Thermal Energy Storage

1. Sensible Heat
2. Latent Heat
3. Thermochemical Decomposition
4. Photochemical Decomposition

Thermal Energy Storage

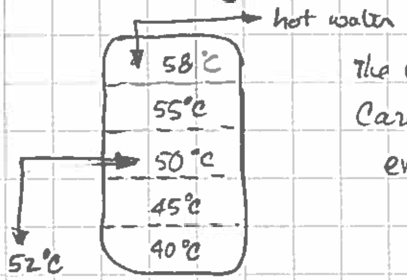
Sensible Heat

Table 4.1. Physical properties of some sensible heat storage materials Goswami, Kreith & Kreider

Storage Medium	Temperature Range, °C	Density (ρ), kg/m³	Specific Heat (C), J/kg K	Energy Density (ρC) kWh/m³ K	Thermal Conductivity (W/m K)
Water	0–100	1000	4190	1.16	0.63 at 38°C
Water (10 bar)	0–180	881	4190	1.03	—
50% ethylene glycol-50% water	0–100	1075	3480	0.98	—
Dowtherm A® (Dow Chemical, Co.)	12–260	867	2200	0.53	0.122 at 260°C
Therminol 66® (Monsanto Co.)	−9–343	750	2100	0.44	0.106 at 343°C
Draw salt ($50NaNO_3$-$50KNO_3$)[a]	220–540	1733	1550	0.75	0.57
Molten salt ($53KNO_3$/$40NaNO_3$/$7NaNO_3$)[a]	142–540	1680	1560	0.72	0.61
Liquid Sodium	100–760	750	1260	0.26	67.5
Cast iron	m.p. (1150–1300)	7200	540	1.08	42.0
Taconite	—	3200	800	0.71	—
Aluminum	m.p. 660	2700	920	0.69	200
Fireclay	—	2100–2600	1000	0.65	1.0–1.5
Rock	—	1600	880	0.39	—

[a] Composition in percent by weight.
Note: m.p. = melting point.

water storage – stratification



The water in the top of the tank is warmer than in the bottom. Careful control of cold water return can improve overall energy storage

Packed Bed Thermal Storage

- Pebble Bed
- Rock Pile

Typically air is the thermal transfer fluid.

Duffie & Beckman

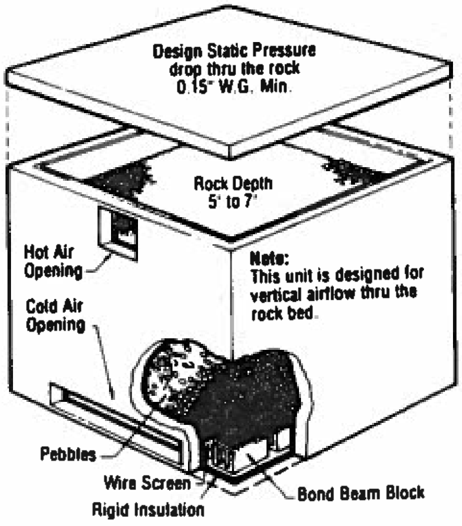


Figure 8.5.1 A packed-bed storage unit. Courtesy of Solaron Corp.

high, which promotes thermal stratification; the costs of the storage material and container are low; the conductivity of the bed is low when there is no air flow; and the pressure drop through the bed can be low.

A major advantage of a packed-bed storage unit is its high degree of stratification. This can be visualized by consideration of a hypothetical situation of a bed initially at a fixed temperature, which has air blown into it at a higher fixed temperature. The temperature profiles in the bed during heating are shown in Figure 8.5.2. The high heat transfer coefficient–area product between the air and pebbles means that high-temperature

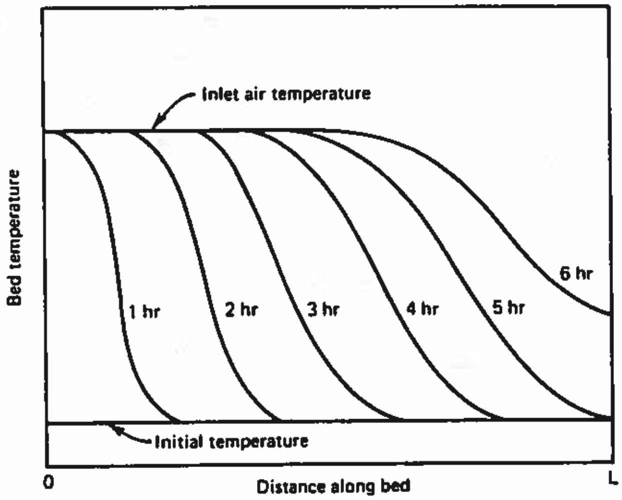
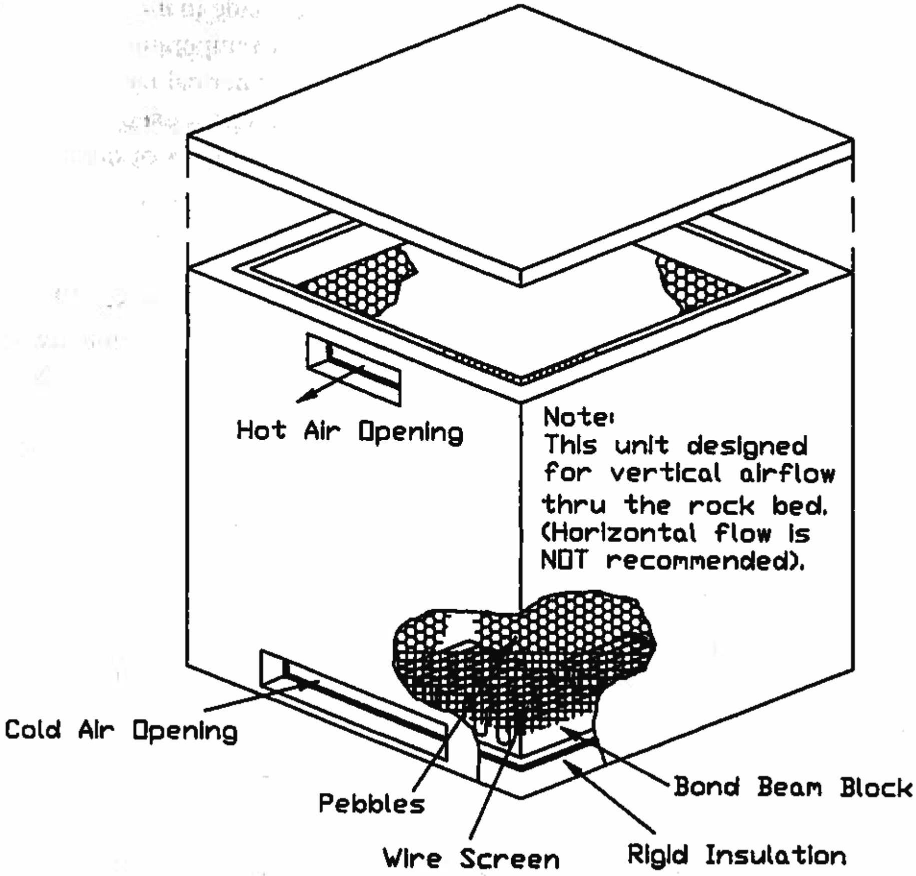
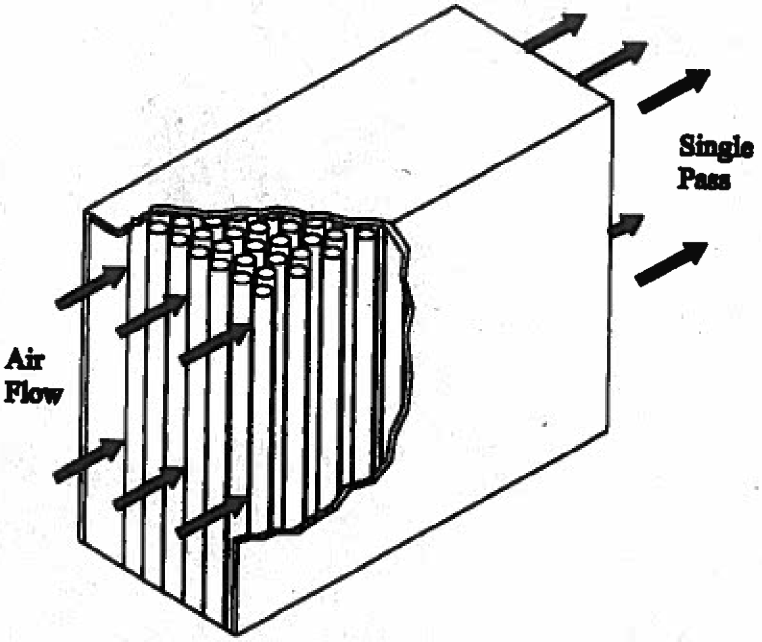


Figure 8.5.2 Temperature distributions in a pebble bed while charging with inlet air at constant temperature.

Goswamis Kreith & Kreider



(a)



(b)

Figure 4.4. Storage systems using: (a) pebble bed storage unit (Courtesy Solaron Corporation, Englewood, CO); and (b) PCM encapsulated in tubes.

Table 4.6. Represe
from Clark [6].

Particle Type
Sphere
Sphere
Sphere
Sphere
Sphere
Crushed rock
Sphere
Sphere
Sphere

where G_o is the sup
transfer fluid ($\dot{m}$) thr
and Prandtl numbers

where D_s is the diam
cific heat and therma

For flow of air
2,000 to 40,000, Mc

where A = 0.33 for
cates that the therma
age of the tube and th

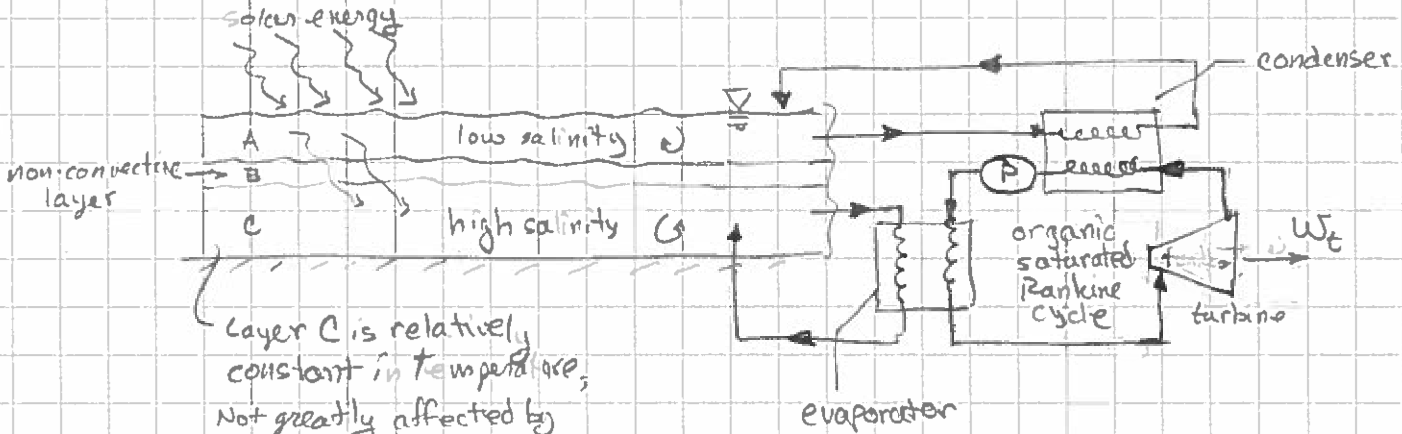
or the mass flow rate
sure drop in packed b

Solar Ponds

- Typical Lake
  - Thermal stratification due to buoyancy; warmer water at surface and cooler water at bottom (thermocline)
  - solar energy absorbed at surface
    - some energy returned to atmosphere via evaporation
    - partial pressure of $H_2O_{(v)}$ usually greater at surface than in the atmosphere, which reduces energy loss by evaporation

- Salt Water Lake
  - Temperature difference is reversed; warmer fluid at bottom
  - Lake can have a non-uniform salt concentration; greater concentration at bottom even though the water is warmer than the surface
  - solar energy absorbed at deeper layers remains deep

- Solar Ponds; Salt Ponds
  - Designed to take advantage of this phenomena



Layer C is relatively constant in temperature; Not greatly affected by daily & weekly solar energy fluctuations; can reach as high as 93°C

- El Paso, Texas:
  - 3350 m^2 water storage pond near a food canning plant converted into a solar pond in 1986
- Israel
  - 6250-m^2 salt pond at En Bagek; 150 kW plant
  - 40000 & 210,000 m^2 ponds for a 5 MW plant

Phase Change Energy Storage (PCM)

sensible + latent heat

$$q_s = c_{solid}(T^* - T_1) + h_{fg} + c_{liquid}(T_2 - T^*)$$

$T^* \equiv$ phase transition temperature

Table 4.3. Physical properties of latent heat storage materials or PCMs Goswami, Kreith & Kreider

Storage Medium	Melting Point °C	Latent Heat, kJ/kg	Specific Heat (kJ/kg °C)		Density (Kg/m³)		Energy Density (kWhr/m³K)	Thermal Conductivity (W/m K)
			Solid	Liquid	Solid	Liquid		
$LiClO_3 \cdot 3H_2O$	8.1	253	—	—	1720	1530	108	—
$Na_2SO_4 \cdot 10H_2O$ (Glauber's Salt)	32.4	251	1.76	3.32	1460	1330	92.7	2.25
$Na_2S_2O_3 \cdot 5H_2O$	48	200	1.47	2.39	1730	1665	92.5	0.57
$NaCH_3COO \cdot 3H_2O$	58	180	1.90	2.50	1450	1280	64	0.5
$Ba(OH)_2 \cdot 8H_2O$	78	301	0.67	1.26	2070	1937	162	0.653ℓ
$Mg(NO_3) \cdot 6H_2O$	90	163	1.56	3.68	1636	1550	70	0.611
$LiNO_3$	252	530	2.02	2.041	2310	1776	261	1.35
$LiCO_3/K_2CO_3$, (35:65)[a]	505	345	1.34	1.76	2265	1960	188	—
$LiCO_3/K_2CO_3/Na_2CO_3$ (32:35:33)[a]	397	277	1.68	1.63	2300	2140	165	—
n-Tetradecane	5.5	228	—	—	825	771	48	0.150
n-Octadecane	28	244	2.16	—	814	774	52.5	0.150
HDPE (cross-linked)	126	180	2.88	2.51	960	900	45	0.361
Steric acid	70	203	—	2.35	941	347	48	0.172ℓ

[a] Composition in percent by weight.

Note: ℓ = liquid.

Ex: Glauber's Salt ($Na_2SO_4 \cdot 10H_2O$)

$$Na_2SO_4 \cdot 10H_2O \underset{Q}{\longleftrightarrow} Na_2SO_4 + 10H_2O$$

$$\left.\begin{aligned} c_{(s)} &= 1.76\ \tfrac{kJ}{kg\,K} \\ c_{(\ell)} &= 3.32\ \tfrac{kJ}{kg\,K} \\ h_{(s\ell)} &= 251\ \tfrac{kJ}{kg} \text{ at } 32.4°C \end{aligned}\right\}$$

1 kg heated from 25°C to 50°C

$$q_s = \underbrace{13.0\ \frac{kJ}{kg}}_{\text{sensible heat of solution}} + \underbrace{251\ \frac{kJ}{kg}}_{\text{latent heat of fusion}} + \underbrace{58.4\ \frac{kJ}{kg}}_{\text{sensible heat of separate phases}}$$

For 1 kg heated from 25°C to 50°C: $Q_s = 322.4$ kJ

Thermal chemical Energy Storage

Thermochemical Decomposition : Sensible + Chemical Heat

Ex : Potassiumoxide $4KO_2 \longleftrightarrow 2K_2O + 3O_2$

$Q = 2.1$ MJ/kg 300 - 800°C

Ex : lead oxide $2PbO_2 \longleftrightarrow 2PbO + O_2$

$Q = 0.26$ MJ/kg 300 - 350°C

Can be used with:

- metal hydrides
- metal oxides
- peroxides
- ammoniated salts
- carbonates
- salfer trioxide

$A + \Delta H_f \longleftrightarrow B + C$

forward direction is endothermic (heat storage)

reverse direction is exothermic (heat release)

$$Q_{stored} = M_f \cdot \Delta H_f + (\text{sensible heat})$$

↑ fraction of mass reacted

Table 4.4. Properties of thermochemical storage media Goswomi, kreith & kreider

	Condition of Reaction						
Reaction	Pressure, kPa	Temperature, °C	Component (Phase)	Pressure, kPa	Temperature, °C	Density, kg/m³	Volumetric Storage Density, kWh/m³
$MgCO_3(s)$ + 1200 kJ/kg = $MgO(s) + CO_2(g)$	100	427–327	$MgCO_3(s)$ $CO_2(\ell)$	100 7400	20 31	1500 465	187
$Ca(OH)_2(s)$ + 1415 kJ/kg = $CaO(s) + H_2O(g)$	100	572–402	$Ca(OH)_2(s)$ $H_2O(\ell)$	100	20	1115	345
$SO_3(g)$ + 1235 kJ/kg = $SO_2(g) + \frac{1}{2}O_2(g)$	100	520–960	$SO_3(\ell)$ $SO_2(\ell)$ $O_2(g)$	100 630 10000	45 40 20	1900 1320 130	280

Note: s = solid; ℓ = liquid; g = gas