Ref. No. Ex/PG/PE/T/129A/31/2018

M. POWER ENGINEERING EXAMINATION, 2018

Second Semester

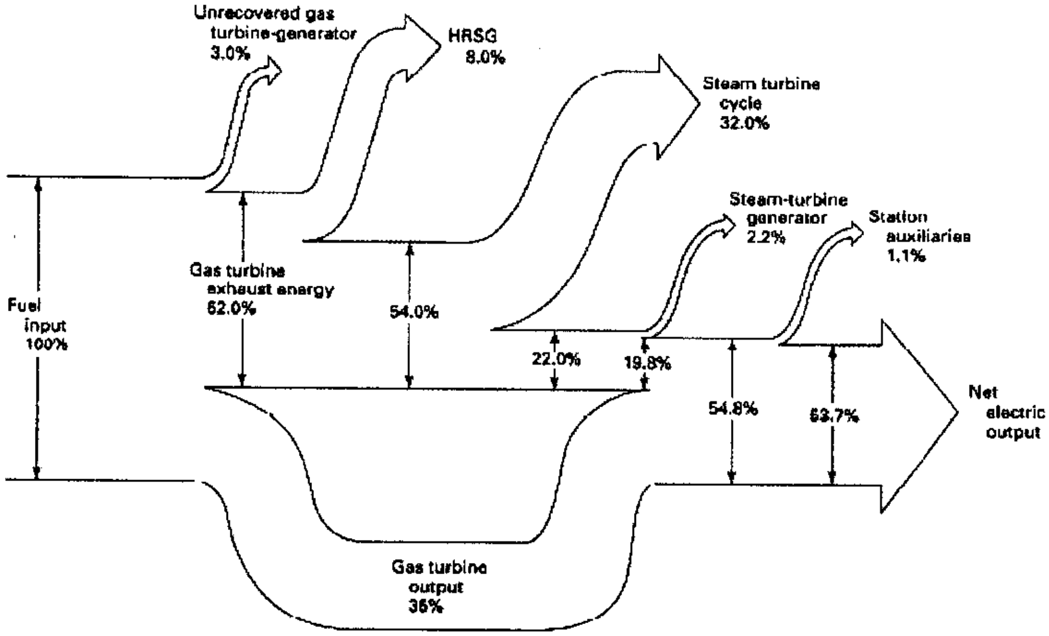
SUBJECT: ***ADVANCED POWER CYCLES AND ECONOMICS***

Time: Three Hours **Full Marks 100**

Answer Q No 1 and any four from the rest

1.

(a) The Sankey diagram of a typical 250 MW GTCC plant is shown below:



Find the followings:

(i) Heat rates of the GT cycle and the ST cycle. **2 marks**

(ii) Net plant heat rate of the GTCC plant. **1 mark**

(iii) HRSG efficiency. **1 mark**

(iv) Heat rejected in the condenser. **1 mark**

(v) ST and GT outputs. **2 marks**

(vi) Heat supply rate. **1 mark**

(b) Considering the fuel supplied in the above problem to be liquid n-octane (C_8H_{18}, HHV of 48275 kJ/kg) at 25° C, determine the exergy supplied to the GTCC plant. Assume an environment consisting of a gas phase at 25° C, 1 atm, obeying the ideal gas model with the following composition on a molar basis: N_2, 75.67%; O_2, 20.35%; H_2O, 3.12%; CO_2, 0.03%; other, 0.83%. Use the table supplied at the end of the question paper. **10 marks**

(c) What is the exergy efficiency of the GTCC plant? **2 marks**

2. Justify the following statements **(5×4 = 20 Marks)**

a) Reheating in a gas turbine cycle, at a reheat pressure ratio corresponding to maximum specific work output, leads to reduction in cycle efficiency.

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b) Fogging of inlet air-stream is often adopted in large gas turbine plants in hot and dry climates.

c) To increase the specific work output in a GTCC cycle, it is always better to use reheating in GT cycle than using supplementary firing at the HRSG.

d) Regenerative feed heating is not encouraged in the steam cycle of a GTCC plant.

e) Air separation units in improve IGCC performance.

3. Figure P2 shows the energy flow diagram of a 300 MW combined cycle power plant. The Power plant has two power cycles coupled in such a manner that 25% of the total input heat is fed to the bottoming cycle directly, while the heat rejection from the topping cycle is fed to a heat exchanger at 600 K. The bottoming cycle receives heat from the heat exchanger at an average temperature of 570 K. The topping and bottoming cycles have 2nd Law efficiencies of 80% and 70%, respectively. Ambient temperature is 298 K. Find

i. First law efficiencies of the topping and bottoming cycles

ii. First and second law efficiencies of the overall cycle

iii. Rate of exergy destruction in the topping cycle, bottoming cycle and the Heat Exchanger.

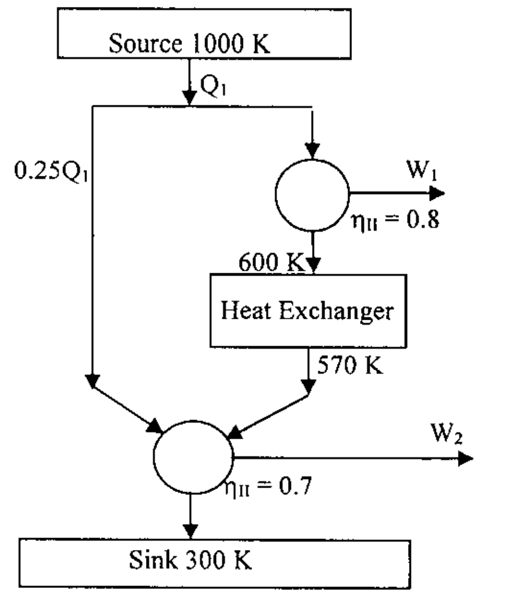

Figure P3

20 Marks

4.

(a) Deduce the expression of a regenerative GT cycle efficiency in terms of the pressure ratio r, adiabatic index γ, temperature ratio t, combustion chamber efficiency η_{cc}, and the isentropic efficiencies η_c of the compressor and η_T of the turbine, and the heat exchanger effectiveness R. Also deduce the expression for work ratio. **14 marks**

(b) The following data refers to a gas turbine set employing a regenerator: Isentropic efficiency of the compressor: 82%, Isentropic efficiency of the turbine: 85%, pressure ratio: 7:1, Maximum cycle temperature: 1000 K, Combustion efficiency: 97%, Calorific value of fuel: 43.1 MJ/kg, Air mass flow rate: 20 kg/s, Effectiveness of the regenerator: 75%, Ambient temperature and pressure: 327 K, 1 bar. Calculate the output, specific fuel consumption and overall thermal efficiency of the cycle.

6 Marks

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5.

A GTCC plant operates with simple GT cycle with a HRSG. The GT, HRSG and ST operating parameters are as follows:

GT Cycle: Temperature ratio = 4.2, Pressure ratio = 5, Isentropic efficiencies for compressor and turbine are 85% and 90%, respectively, GT output = 150 MW

HRSG: Pinch point temperature difference 15 °C, Acid dew point = 170 °C. Exit gas temperature is to be maintained at least 10 °C above the acid dew point.

Steam Cycle: Simple Rankine cycle with a boiler and condenser back pressures of 16 bar and 0.07 bars, respectively. Assume steam turbine expansion isentropic, and neglect pump work.

Ambient condition: 1 bar and 25 °C

Determine, (i) GT cycle efficiency, (ii) ST cycle output, (iii) ratio of gas to steam turbine mass flow rates, and (iv) Overall plant efficiency.

20 Marks

6.

(a) What is an EFGT cycle? What are the merits and demerits of an EFGT cycle compared to an ordinary GT cycle? **6 marks**

(b) What do you mean by HAT cycle? Why are they used? **4 Marks**

(c) Draw a neat sketch of a mercury-steam binary vapor power cycle with the corresponding T-s plot, and deduce the expression of the overall cycle efficiency. **10 marks**

7. As a project manager of a power project, you are to select a 500 MW (gross) steam plant out of the following 3 models of Turbine-generator (including the turbine auxiliaries) proposed by three TG manufacturing companies:

TG Model	**TG Model A**	**TG Model B**	**TG Model C**
Turbine HR (kCal/ kWh)	1935	1925	1950
Quoted price of TG set (Including taxes) (Rs. Millions)	8000	9000	6500
Incremental cost of interfacing equipment (assuming model A as the base case) (Rs. Millions)	70	150	50

Other data:

1. Boiler efficiency = 88%
2. landed cost of coal = Rs. 1200 /T, GCV of coal = 4000 kCal/ kg
3. Annual insurance to be paid on the cost of equipment @1%
4. Discounting rate applicable = 11%
5. Accounting period = 25 years.

Select the best model for the power plant if the predicted plant load factor is 100%

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Time: Three Hours **Full Marks 10**

8.

(a) Define Diversity Factor, and Load Factor of a grid. **2**

(b) The annual costs (in Rs) of operation for two plants A and B are $C_A = 1500 \times L + 0.5 \times Q$ and $C_B = 2000 \times L + 1.5 \times Q$, respectively. Here L and Q and C denote the power (in kW) and energy (in kWh), respectively. The plants are connected to a grid that has a maximum demand of 250 MW, and a minimum demand of 20 MW, and the annual load duration curve approximated by a straight line. Keeping in view the scope for future expansion, the peak-load plant is designed with a 20% capacity margin. Answer the followings:

i) Which one is the peak load plant? What should be the installation capacities of the two plants?
ii) What is the annual load factor of the grid?
iii) Calculate the annual Plant Load Factor and Plant Capacity Factor for A and B.
iv) What is the cost of electricity per unit kWh?

18

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Marks 100

2

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18

Table for Problem 1(b)

TABLE A-25 Thermochemical Properties of Selected Substances at 298K and 1 atm

Substance	Formula	Molar Mass, M (kg/kmol)	Enthalpy of Formation, $\bar{h}_f^\circ$ (kJ/kmol)	Gibbs Function of Formation, $\bar{g}_f^\circ$ (kJ/kmol)	Absolute Entropy, $\bar{s}^\circ$ (kJ/kmol · K)	Heating Values: Higher, HHV (kJ/kg)	Heating Values: Lower, LHV (kJ/kg)
Carbon	$C(s)$	12.01	0	0	5.74	32,770	32,770
Hydrogen	$H_2(g)$	2.016	0	0	130.57	141,780	119,950
Nitrogen	$N_2(g)$	28.01	0	0	191.50	—	—
Oxygen	$O_2(g)$	32.00	0	0	205.03	—	—
Carbon monoxide	$CO(g)$	28.01	−110,530	−137,150	197.54	—	—
Carbon dioxide	$CO_2(g)$	44.01	−393,520	−394,380	213.69	—	—
Water	$H_2O(g)$	18.02	−241,820	−228,590	188.72	—	—
Water	$H_2O(l)$	18.02	−285,830	−237,180	69.95	—	—
Hydrogen peroxide	$H_2O_2(g)$	34.02	−136,310	−105,600	232.63	—	—
Ammonia	$NH_3(g)$	17.03	−46,190	−16,590	192.33	—	—
Oxygen	$O(g)$	16.00	249,170	231,770	160.95	—	—
Hydrogen	$H(g)$	1.008	218,000	203,290	114.61	—	—
Nitrogen	$N(g)$	14.01	472,680	455,510	153.19	—	—
Hydroxyl	$OH(g)$	17.01	39,460	34,280	183.75	—	—
Methane	$CH_4(g)$	16.04	−74,850	−50,790	186.16	55,510	50,020
Acetylene	$C_2H_2(g)$	26.04	226,730	209,170	200.85	49,910	48,220
Ethylene	$C_2H_2(g)$	28.05	52,280	68,120	219.83	50,300	47,160
Ethane	$C_2H_6(g)$	30.07	−84,680	−32,890	229.49	51,870	47,480
Propylene	$C_3H_6(g)$	42.08	20,410	62,720	266.94	48,920	45,780
Propane	$C_3H_8(g)$	44.09	−103,850	−23,490	269.91	50,350	46,360
Butane	$C_4H_{10}(g)$	58.12	−126,150	−15,710	310.03	49,500	45,720
Pentane	$C_5H_{12}(g)$	72.15	−146,440	−8,200	348.40	49,010	45,350
Octane	$C_8H_{18}(g)$	114.22	−208,450	17,320	463.67	48,260	44,790
Octane	$C_8H_{18}(l)$	114.22	−249,910	6,610	360.79	47,900	44,430
Benzene	$C_6H_6(g)$	78.11	82,930	129,660	269.20	42,270	40,580
Methyl alcohol	$CH_3OH(g)$	32.04	−200,890	−162,140	239.70	23,850	21,110
Methyl alcohol	$CH_3OH(l)$	32.04	−238,810	−166,290	126.80	22,670	19,920
Ethyl alcohol	$C_2H_5OH(g)$	46.07	−235,310	−168,570	282.59	30,590	27,720
Ethyl alcohol	$C_2H_5OH(l)$	46.07	−277,690	174,890	160.70	29,670	26,800

Source: Based on JANAF Thermochemical Tables, NSRDS-NBS-37, 1971; *Selected Values of Chemical Thermodynamic Properties*, NBS Tech. Note 270-3, 1968; and *API Research Project 44*, Carnegie Press, 1953. Heating values calculated.

Table A-25