Chapter 4.3: Cogeneration, Turbines (Gas, Steam)

Short type questions

1.	What could be the range of energy saving potential from co-generation systems? **Ans.** Co-generation offers energy savings in the range of 15-40% when compared against the supply of electricity and heat from conventional power stations and boilers.
2.	Specify the efficiency level of co-generation systems? **Ans.** Cogeneration system efficiency can go up to 90% and above.
3.	Write formula for heat recovery steam generator (HRSG) efficiency, without supplementary firing? **Ans.** Heat recovery steam generator efficiency (%) $\frac{\text{Steam generated} \times [hs - hw]}{\text{Mass flow of flue gas} \times Cp \; x \, (t_{in} - t_{out})}$ Where, hs : Enthalpy of steam, kcal/kg — Steam generation in kg/h hw: Enthalpy of feed water, kcal/kg — Flue as in kg/h t_{in} : Inlet temperature of flue gas , °C t_{out}: outlet temperature of flue gas, °C
4.	What is the function of 'back pressure steam turbine'? **Ans** In back pressure steam turbine steam enters the turbine chamber at high pressure and expands to low or medium pressure. Enthalpy difference is used for generating power/work.
5.	Define the gas turbine efficiency? For stand alone gas turbine without heat recovery system what will be the efficiency? **Ans.** Turbine efficiency is the ratio of actual work output of the turbine to the net input energy supplied in the form of fuel. For stand alone gas turbines, without any heat recovery system the efficiency will be as low as35 to 40%.
6.	Name two components of energy consuming equipments in evaluating overall gas turbine efficiency? **Ans.** Overall gas turbine efficiency includes two components – air compressors, gas turbine.
7.	List any three energy intensive industries from designated consumes (as per EC act, 2001), where cogeneration systems are popular? **Ans.** Fertilizer, pulp and paper, sugar.
8.	List out electrical energy parameters required while carrying out cogeneration system performance evaluation **Ans.** Required electrical energy parameters i) Total power generation for the trial period from individual turbines ii) Hourly average power generation iii) Quantity of power import from utility / (or DG sets) iv) Auxiliary power consumption

9.	Mention the waste heat sources from reciprocating engines? **Ans.** Waste heat sources from reciprocating engines are: 1. Exhaust flue gases 2. Engine jacket cooling water 3. Lube oil cooler
10.	List out any three important factors to be mentioned along with heat rate (kcal/kWh) of cogeneration plant (condensing type of steam turbine)? **Ans.** Important factors to be considered for cogeneration plant performance are: - Plant % loading - Condenser vacuum level - Inlet cooling water temperature

Long type questions

1.	Indicate where the cogeneration is applicable? **Ans.** Where there is simultaneous need for heat and power (electrical and thermal (mechanical)), there is a potential for cogeneration. However, significant savings is energy costs can be achieved and cogeneration system can be more meaningful if the energy consuming facility has the following characteristics. 1) Reliable power requirement 2) Utilisation of higher thermal energy than electricity 3) Quite stable load patterns of thermal energy and electricity 4) Long operating hours 5) High price of grid electricity or inaccessibility to grid Thermal energy need of a facility may be for the following purposes. o Drying, preheating, process steam, o producing chilled water, o hot water generation, heating fluids etc. Some of the application areas where cogeneration has been successfully practised are listed below: ✓ Industrial cogeneration: Food processing, Pharmaceutical, Pulp and paper, Refinery, Fertilizers, Textile, Brewery and distillery, Steel, cement, Glass, Ceramic industry, etc. ✓ Residential / commercial / institutional cogeneration: Hospitals, Hotels and Commercial buildings
2.	How does cogeneration make sense? Mention a typical example **Ans.** Cogeneration is an energy efficient technology. It has an advantage of reducing the primary energy use thereby reducing the energy cost; while providing the same quantity of two different required forms of energy; i.e. heat and electricity. Conventional energy supply system requires about 40% more primary energy than the cogeneration system to meet the same energy needs. The soundness of cogeneration system can be highlighted more by a practical example, given below. A plant needs 10.7 tph of steam of low pressure steam and electrical energy of 4.7 MW.

In a conventional energy system the input energy would be around 22 MW. However, co-generation system can provide the same by using 16 MW, as primary energy source.

Numerical type questions

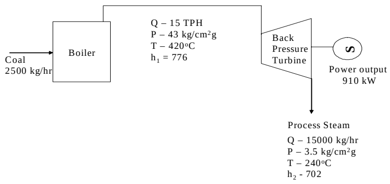
1. A medium size paper plant having an average production 120 MT/h of Kraft paper is having a cogeneration system with a back pressure turbine. The plant steam and electrical demands are 15 TPH and 910 kW. The process flow diagram is given below. Gross caloric valve of Indian coal is 4000 kcal/kg, average fuel consumption (boiler) is around 2.5 TPH.

Design parameters:

Efficiency of alternator : 92%

Efficiency of gear transmission : 98%

Evaluate efficiency of turbine and overall plant fuel rate (kg of coal/kWh) including boiler.



Ans. Total heat of steam at turbine inlet conditions at 43 kg / cm^2 and 420 °C, h1 : 776 kcal

Total heat of steam at turbine outlet conditions at 3.5 kg/cm^2 and 240^{o}C, h_2 : 702 kCal/kg

Heat energy input turbine / kg of inlet steam h_1- h_2): (776-702) = 74 kCal / kg

Total steam flow rate Q_1	: 15000 kg/hr
Power generation	: 910 KW
Equivalent thermal energy	: 910 x 860 = 7,82,600 kCal /hr
Energy input to the turbine	: 15000 x 74 = 11,10,000 kCal/hr.

Power generation efficiency of the turbo alternator (turbine η x alternator η x gear η)

$$: \frac{\text{Energy output}}{\text{Energy input}} \times 100 \quad = \quad \frac{7,82,600}{11,10,000} \times 100 = 70\%$$

Efficiency of the turbo alternator	: 70%
Efficiency of Alternator	: 92 %
Efficiency of gear transmission	: 98 %

$$EfficiencyofTurbine = \frac{Power\ generation\ efficiency\ of\ turbo\ alternator}{Efficiency\ of\ gear\ transmission * Efficiency\ of\ Alternator}$$

$$: = \frac{0.70}{0.92 \times 0.98} = 0.78$$

Coal consumption of the boiler	: 2500 kg/Hr.
Overall plant fuel rate including boiler	: 2500/910 : 2.75 kg coal / kW

2. Calculate the turbine efficiency of a condensing turbine for the following steam conditions. Assume generator efficiency as 92%.

Conditions	Flowrate, TPH	Pressure, kg/cm2 g	Temperature, oC
Inlet steam	39.13	27.0	372
Extraction	31.9	3.9	200
Exhaust	7.23	-0.96	38

Power generated from the turbine is 3.0 MW.

Ans. Enthalpy of steam at turbine inlet : 756 kCal / kg

Heat of steam at turbine inlet : 756 x 39130

: 29582280 kCal/h

Enthalpy of steam at turbine extraction (3.9 kg/cm²g at 200°C) : 683 kCal / kg

Heat of steam at turbine extraction : 683 x 31900

: 21787700 kCal/h

Enthalpy of steam at turbine exhaust (-0.096 kg/cm²g at 38°C) : 608 kCal / kg

Heat of steam at turbine exhaust : 608 x 7230

: 4395840 kCal/h

Theoretical power generation :

$$\frac{29582280 - (21787700 + 4395840)}{860}$$

: 3.95 MW

Turbine efficiency : [3.0 / (3.95 x 0.92)] x 100

: 82.6%

3. A process industry has decided to go for co-generation plant. Steam is available at 31.25 TPH with a pressure of 63 kg/cm² g and 486 °C. The steam for the process is required as per the following table.

Process	Steam Flow, TPH	Pressure, kg/cm² g	Temperature, °C
Process # 1	3.25	21	310
Process # 2	8.00	8.0	174
Process # 3	20.0	5.0	160

Arrive at a co-generation scheme with single turbine. The plant requires 4.0 MW of electrical power. Find out whether the co-generation schemes are self sufficient or any additional power needs to be purchased from the state grid, assuming the turbine efficiency of 70 % and generator efficiency of 90%.

Enthalpy of steam at turbine inlet : 808 kCal / kg

Heat of steam at turbine inlet : 808 x 31250

: 25250000 kCal/h

Enthalpy of steam at turbine extraction # 1 : 669 kCal / kg

Heat of steam at turbine extraction # 1 : 669 x 3250

: 2174250 kCal/h

Enthalpy of steam at turbine extraction # 2 : 662 kCal / kg

Heat of steam at turbine extraction # 2 662 x 8000

: 5296000 kCal/h

	Enthalpy of steam at turbine extraction # 3 : 659 kCal / kg Heat of steam at turbine extraction # 3 : 659 x 20000 : 13180000 kCal/h Power generation : 25250000 – (2174250 + 5296000+ 13180000) x 0.7 x 0.9 / 860 : 3.37 MW Additional power required : 4.0 – 3.36 : 0.64 MW