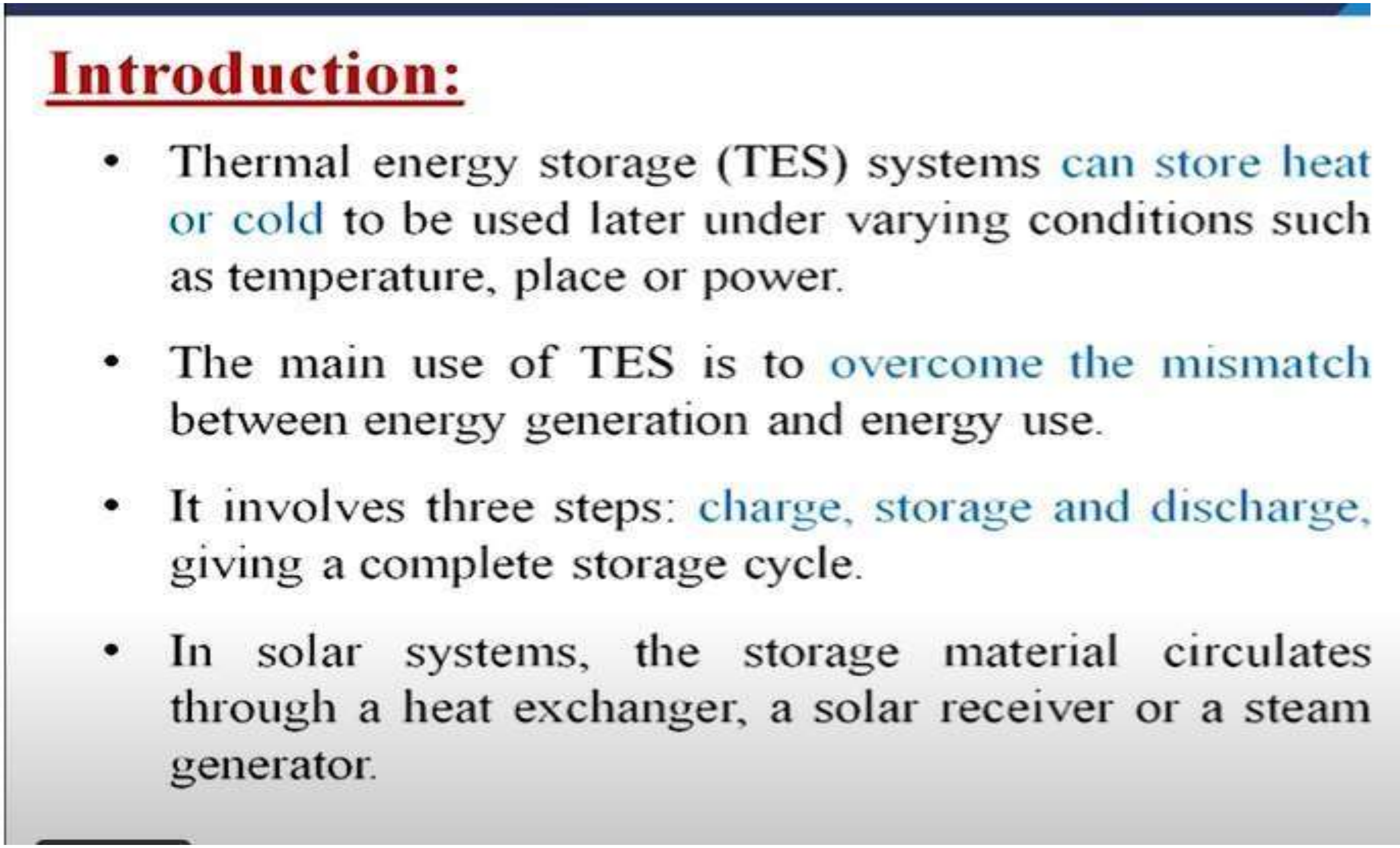
Dr.Eng. Azher M. Abed
Dr. Haleemah J. Mohammed

2023-2024



Solar Thermal Storage

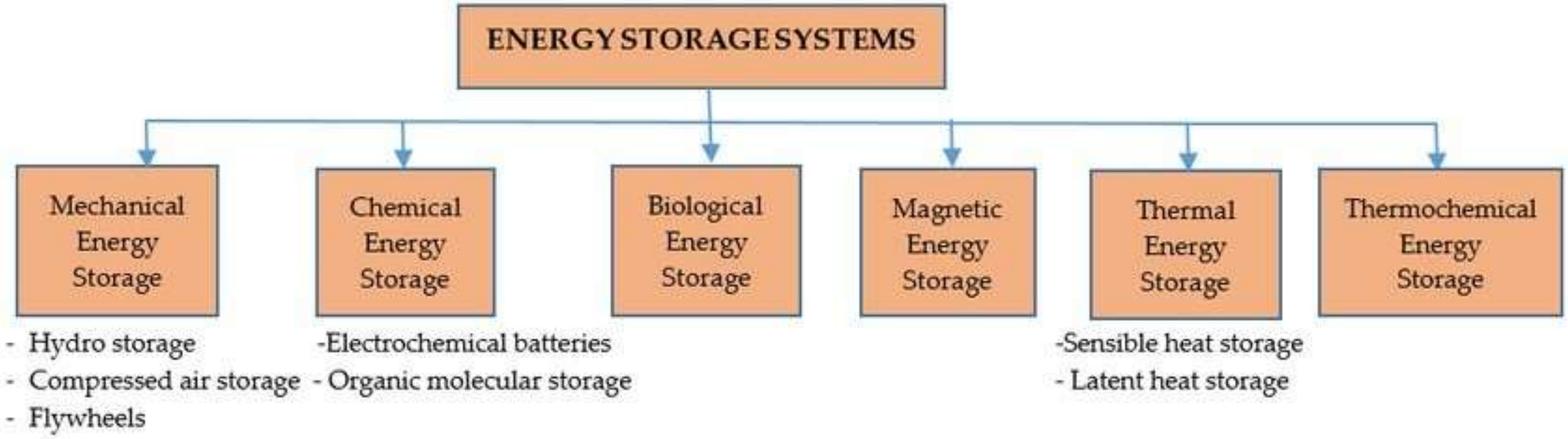
Solar Energy Storage



Introduction:

- Thermal energy storage (TES) systems can store heat or cold to be used later under varying conditions such as temperature, place or power.
- The main use of TES is to overcome the mismatch between energy generation and energy use.
- It involves three steps: charge, storage and discharge, giving a complete storage cycle.
- In solar systems, the storage material circulates through a heat exchanger, a solar receiver or a steam generator.

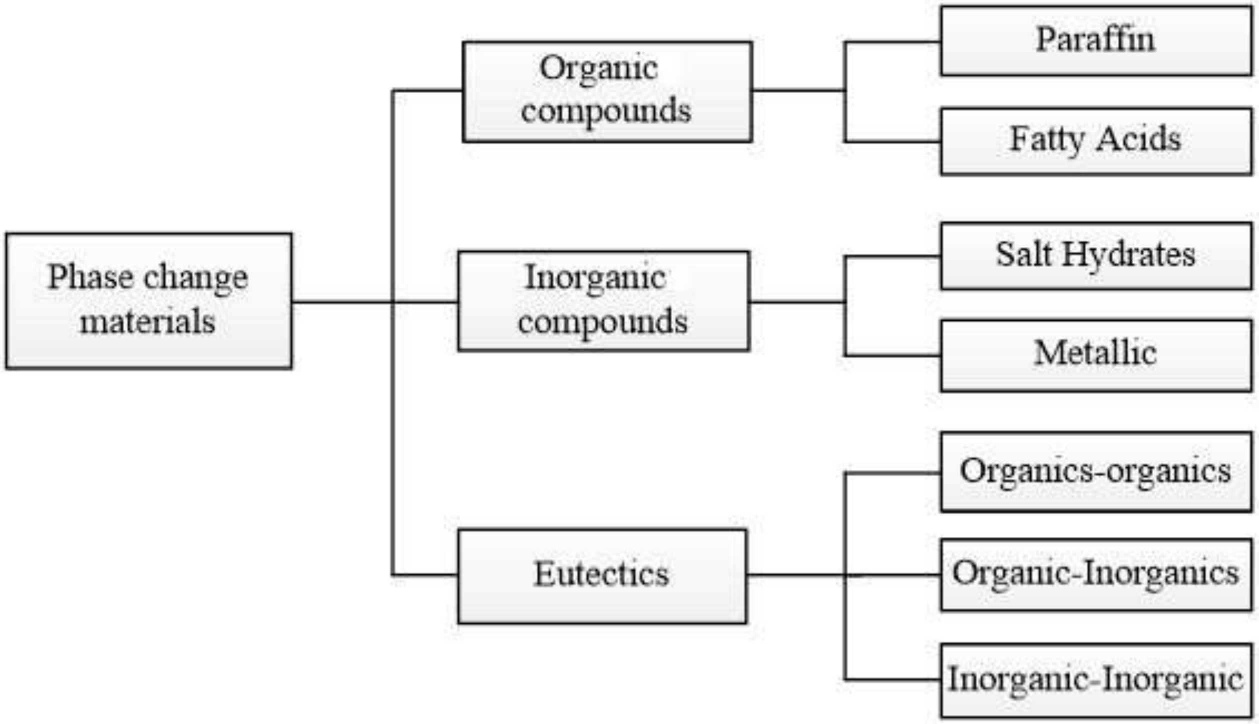
Solar Energy Storage



ENERGY STORAGE SYSTEMS

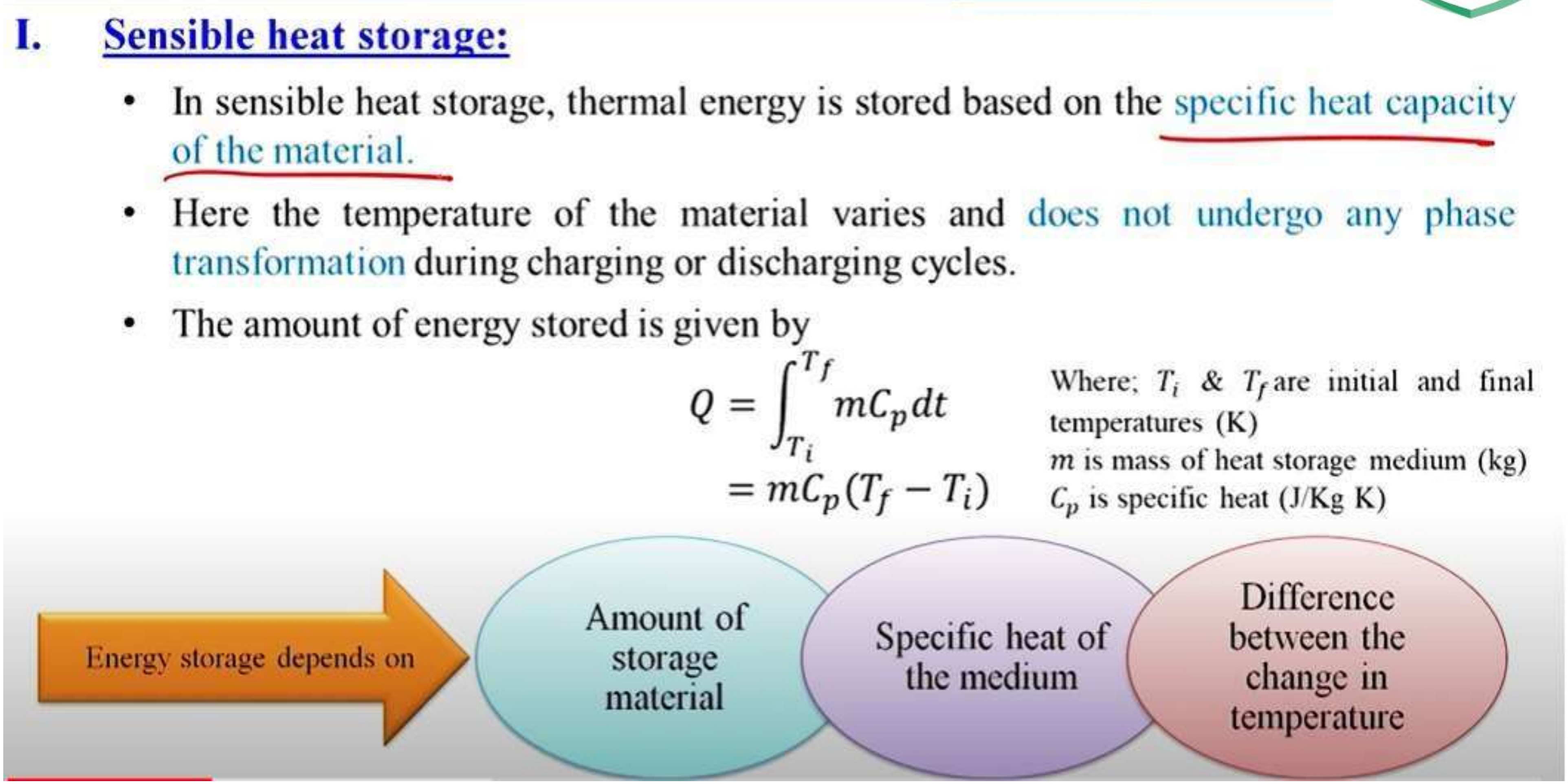
- Mechanical Energy Storage
  - Hydro storage
  - Compressed air storage
  - Flywheels
- Chemical Energy Storage
  - -Electrochemical batteries
  - - Organic molecular storage
- Biological Energy Storage
- Magnetic Energy Storage
- Thermal Energy Storage
  - -Sensible heat storage
  - - Latent heat storage
- Thermochemical Energy Storage

Solar Energy Storage



- Phase change materials
  - Organic compounds
    - Paraffin
    - Fatty Acids
  - Inorganic compounds
    - Salt Hydrates
    - Metallic
  - Eutectics
    - Organics-organics
    - Organic-Inorganics
    - Inorganic-Inorganic

Solar Energy Storage



I. Sensible heat storage:

- In sensible heat storage, thermal energy is stored based on the specific heat capacity of the material.
- Here the temperature of the material varies and does not undergo any phase transformation during charging or discharging cycles.
- The amount of energy stored is given by

$$Q = \int_{T_i}^{T_f} mC_p dt$$
$$= mC_p(T_f - T_i)$$

Where; T_i & T_f are initial and final temperatures (K)
m is mass of heat storage medium (kg)
C_p is specific heat (J/Kg K)

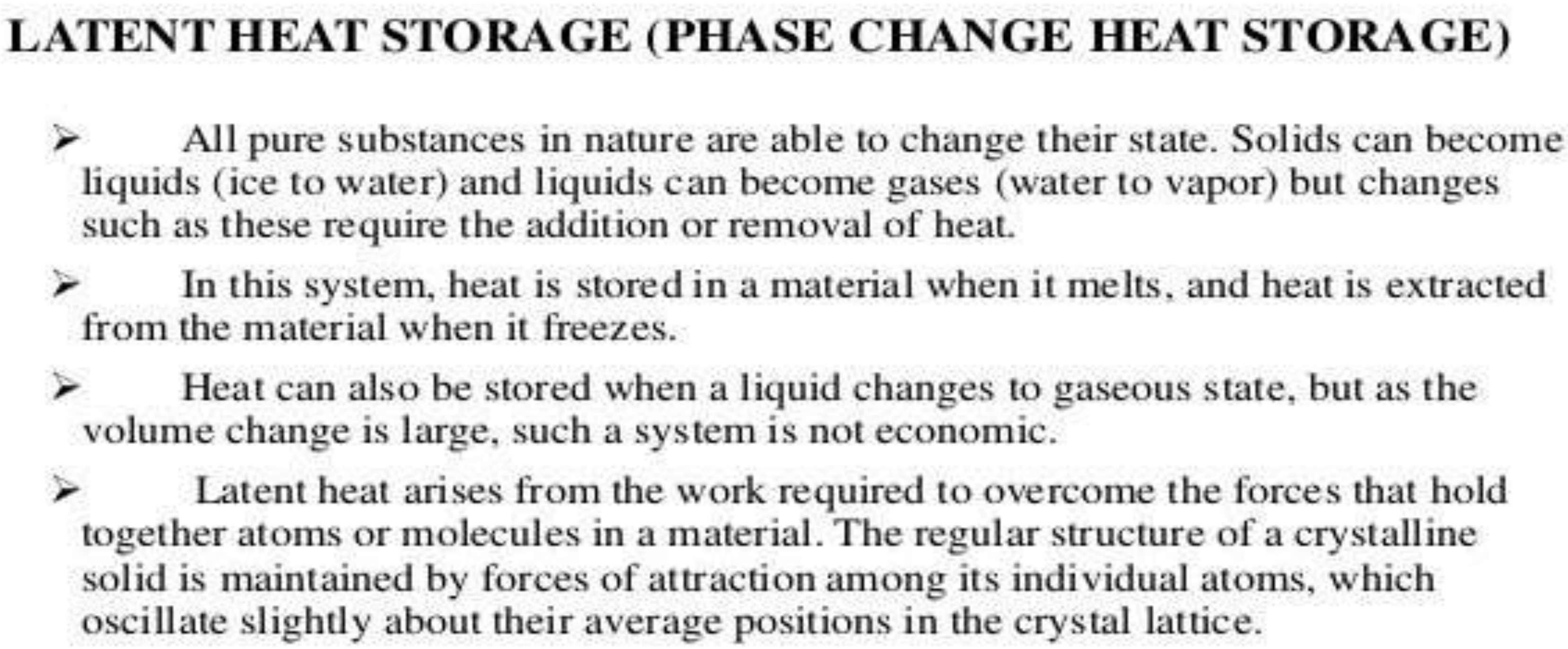
Energy storage depends on

Amount of storage material

Specific heat of the medium

Difference between the change in temperature

Solar Energy Storage

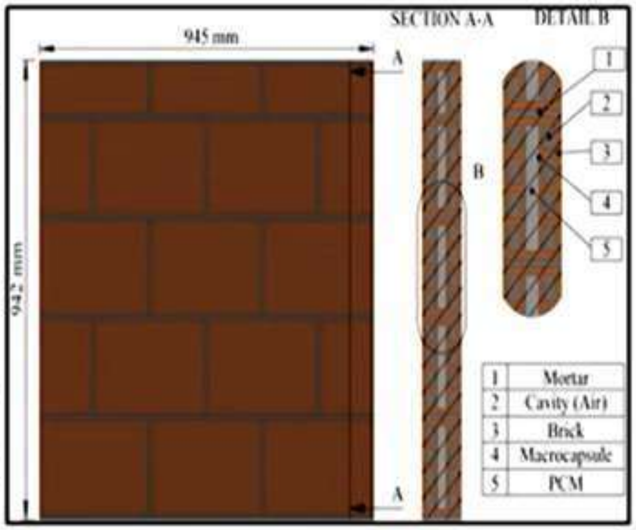


LATENT HEAT STORAGE (PHASE CHANGE HEAT STORAGE)

- All pure substances in nature are able to change their state. Solids can become liquids (ice to water) and liquids can become gases (water to vapor) but changes such as these require the addition or removal of heat.
- In this system, heat is stored in a material when it melts, and heat is extracted from the material when it freezes.
- Heat can also be stored when a liquid changes to gaseous state, but as the volume change is large, such a system is not economic.
- Latent heat arises from the work required to overcome the forces that hold together atoms or molecules in a material. The regular structure of a crystalline solid is maintained by forces of attraction among its individual atoms, which oscillate slightly about their average positions in the crystal lattice.

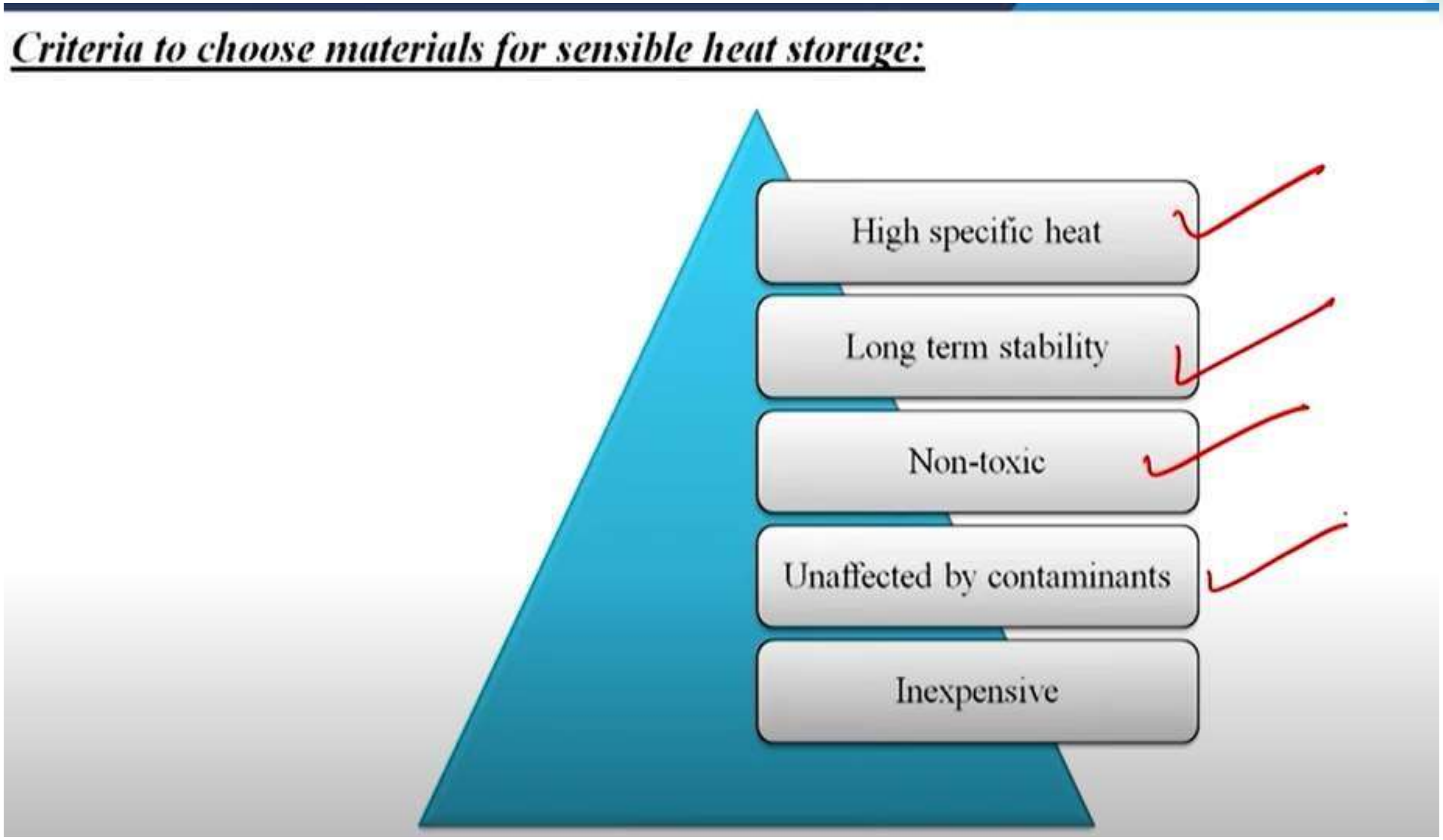
Solar Energy Storage

i. ***Solid storage media:***



- Solid TES materials such as sand, bricks, concrete, and rock etc. are used for both low and high temperature applications.
- The advantages of solid storage materials are low cost, no boiling, freezing and leakage during operation.
- However, the disadvantages include microbial activity due to heat and moisture and require higher volume for storing thermal energy.
- Thermal properties of various solid storage media depend on various parameters such as size, shape, porosity and material.
- Examples: Sand-rock minerals, reinforced concrete, magnesia fire bricks etc.

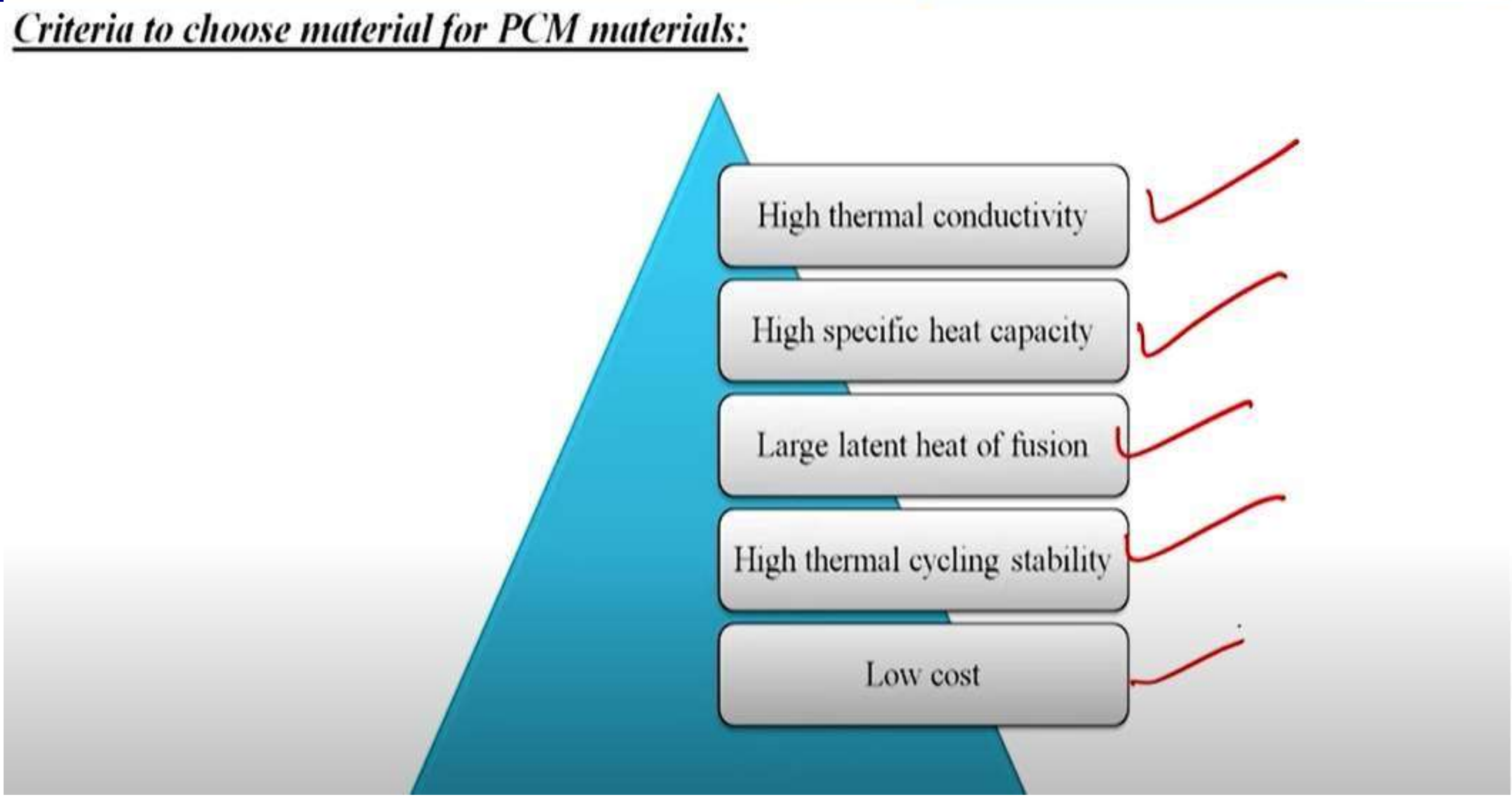
Solar Energy Storage



Criteria to choose materials for sensible heat storage:

- High specific heat ✓
- Long term stability ✓
- Non-toxic ✓
- Unaffected by contaminants ✓
- Inexpensive

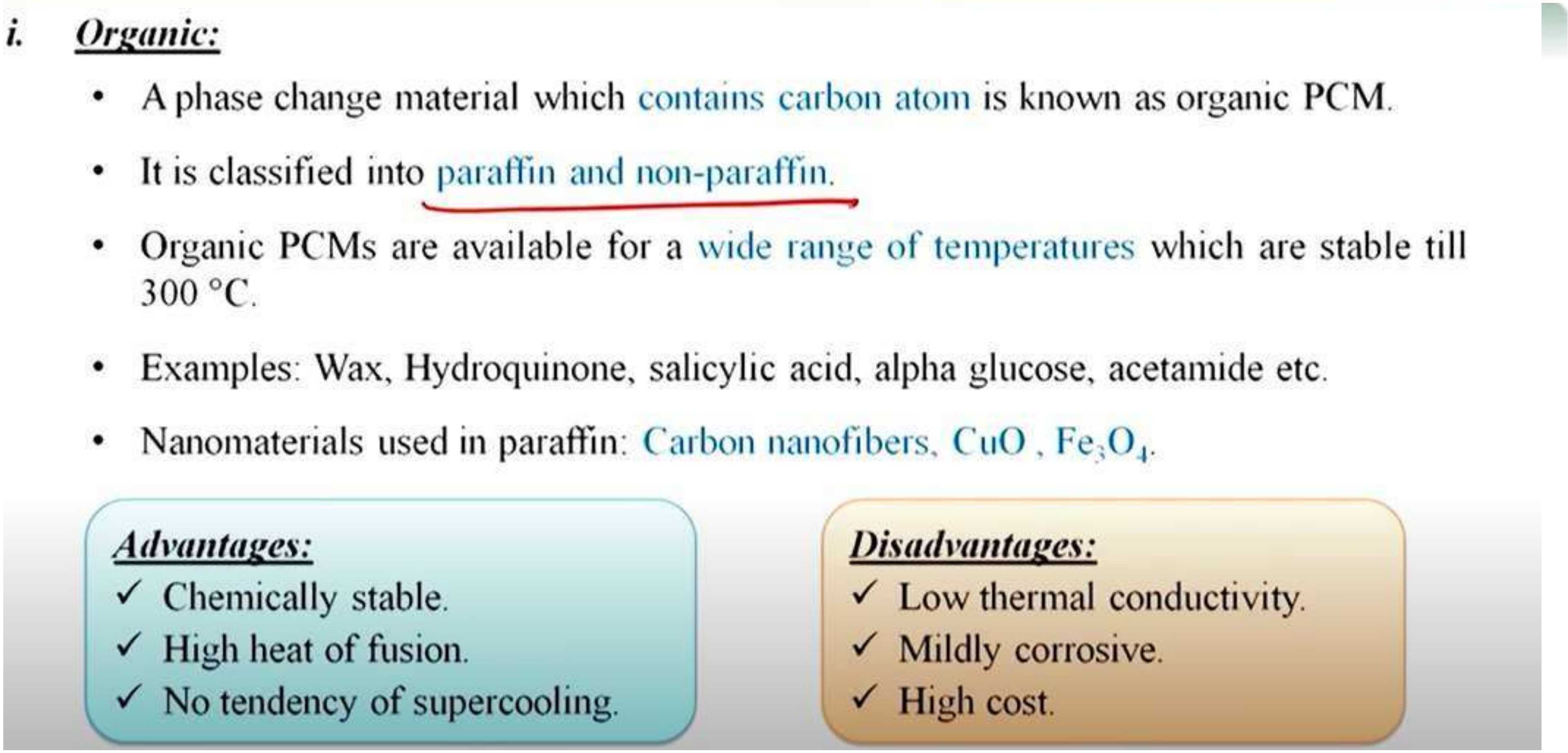
Solar Energy Storage



Criteria to choose material for PCM materials:

- High thermal conductivity ✓
- High specific heat capacity ✓
- Large latent heat of fusion ✓
- High thermal cycling stability ✓
- Low cost ✓

Solar Energy Storage



i. ***Organic:***

- A phase change material which contains carbon atom is known as organic PCM.
- It is classified into paraffin and non-paraffin.
- Organic PCMs are available for a wide range of temperatures which are stable till 300 °C.
- Examples: Wax, Hydroquinone, salicylic acid, alpha glucose, acetamide etc.
- Nanomaterials used in paraffin: Carbon nanofibers, CuO , Fe_3O_4.

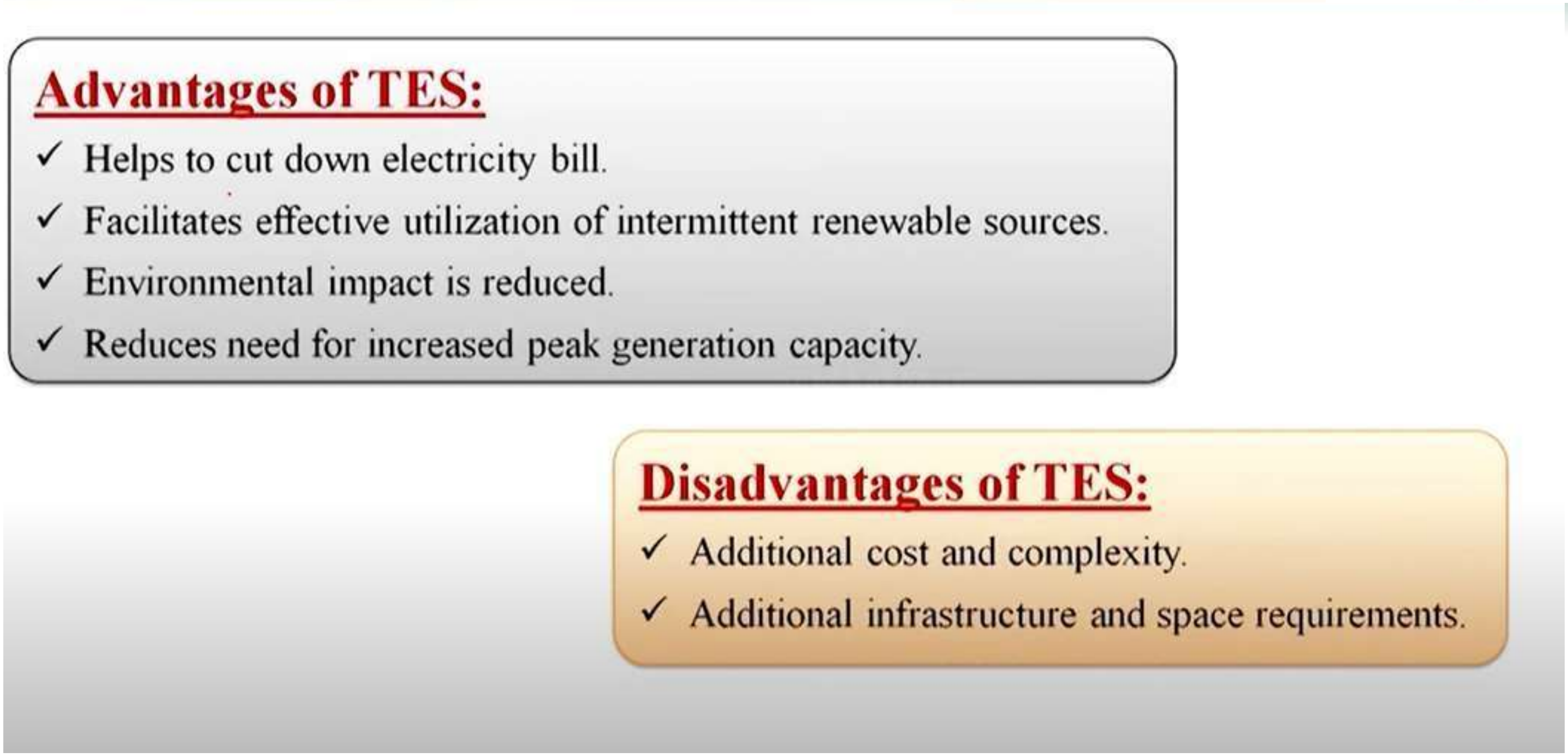
Advantages:

- ✓ Chemically stable.
- ✓ High heat of fusion.
- ✓ No tendency of supercooling.

Disadvantages:

- ✓ Low thermal conductivity.
- ✓ Mildly corrosive.
- ✓ High cost.

Solar Energy Storage



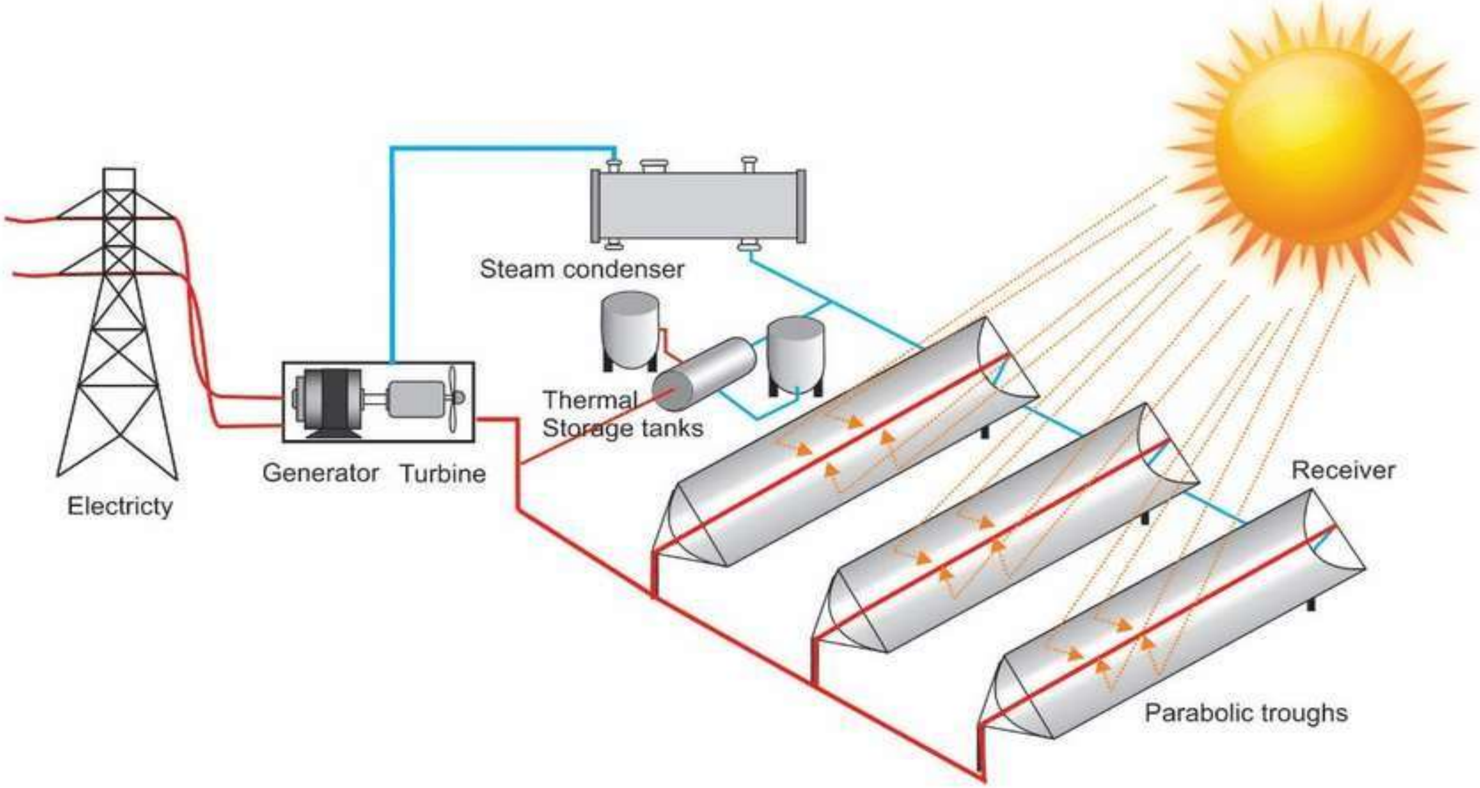
Advantages of TES:

- ✓ Helps to cut down electricity bill.
- ✓ Facilitates effective utilization of intermittent renewable sources.
- ✓ Environmental impact is reduced.
- ✓ Reduces need for increased peak generation capacity.

Disadvantages of TES:

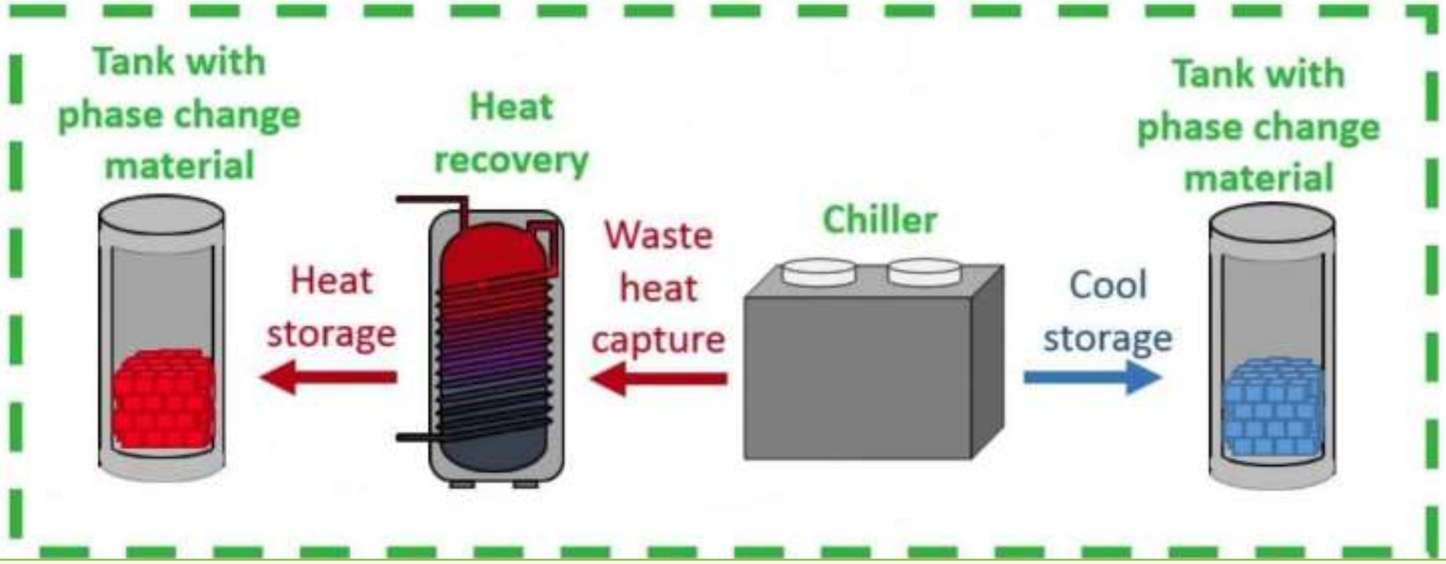
- ✓ Additional cost and complexity.
- ✓ Additional infrastructure and space requirements.

Solar Energy Storage



Schematic diagram of a SEGS plant with TES (thermal energy storage).

Solar Energy Storage



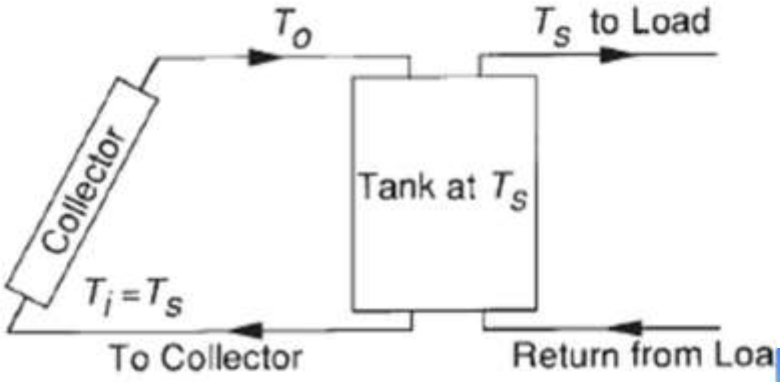
https://youtu.be/3oEofOg23VE

Heat Recovery and Thermal Energy Storage Integration

Thermal Analysis of Storage Systems

A relationship between the average collector temperature and the temperature at which heat is delivered to the load can be written as

$$
\begin{aligned}
T(\text{collector}) - T(\text{delivery}) = {} & \Delta T \ \ (\text{transport from collector to storage}) \\
& + \Delta T \ \ (\text{into storage}) \\
& + \Delta T \ \ (\text{storage loss}) \\
& + \Delta T \ \ (\text{out of storage}) \\
& + \Delta T \ \ (\text{transport from storage to application}) \\
& + \Delta T \ \ (\text{into application})
\end{aligned}
$$



WATER STORAGE

For many solar systems water is the ideal material in which to store usable heat. Energy is added to and removed from this type of storage unit by transport of the storage medium itself, thus eliminating the temperature drop between transport fluid and storage medium. Atypical system in which a water tank is used is shown in Figure 6.

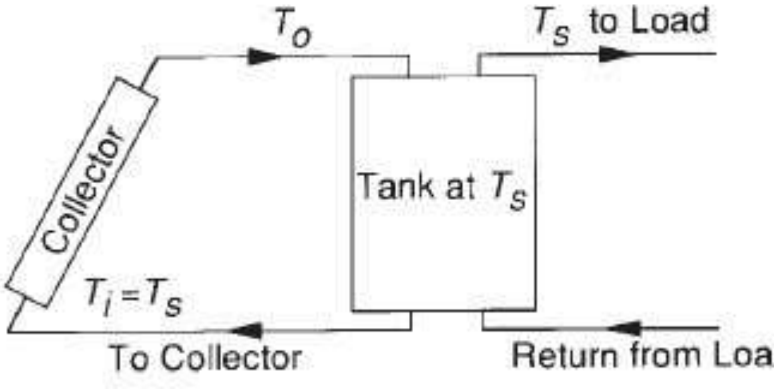
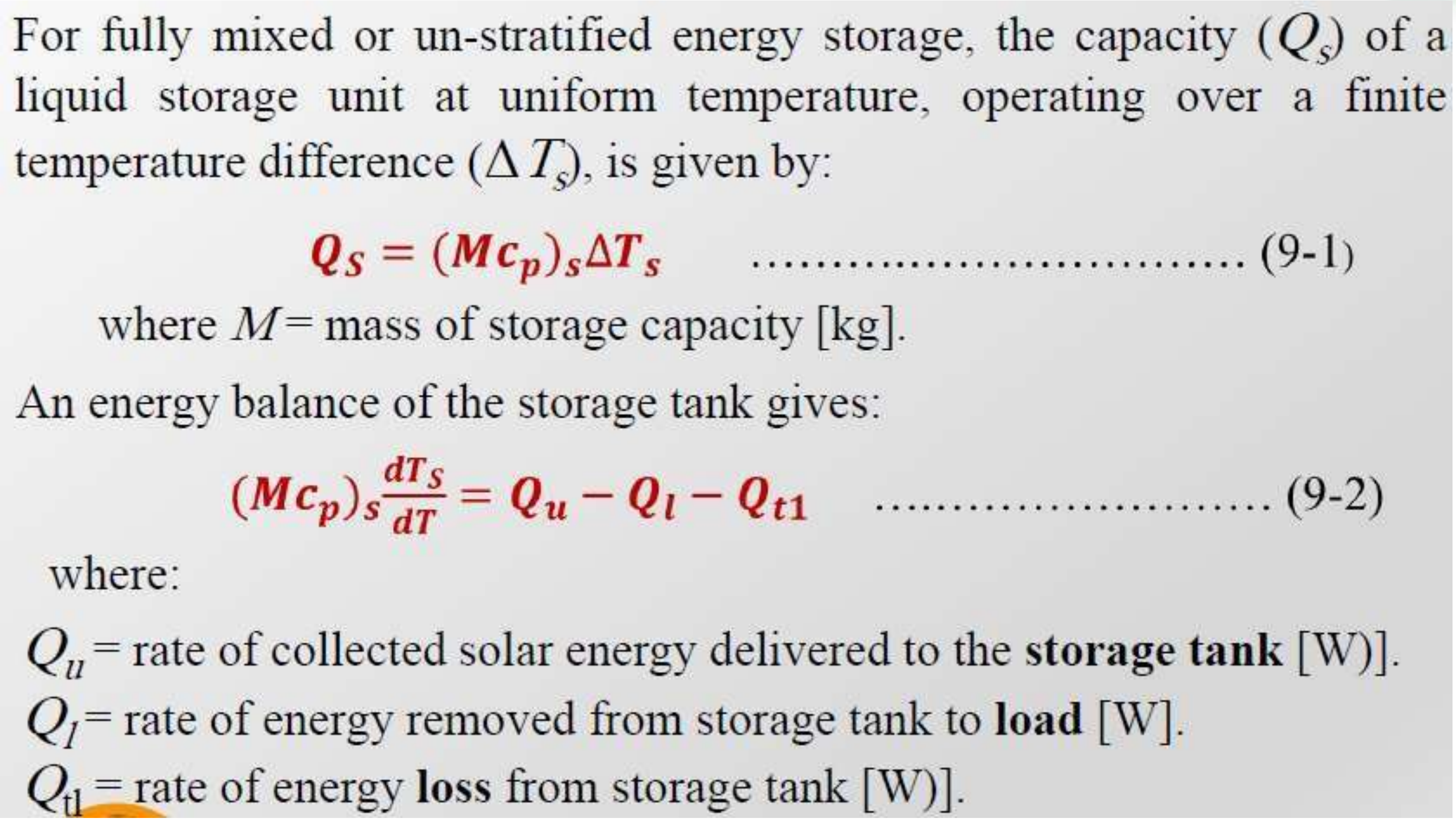


Figure 6 A typical system using water tank storage, with water circulation through collector to add energy and through the load to remove energy.

Thermal Analysis of Storage Systems



For fully mixed or un-stratified energy storage, the capacity (Q_s) of a liquid storage unit at uniform temperature, operating over a finite temperature difference (ΔT_s), is given by:

$$Q_S = (Mc_p)_s \Delta T_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9\text{-}1)$$

where M = mass of storage capacity [kg].

An energy balance of the storage tank gives:

$$(Mc_p)_s \frac{dT_S}{dT} = Q_u - Q_l - Q_{t1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9\text{-}2)$$

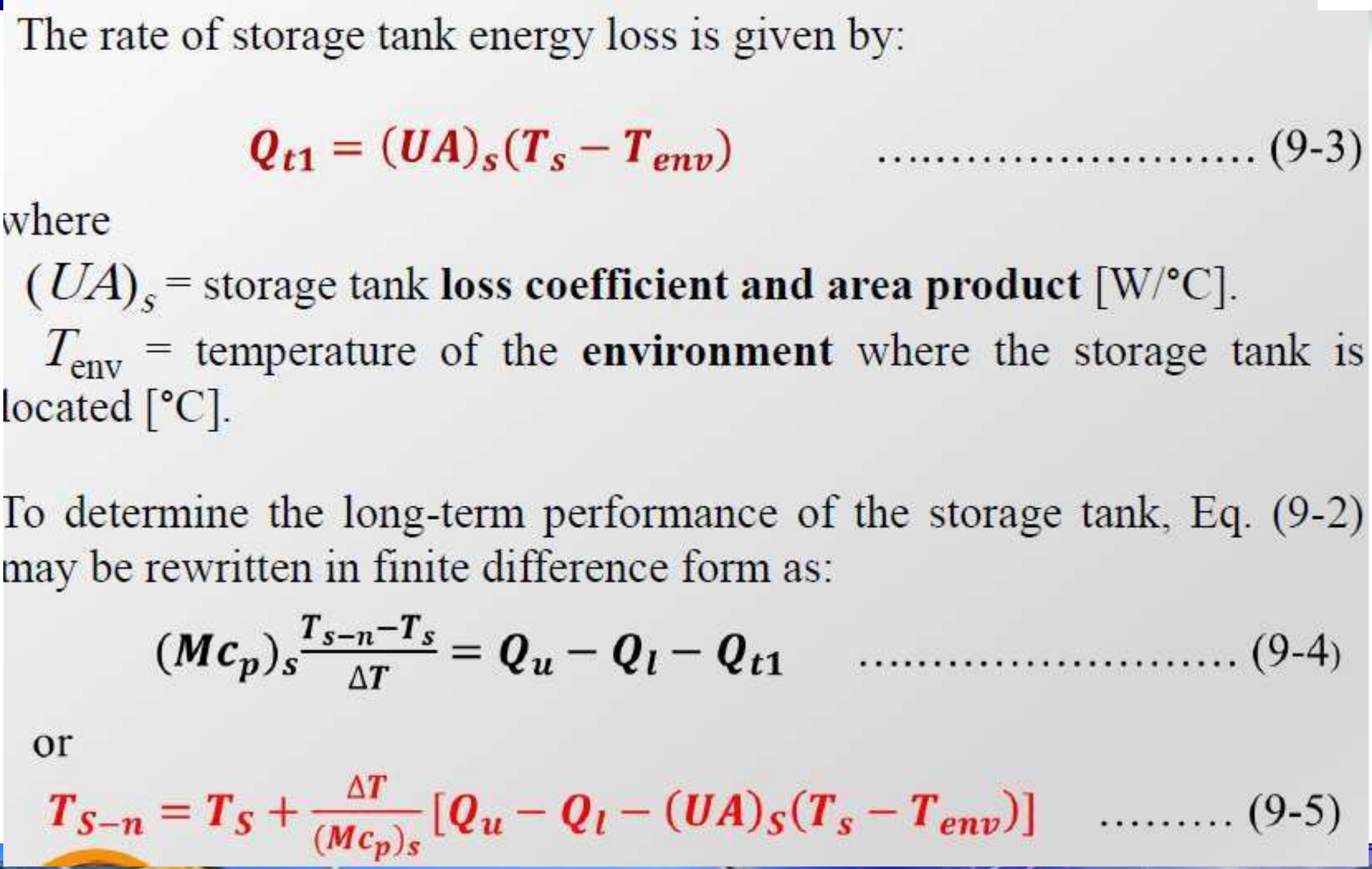
where:

Q_u = rate of collected solar energy delivered to the **storage tank** [W)].

Q_l = rate of energy removed from storage tank to **load** [W].

Q_{tl} = rate of energy **loss** from storage tank [W)].

Thermal Analysis of Storage Systems



The rate of storage tank energy loss is given by:

$$Q_{t1} = (UA)_s(T_s - T_{env}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9\text{-}3)$$

where

$(UA)_s$ = storage tank **loss coefficient and area product** [W/°C].

T_{env} = temperature of the **environment** where the storage tank is located [°C].

To determine the long-term performance of the storage tank, Eq. (9-2) may be rewritten in finite difference form as:

$$(Mc_p)_s \frac{T_{s-n} - T_s}{\Delta T} = Q_u - Q_l - Q_{t1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9\text{-}4)$$

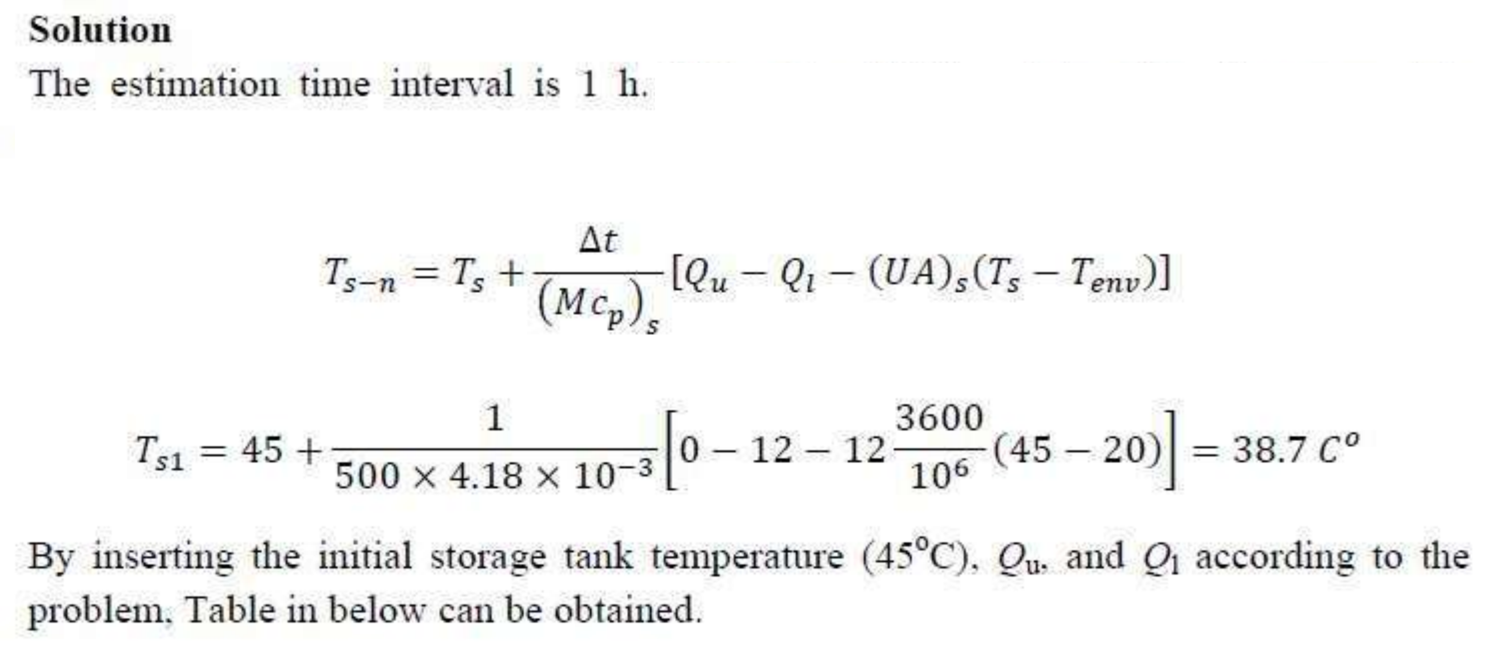
or

$$T_{S-n} = T_S + \frac{\Delta T}{(Mc_p)_s}[Q_u - Q_l - (UA)_S(T_s - T_{env})] \qquad \ldots\ldots\ldots (9\text{-}5)$$

Thermal Analysis of Storage Systems

Example :1

A fully mixed water storage tank contains 500 kg of water, has a *UA* product equal to 12 W/°C, and is located in a room that is at a constant temperature of 20°C. The tank is examined in a 10 h period starting from 5 am where the Q_u is equal to 0, 0, 0, 10, 21, 30, 40, 55, 65, 55 MJ. The load is constant and equal to 12 MJ in the first 3 h, 15 MJ in the next 3 h, and 25 MJ the rest of time. Find the final storage tank temperature if the initial temperature is 45 °C.



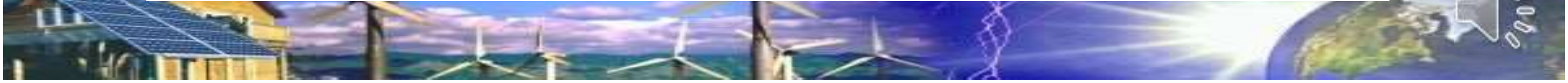
Solution

The estimation time interval is 1 h.

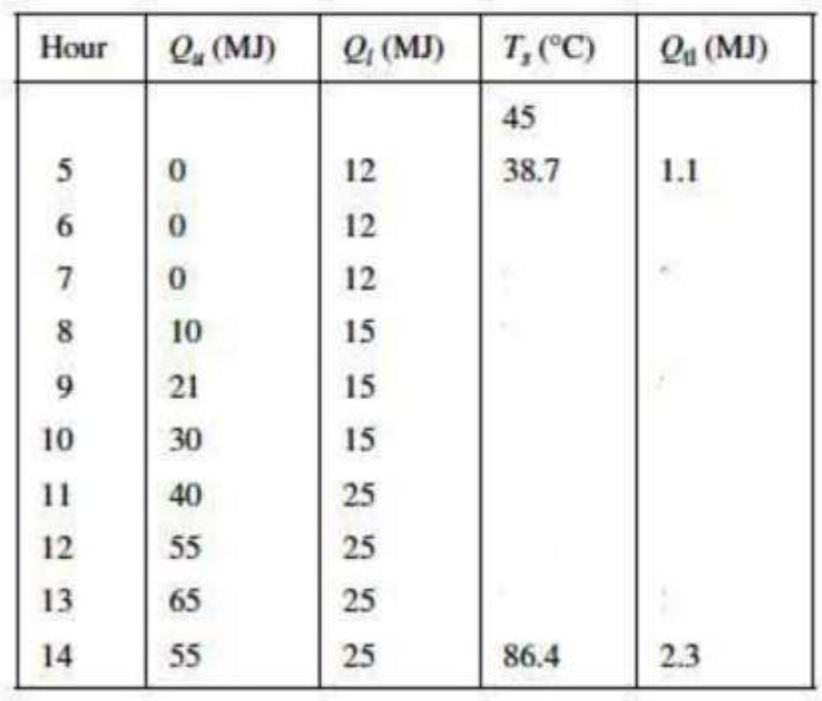
$$T_{s-n} = T_s + \frac{\Delta t}{\left(Mc_p\right)_s}\left[Q_u - Q_l - (UA)_s(T_s - T_{env})\right]$$

$$T_{s1} = 45 + \frac{1}{500 \times 4.18 \times 10^{-3}}\left[0 - 12 - 12\frac{3600}{10^6}(45 - 20)\right] = 38.7\ C^o$$

By inserting the initial storage tank temperature (45°C), Q_u, and Q_l according to the problem, Table in below can be obtained.



Thermal Analysis of Storage Systems



Hour	Q_u (MJ)	Q_l (MJ)	T_s (°C)	Q_{tl} (MJ)
			45	
5	0	12	38.7	1.1
6	0	12		
7	0	12		
8	10	15		
9	21	15		
10	30	15		
11	40	25		
12	55	25		
13	65	25		
14	55	25	86.4	2.3

Therefore, the final storage tank temperature is 86.4°C. For these calculations, the use of a spreadsheet program is recommended.

Do You Have Any Questions?