University of Al−Mustansiriyah − College of Engineering
Department of Mechanical Engineering

Phase Change and Applications I

First Semester − Fall 2020

Lecture (3):

Phase Change Materials (PCM) Storage

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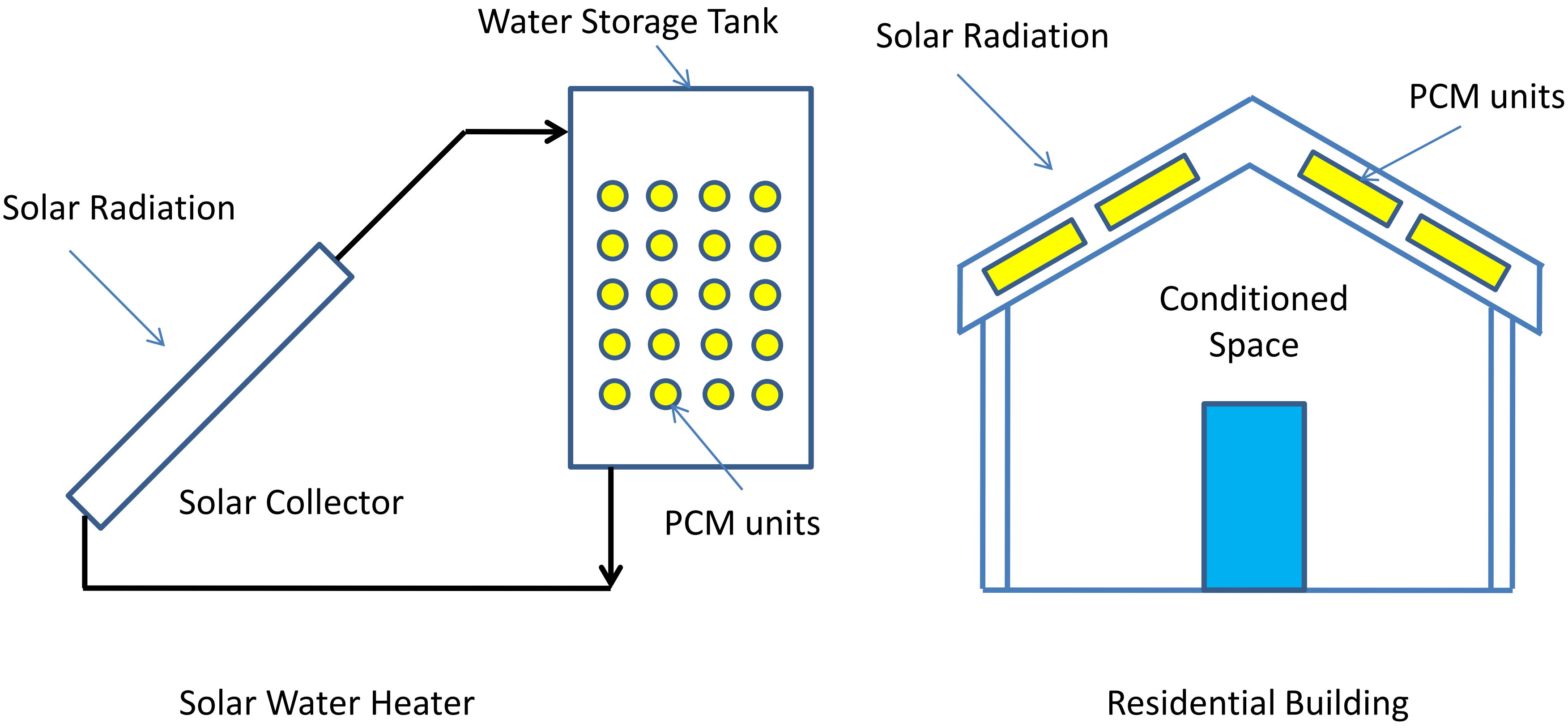
Phase Change Material (PCM)

It is defined as any material that can be used to store or release thermal energy while its phase changes. The processes that are commonly used in engineering are melting associated with absorption of heat and solidification accompanied by the release of heat.

Properties of a feasible PCM

1) Large latent heat (h_{fg}).
2) High thermal conductivity (k).
3) Melting temperature should be within practical range.
4) Has a congruent (homogeneous) melting with minimum subcooling.
5) Chemically stable (does not react with other materials or decomposes).
6) Non toxic and non corrosive.
7) Low in cost.


Water Storage Tank
Solar Radiation
Solar Collector
PCM units
Solar Water Heater
Solar Radiation
PCM units
Conditioned Space
Residential Building

Applications of PCM storage

The use of any PCM depends on its melting temperature (T_m). Accordingly, the common uses of PCMs can be categorized as follows:−

- When (T_m) is **below 15 ºC** the PCM is used in cold storage in air conditioning applications.
- When (T_m) is **between 15 ºC and 90 ºC** the PCM is used to store the surplus collected solar energy and in heat load leveling applications.
- When (T_m) is **above 90 ºC** the PCM is used in absorption refrigeration.

Types of phase change materials (PCMs)

The common types of PCMs used in practice are:−

- Paraffin Waxes (organic)
- Hydrated salts (inorganic)
- Fatty acids (organic)
- Eutectics of organic and non−organic compounds

Paraffin Waxes

They are heavy organic hydrocarbons resulted as byproducts after refining crude oil.

Advantages of Paraffin Waxes

Commercial paraffin waxes are excellent PCMs because they:−

- ❖ Have moderate storage density (~200 kJ/kg or 150 MJ/m^3).
- ❖ Have a wide range of melting temperature depending on chemical formula.
- ❖ Undergo negligible subcooling.
- ❖ Are chemically inert.
- ❖ Are stable with no phase segregation.
- ❖ Are cheap in price.

Disadvantages of Paraffin Waxes

The main disadvantage of paraffin waxes is the low thermal conductivity (~0.2 W/m ^{o}C). Therefore heat transfer enhancement methods should be used.

Hydrated Salts

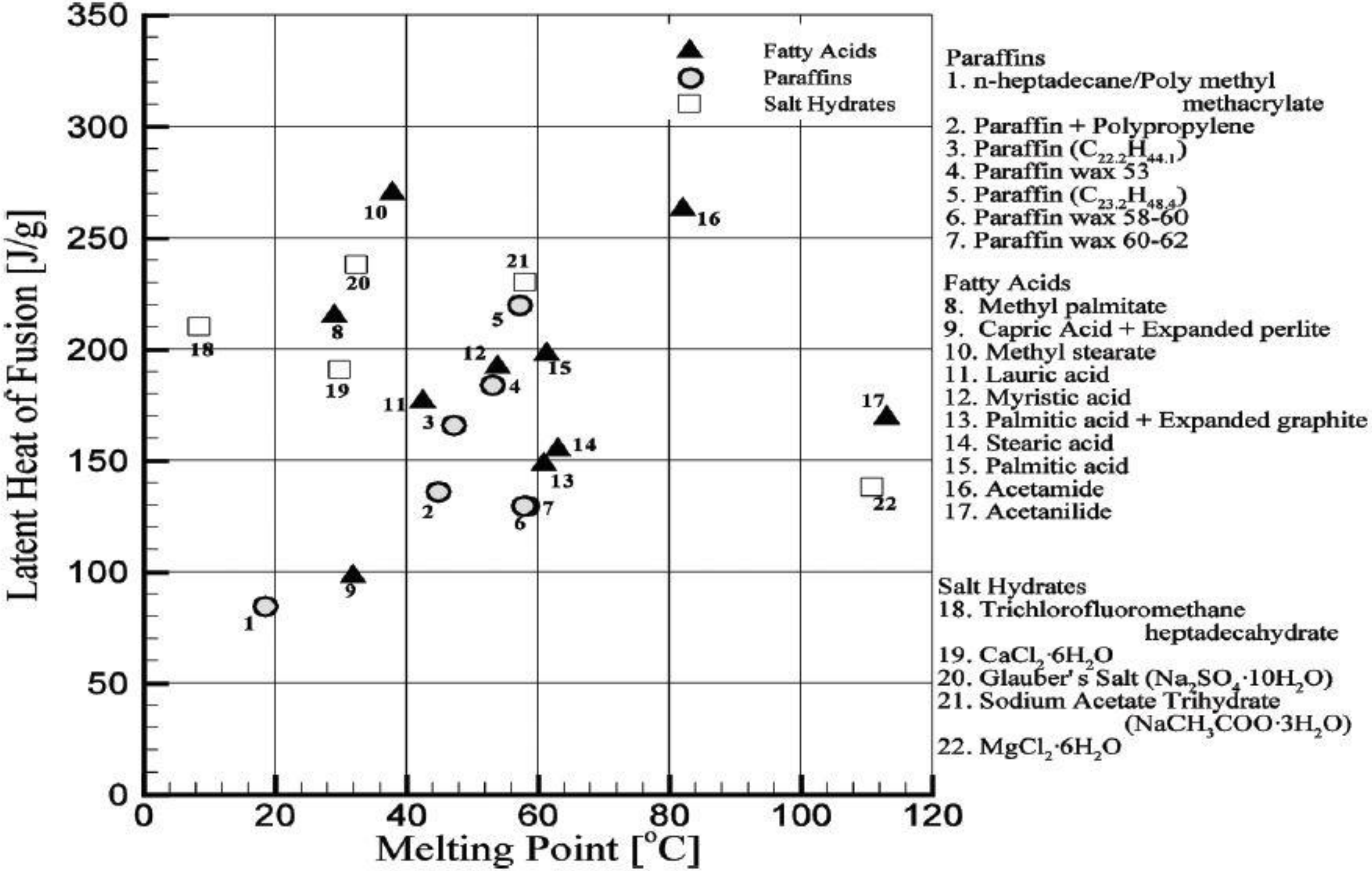
They are inorganic chemical salts dissolved in water at various rates. The addition of heat make them separate from water and form a liquid mixture, while the rejection of heat re−unite them with water in a solid state.

Advantages of Hydrated Salts

- Have a high storage density (~250 kJ/kg or 350 MJ/m^3).
- Have a relatively high thermal conductivity (~0.5 W/m ^{o}C).

Disadvantages of Hydrated Salts

- Undergo subcooling (cool down below melting point without solidification).
- Are sometimes chemically unstable.
- Show phase segregation.
- Higher in price than paraffin waxes.


Latent Heat of Fusion [J/g]
Melting Point [°C]
Fatty Acids
Paraffins
Salt Hydrates
Paraffins
1. n-heptadecane/Poly methyl methacrylate
2. Paraffin + Polypropylene
3. Paraffin ($C_{22.2}H_{44.1}$)
4. Paraffin wax 53
5. Paraffin ($C_{23.2}H_{48.4}$)
6. Paraffin wax 58-60
7. Paraffin wax 60-62
Fatty Acids
8. Methyl palmitate
9. Capric Acid + Expanded perlite
10. Methyl stearate
11. Lauric acid
12. Myristic acid
13. Palmitic acid + Expanded graphite
14. Stearic acid
15. Palmitic acid
16. Acetamide
17. Acetanilide
Salt Hydrates
18. Trichlorofluoromethane heptadecahydrate
19. $CaCl_2 \cdot 6H_2O$
20. Glauber' s Salt ($Na_2SO_4 \cdot 10H_2O$)
21. Sodium Acetate Trihydrate ($NaCH_3COO \cdot 3H_2O$)
22. $MgCl_2 \cdot 6H_2O$

Phase Change Problems and Solutions

The main problems in phase change storage are:−

1− Low Thermal Conductivity (in all PCMs)

This problem is treated by using heat transfer enhancement to facilitate the penetration of heat inside the PCM. This includes:− metallic fillers, meta matrix structures, finned tubes, aluminum shavings and nano−materials.

2- Subcooling (in salt hydrates)

Nucleating agents (like Borax) can be used to minimize subcooling and a thickening agent to prevent the settling of the high density Borax.

3− Phase Segregation (in salt hydrates)

It can be treated by two ways:− a) Through the use of extra water principle to prevent the formation of the heavy anhydrous salt, but this reduces storage density. b) By using some thickening agent (like Bentonite clay with Glauber salt, but this will reduce the rate of crystallization and thermal conductivity.

Encapsulation of PCMs

The PCM should be kept in a suitable container so that it is not affected by the working fluid around it. This is called (encapsulation).

Purposes of Encapsulation

- ❑ Holding the liquid and solid phase and keeping it isolated from surrounding.
- ❑ Keeping the composition of the PCM unchanged.
- ❑ Reducing the reaction of the PCM with the surrounding.
- ❑ Making the PCM easy to handle.
- ❑ Enhancing the heat transfer between the PCM and the working fluid.
- ❑ Keeping hazardous PCMs isolated from environment.

Types of Encapsulation

It can be classified into three major types:−

Macro−encapsulation

In this type the PCM is kept in metallic or plastic containers (capsules) of sizes (> 1 mm). The capsules or modules can be of spherical, tubular, cylindrical or rectangular shape.

Micro−encapsulation

In this type the capsule size is microscopic (1−1000 μm). Higher heat transfer rates are achieved because the surface area to volume ratio is substantially increased. The temperature span between the surface and core of the micro−capsule becomes negligible resulting in efficient and homogeneous phase change. The micro−shell better withstand volume change effects during phase change and also less chemically reactive with the PCM.

Nano−encapsulation

It is a new type in which the capsules sizes are less than (1 μm) or (1000 nm). The phase change processes are greatly enhanced at such extremely small sizes.