Benha University
Benha Faculty of Engineering
Mechanical Department.

Non-Conventional Energy
4th Year 2015/2016
Final – Exam (Code: M 1423)

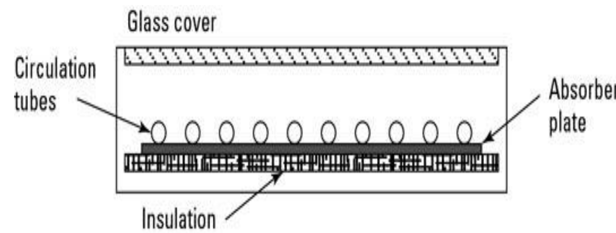
Time: Three Hours ***Only solar insolation tables are allowable***

Question one (20 points)

<u>1.1</u> Explain briefly with drawing the types of solar energy collectors that can be used for low temperature limits? **(5 points)**

1. Flat plate Collectors

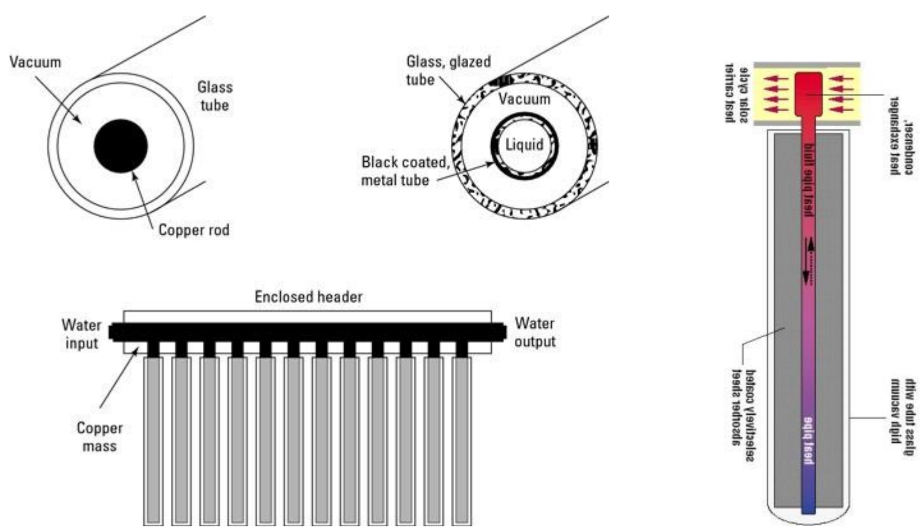
Flat plate collectors, where temperatures below about 90oC are adequate as they are for space and service water heating flat plate collectors, which are of the non-concentrating type, are particularly convenient.



There are many flat-plate collector designs, but most are based on the principle shown in figure up. It is the plate and tube type collector. It basically consists of a flat surface with high absorptivity for solar radiation called the absorbing surface.

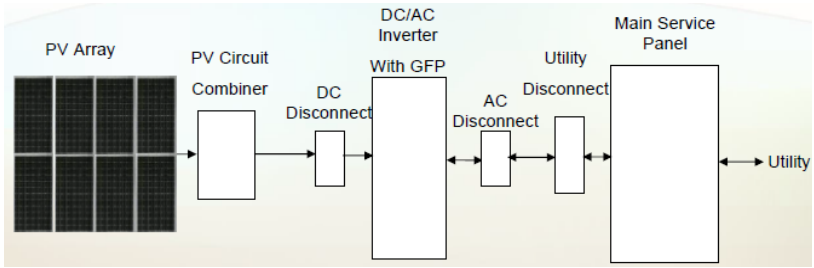
2. Evacuated-tube collectors

Convection heat loss due to air movements inside the collector can be significantly reduced by maintaining a vacuum between the front cover and the absorber of a flat plate collector.

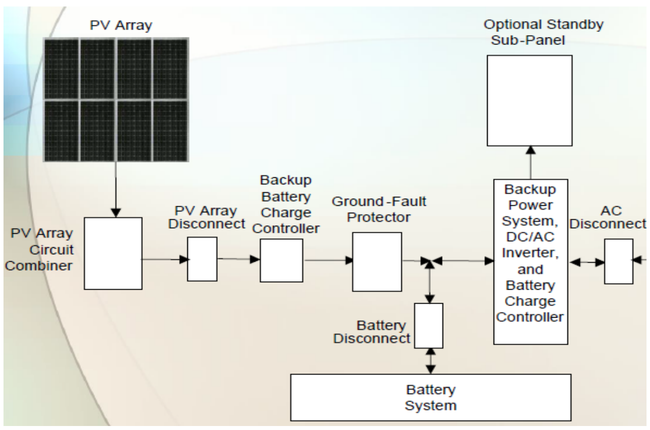


<u>1.2</u> Compare between the different types of photovoltaic solar systems (operation, equipment and advantage) with drawing. **(5 points)**

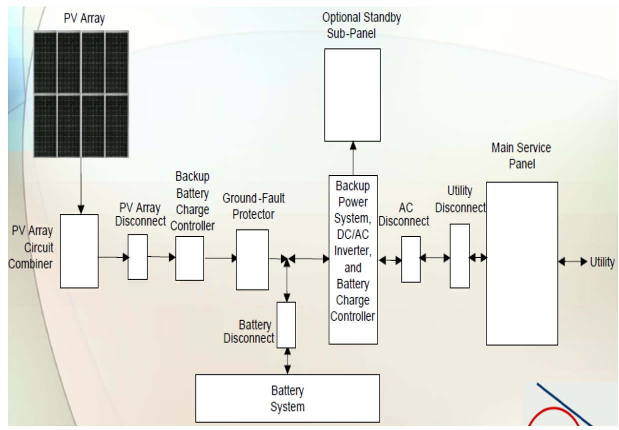
1. Grid-Tied Solar Systems



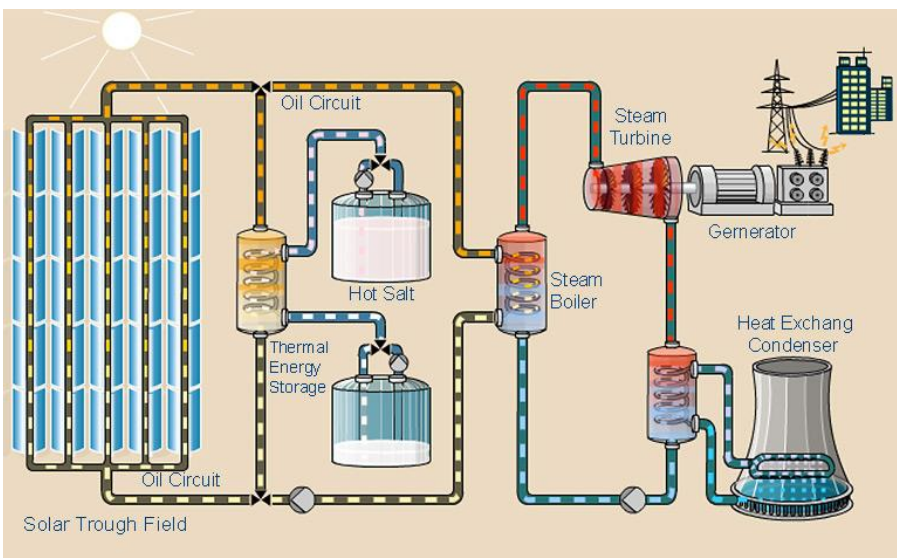
2. Off-Grid Solar Systems



3. Hybrid Solar Systems



1.3 Explain with drawing, components of steam power plant depend on parabolic trough concentrating solar thermal energy system and thermal storage tanks? **(5 points)**



1.4 Calculate the amount of energy (in kWhr per day) which one flat-plate collector (1.0 m wide and 2 m long) may provide if the collector is placed at the *best angle* of south-facing surface with horizontal in a location of 48˚ North Latitude during October from 8 am to 4 pm. Assume that the average temperature inside the collector 335 ˚K, and the atmosphere temperature is 300 ˚K. The overall heat transfer coefficient of the glass cover and the wood bake are 4.5 W/m^2.˚C and 1.1 W/m^2.˚C respectively, the absorptivity of the glass 95 %.

(5 points)

From table I = Btu/h.ft^2 * 3.152 = W/m^2

$Q_{useful} = A_c \,.\, [\tau_\alpha \,.I - U_L.(T_{insid} - T_\infty)\,] =$ W

$Q_{useful} =$ kW

Question Two (20 points)

<u>2.1</u> What is the construction of wind turbines? **(5 points)**

- **<u>(1) Tower</u>**

Towers are made from tubular steel or steel lattice.

- **<u>(2) Blade (turbine function)</u>**

Most turbines have either two or three blades. Each blade acts much like an airplane wing. When the wind blows, a pocket of low-pressure air forms on the downwind side of the blade.

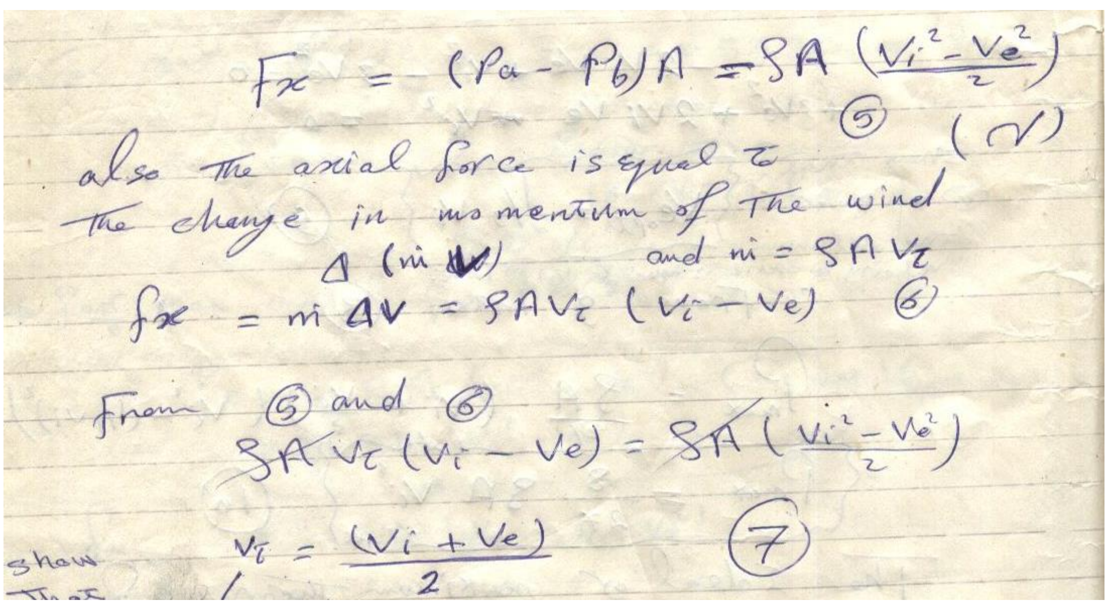
- **<u>(3) Generator</u>**

Converts the mechanical energy of the spinning blades into 60-cycle AC electricity.

- **<u>(4) Controller</u>**

The controller starts up the machine at wind speeds of about 8 to 16 miles per hour and shuts off the machine at about 65 mile per hour.

<u>2.2</u> Show that for wind turbine $V_{e)\,opt} = (1/3)\, V_i$ **(5 points)**



$F_x = (P_a - P_b) A = \rho A \left(\frac{V_i^2 - V_e^2}{2}\right)$ (5) (✓)

also the axial force is equal to the change in momentum of the wind $\Delta(\dot{m} V)$ and $\dot{m} = \rho A V_t$

$f_x = \dot{m}\,\Delta V = \rho A V_t (V_i - V_e)$ (6)

From (5) and (6)

$\rho A V_t (V_i - V_e) = \rho A \left(\frac{V_i^2 - V_e^2}{2}\right)$

$V_t = \frac{(V_i + V_e)}{2}$ (7)

show that

$$W = K.E_i - K.E_e = \frac{V_i^2 - V_e^2}{2} \quad (m^2/sec^2) \; (J/kg)$$

$$Power = \dot{m}\, w = \dot{m}\left(\frac{V_i^2 - V_e^2}{2}\right)$$

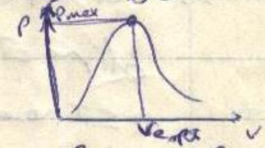
$$= \rho A V_t \left(\frac{V_i^2 - V_e^2}{2}\right)$$

$$= \rho A \frac{(V_i + V_e)}{2}\left(\frac{V_i^2 - V_e^2}{2}\right)$$

$$Power = \frac{\rho A}{4}(V_i + V_e)(V_i^2 - V_e^2) \qquad (8)$$

To obtain maximum Power

The optimum exit velocity must be determind $V_{e\,opt} = ??$ by



$$\frac{dP}{dV_e} = 0 \quad \therefore \frac{d}{dV_e}\left(V_i^3 - V_i V_e^2 + V_e V_i^2 - V_e^3\right) = 0$$

$$-2 V_i V_e + V_i^2 - 3 V_e^2 = 0$$

$$+3V_e^2 + 2 V_i V_e - V_i^2 = 0$$

Show That for the turbine @ max Power

$$V_{e\,opt} = \frac{1}{3} V_i \qquad (9)$$

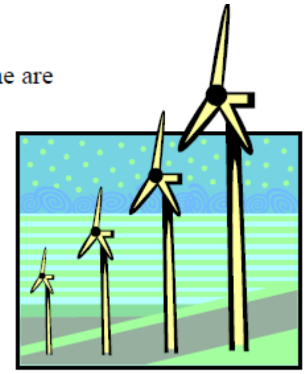
The optimum velocity @ exite is equal to (1/3) of inlet.

$\therefore$ From 9 into (8) $\quad \frac{8}{3} + \frac{8}{9}$

2.3 Consider a wind turbine with an 80-m-diameter rotor that is rotating at 20 rpm under steady winds at an average velocity of 30 km/h. Assuming the turbine has an efficiency of 35 percent (i.e., it converts 35 percent of the kinetic energy of the wind to electricity), determine (a) the power produced, in kW; (b) the tip speed of the blade, in km/h; and (c) the revenue generated by the wind turbine per year if the electric power produced is sold to the utility at \$0.06/kWh. Take the density of air to be 1.20 kg/m^3. **(10 points)**

Properties The density of air is given to be $\rho = 1.20$ kg/m^3.

Analysis (*a*) The blade span area and the mass flow rate of air through the turbine are



$$A = \pi D^2/4 = \pi(80\text{ m})^2/4 = 5027\text{ m}^2$$

$$V = (30\text{ km/h})\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 8.333\text{ m/s}$$

$$\dot{m} = \rho A V = (1.2\text{ kg/m}^3)(5027\text{ m}^2)(8.333\text{ m/s}) = 50{,}270\text{ kg/s}$$

Noting that the kinetic energy of a unit mass is $V^2/2$ and the wind turbine captures 35% of this energy, the power generated by this wind turbine becomes

$$\dot{W} = \eta\left(\frac{1}{2}\dot{m}V^2\right) = (0.35)\frac{1}{2}(50{,}270\text{ kg/s})(8.333\text{ m/s})^2\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{610.9\ kW}$$

(*b*) Noting that the tip of blade travels a distance of πD per revolution, the tip velocity of the turbine blade for an rpm of $\dot{n}$ becomes

$$V_{tip} = \pi D\dot{n} = \pi(80\text{ m})(20/\text{min}) = 5027\text{ m/min} = 83.8\text{ m/s} = \mathbf{302\ km/h}$$

(*c*) The amount of electricity produced and the revenue generated per year are

$$\text{Electricity produced} = \dot{W}\Delta t = (610.9\text{ kW})(365\times 24\text{ h/year})$$
$$= 5.351\times 10^6\text{ kWh/year}$$

$$\text{Revenue generated} = (\text{Electricity produced})(\text{Unit price}) = (5.351\times 10^6\text{ kWh/year})(\$0.06/\text{kWh})$$
$$= \mathbf{\$321{,}100/year}$$

Question Three (20 points)

<u>3.1</u> What is bio energy and anaerobic digestion? ***(5 points)***

- ✓ Bio gas is generated through a process of anaerobic digestion of Bio-Mass.
- ✓ Bio gas is produced by the bacterial decomposition of wet sewage sludge, animal dung or green plants in the absence of oxygen. Feed stocks like – wood shavings, straw, and refuse maybe used, but digestion takes much longer.
- ✓ With the aid of sketch explain the Biogas energy plant, including all components?

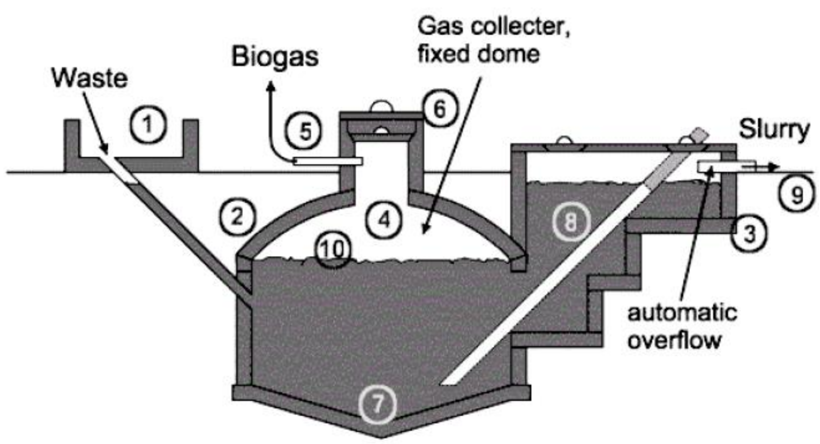
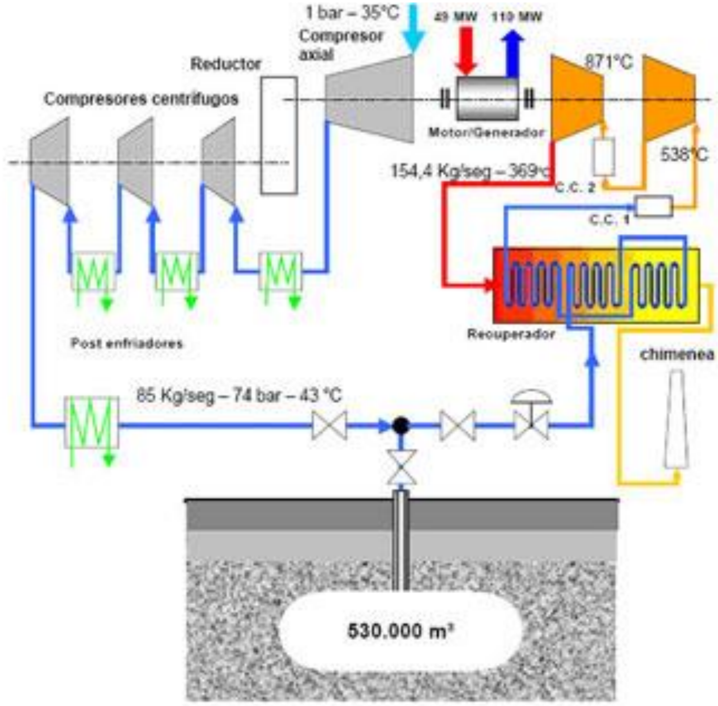


Figure 1: Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap. 2. Digester. 3. Compensation and removal tank. 4. Gasholder. 5. Gaspipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10. Supernatant scum, broken up by varying level.

3.2 Draw a Multi-stage adiabatic compressed-air energy storage system with pressure compensation pond? ***(5 points)***



3.3 Calculate the air flow, compressed air temperature, and storage volume for a 1000 MWhr peaking unit charging for 7.5 hr. Assume compressor inlet is at 1 bar and 25˚C, compressor exit at 100 bar a compressor polytrophic efficiency of 75%, a peaking turbine efficiency of 65%, and a constant specific heat for the air is 1.05 kJ/ (kg. ˚C). The air gas constant R=284.75 kJ/kg K. ***(10 points)***

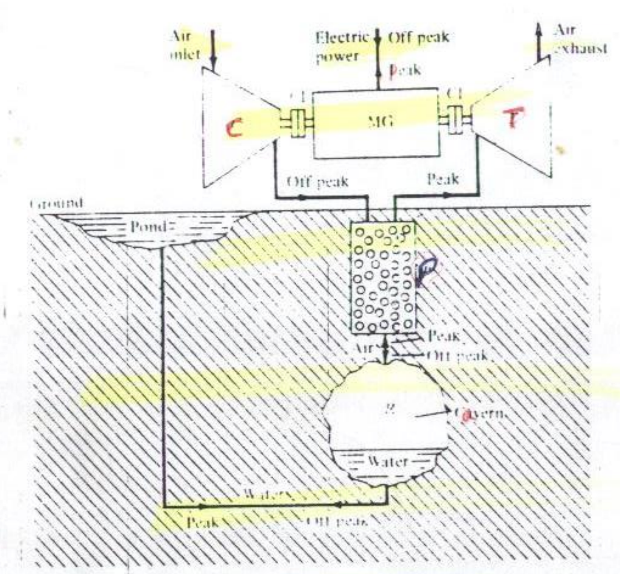


Figure 16-8 Schematic of a simple single-stage adiabatic compressed-air energy storage system with pressure-compensation pond. C = compressor, T = turbine, MG = motor-generator set, P = packed-bed thermal-energy storage, R = air-storage reservoir.

efficiency of 70 percent, a peaking turbine efficiency of 60 percent, and a constant specific heat for air $c_p = 1.05$ kJ/(kg · °C). The air-gas constant $R = 284.75$ kJ/(kg · K).

0.28475

SOLUTION For a compressor polytropic efficiency of 70 percent and constant specific heat

$$0.7 = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{T_{2s} - T_1}{T_2 - T_1}$$

where the subscripts 1, 2, and 2*s* are for compressor inlet, exit, and isentropic exit conditions, respectively.

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (20 + 273)\left(\frac{100}{1}\right)^{(1.4-1)/1.4} = 1092 \text{ K} = 819°\text{C}$$

$$T_2 = \frac{819 - 20}{0.7} + 20 = 1162°\text{C}$$

(This corresponds to a polytropic exponent $n = 1.5266$.)

For a turbine output of 1500 MWh

$$\text{Storage capacity} = \frac{1500}{0.60} = 2500 \text{ MWh}$$

$m_{air} C_{p\,air} (T_{c_2} - T_{c_1}) = \text{storage capacity}$

$$\text{Mass of air required} = \frac{2500 \times 3.6 \times 10^6}{1.05(1162 - 20)} = 7.5 \times 10^6 \text{ kg}$$

Assuming air is stored in the cavern at 100 bar (10^7 Pa) and 20°C

$V = \frac{mRT}{P}$

$$\text{Total volume needed} = \frac{7.5 \times 10^6 \times 284.75(20 + 273)}{10^7} = 62{,}575 \text{ m}^3$$

Average air flow to cavern during 7.5 h of charging = 8343 m³/h

With best wishes

Dr. Mohamed Ramadan