Second International Postgraduate Student Workshop
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Storage of energy

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WHY DO WE WANT TO STORE ENERGY

- *Renewable energy sources such are time dependent energy sources*
- *Our energy demands usually do not match these periods*

  ➡ *need for establishing a form of energy storage*

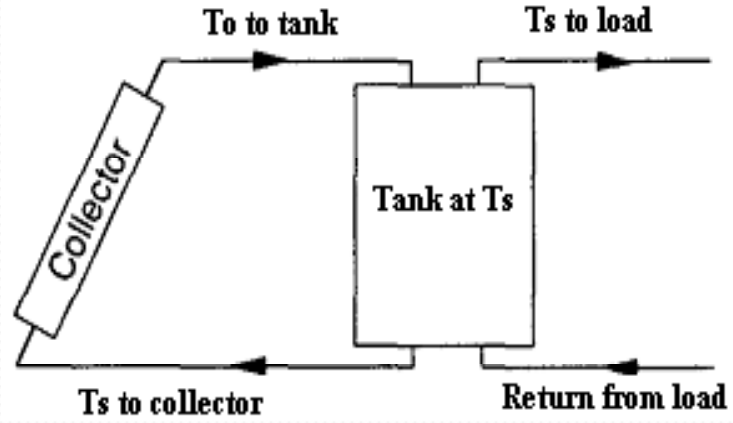
WE MAY STORE

- Heat
- Electricity
- Mechanical rotational energy
- Compressed air
- Hydrogen
- etc.

HEAT ENERGY STORAGE

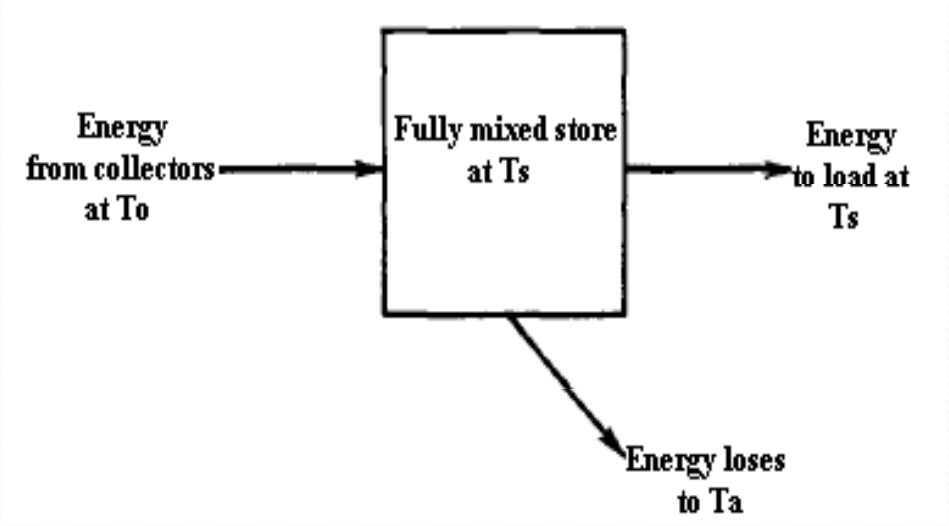
WATER MEDIUM STORAGE

- Heat is added to and retrieved from the water medium
- Water contemporaneously serves for transporting the heat
- Layout of a system wherein the water is used as a solar heat energy storage medium.



- Capacity of storing energy into the water

$$Q_s = (mC_p)_s \Delta T_s$$



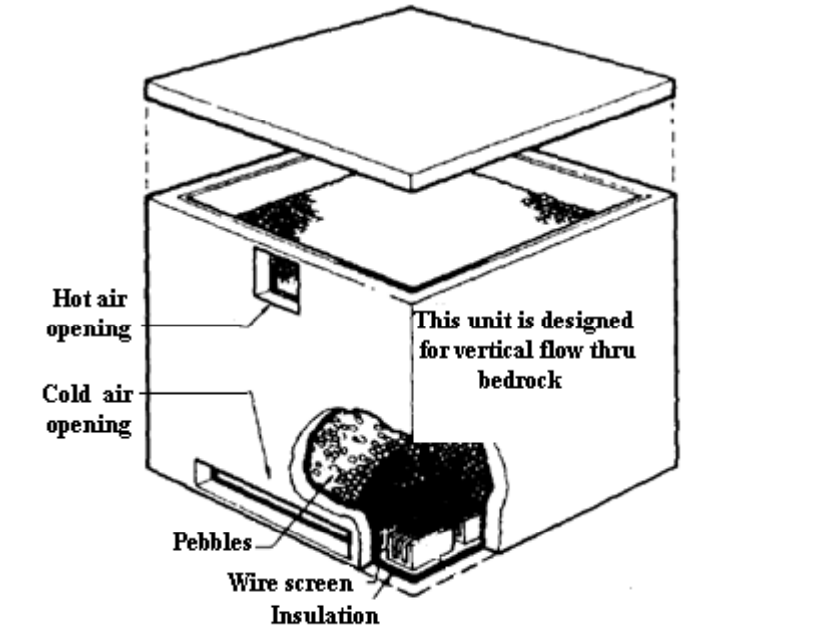
- Energy flow through storage

$$(mC_p)_s \frac{dT_s}{dt} = Q_u - L_s - (UA)_s(T_s - T_a)$$

- The operation of the system within a prolonged period will be perceived by way of integration of the above equation

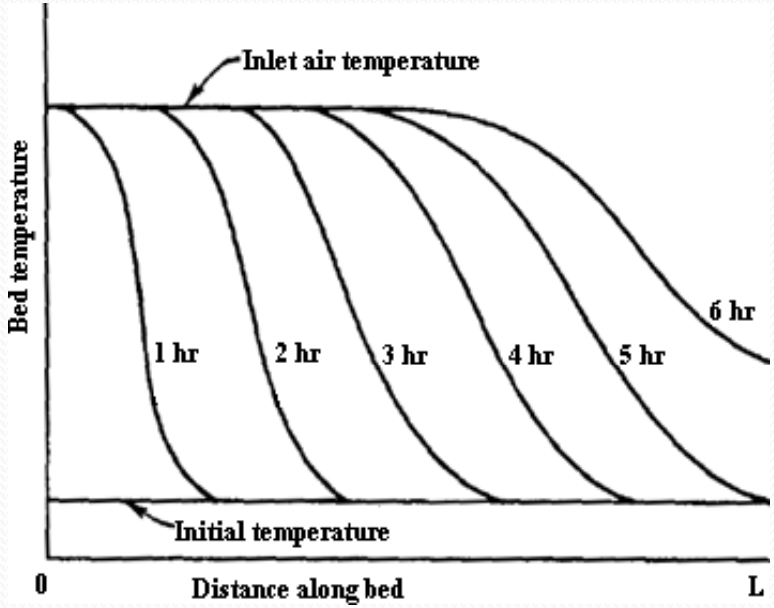
PACKED BED STORAGE

- Contains gravel or optionally another fine granulate material possessing high specific heat capacity
- A fluid, usually air, is used to add and extract heat from the storage



- Contemporaneous action of adding and extracting heat could not be effected

- The high degree of stratification is the major feature of the storage



$$(\rho C_p)_f \varepsilon \frac{\partial T_f}{\partial t} = -\frac{(\dot{m} C_p)_f}{A} \frac{\partial T_f}{\partial x} + h_V (T_b - T_f)$$

$$(\rho C_p)_b (1-\varepsilon) \frac{\partial T_b}{\partial t} = h_V (T_f - T_b)$$

- These equations shall be solved by use of complex numerical methods presented by Highes in 1975.

PHASE CHANGE HEAT STORAGE

- Substances subject to phase change within a specific temperature range are convenient for storing energy purposes

- The phase change process shall be a reversible type process that may be repeated in a large number of cycles causing no decomposition of the substance.

- The heat stored in the substance undergoing a phase change is equal to the sum of the sensible heat transferred to the solid substance, then the latent heat of the phase transition of the substance and the sensible heat being conveyed to the next phase of the substance

$$Q_s = m[C_{so}(T^* - T_1) + \lambda + C_{Li}(T_2 - T^*)]$$

CHEMICAL STORAGE OF HEAT

- The chemical storage of heat is based on the use of compounds that release and receive heat during a chemical reaction.

$$AB + \text{heat} \leftrightarrow A + B$$

- Unfortunately, compounds to act as serious candidates for such reaction at temperatures that may be provided from the solar processes, have not been discovered, yet.

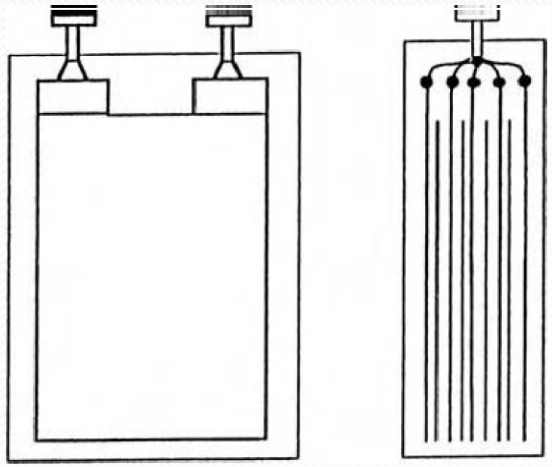
$$4KO_2 \leftrightarrow 2K_2O + 3O_2$$

- The above reaction occurs at temperatures between 300°C and 800°C, producing heat of 2.1 MJ/kg during the decomposition thereof.

STORING OF ELECTRICITY

STORING INTO A BATTERY

- The electrochemical energy exists in a semi-ordered form between the electrical and the thermal form of stored energy.
- The efficiency of conversion varies between 85% and 90%.
- Internal structure of a typical electrochemical cell.



- Despite its lowest capacity per unite volume and unit weight, the lead-acid battery is the most commonly used battery of the reload types of battery, due to its lowest price in comparison with the other types of batteries.

STORING INTO A SUPERCONDUCTOR

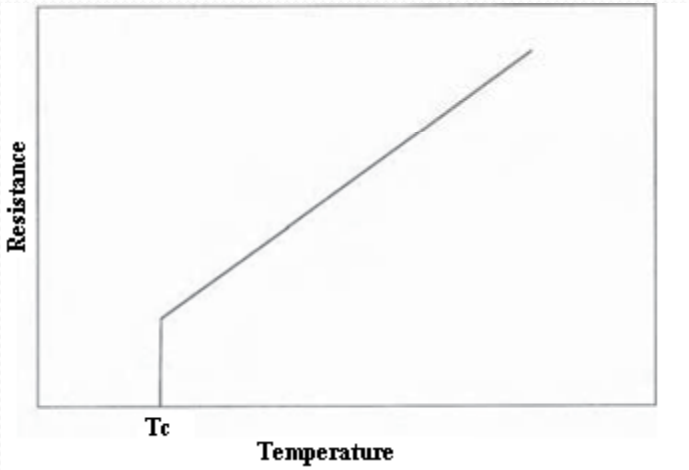
- The efficiency of the entire cycle of loading and discharging is very high (95%).
- The energy *E* that is stored in a coil conducting the current *I*, is presented as follows:

$$E = \frac{1}{2} I^2 L$$

- The relation between the current flowing through the coil I and the voltage V is presented as follows:

$$V = RI + L\frac{dI}{dt}$$

- The resistance declines abruptly down to zero, at a certain critical temperature



- Bonneville, Portland

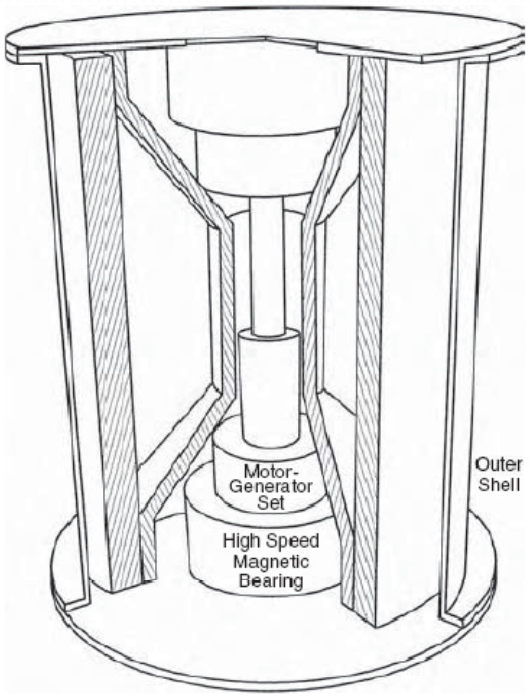
STORING MECHANICAL ENERGY IN A FLYWHEEL

- The flywheel enables storing kinetic energy within the rotating mass thereof
- The efficiency of the conversion within one cycle in the system of large flywheel may reach up to 90%.
- The energy stored in the flywheel having a moment of inertia *J* and rotating at an angular speed ω is presented as follows:

$$E = \frac{1}{2} J \omega^2$$

- A good system incorporating flywheel consists of composite rotor of epoxy fibers, supported with magnetic bearings, rotating under vacuum conditions, and being mechanically connected with an electrical machine operating as an engine or a generator.

- Flywheel configuration with rotor outside enclosing the motor generator and the bearing.



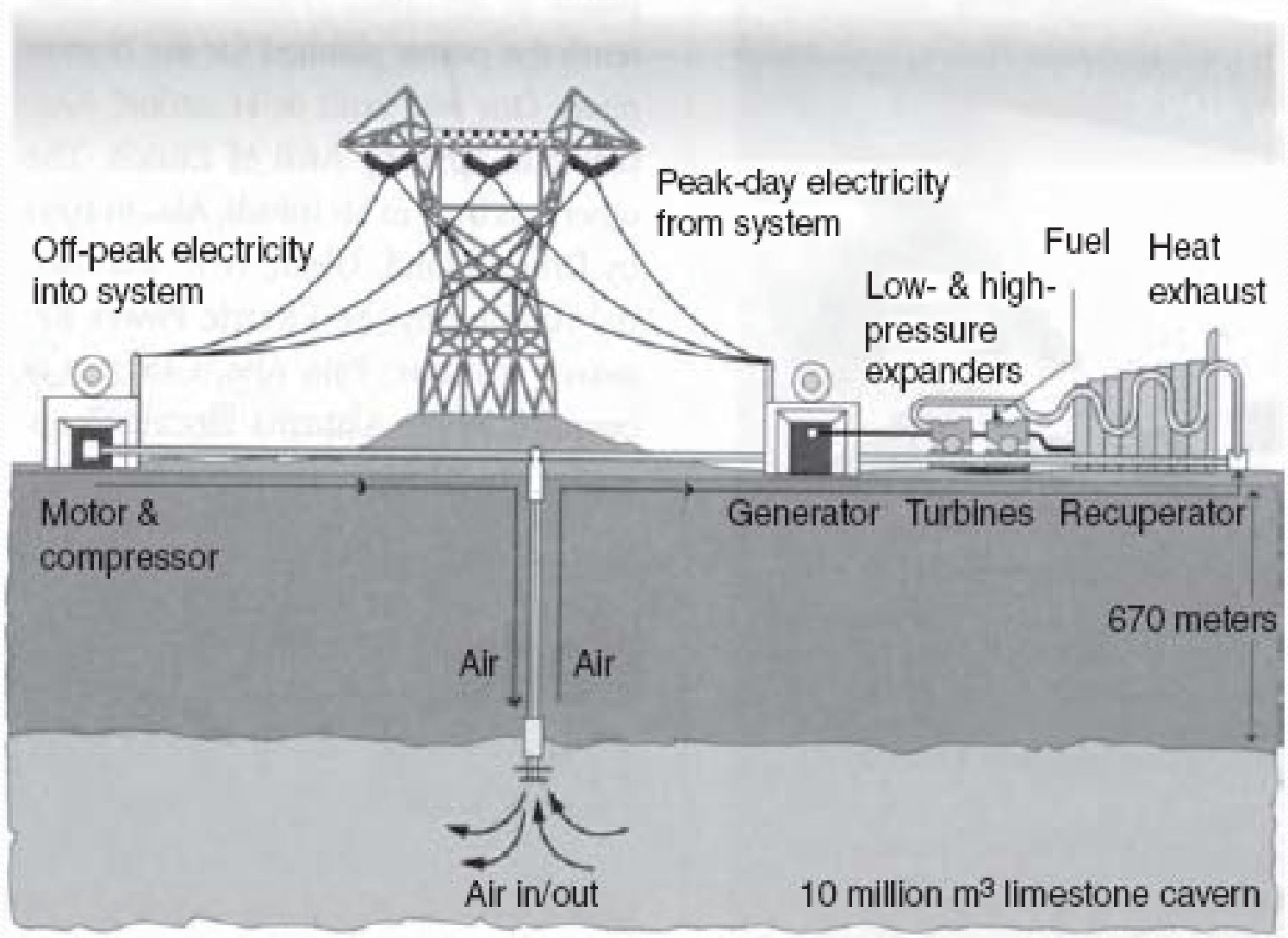
- Flywheels comprising composite rotors have already been produced and tested and they may endure more than 10.000 cycles of complete loading and discharge.

STORING ENERGY WITHIN A COMPRESSED AIR

- The compressed air stores the energy by way of pressure variation.

$$\text{Energy stored} = \frac{n(P_2V_2 - P_1V_1)}{n-1}$$

- When the air having higher temperature upon compression under a constant volume has been cooled, one portion of the pressure is lost, accompanied with a proportionate reduction of the stored energy.
- Air may be stored in cistern under pressure, a pit, an exhausted oil or gas field or in abandoned mines, or in an underground cavity filled with water.
- The overall round-trip energy efficiency of about 50% has been estimated.
- A 2,700 megawatt system for storing energy within a compressed air of, is scheduled for construction in Ohio.


Peak-day electricity
from system
Off-peak electricity
into system
Fuel
Heat
exhaust
Low- & high-
pressure
expanders
Motor &
compressor
Generator
Turbines
Recuperator
670 meters
Air
Air
Air in/out
10 million m3 limestone cavern

STORING HYDROGEN

- The hydrogen may be stored under the ground in cavities filled with water, in the exhausted oil fields or natural gas reservoirs, in artificial pits created as a result of mining, as well as in the form of metal hydrides and in activated coal.
- The hydrogen may be transported in the form of gas through buried penstocks, whereas in the liquid form it may be conveyed by supertankers.
- The hydrogen may be used as a substitute for the fossil fuels practically for any purpose.
- The hydrogen may be converted in electricity by electrochemical route, in fuel cells with high efficiency.
- Hydrogen is the cleanest fuel, being non-toxic with virtually no environmental problems.

CONCLUSION

THANK YOU