Practice Problems

1. The gas-turbine portion of a combined gas-steam power plant has a pressure ratio of 15. Air enters the compressor at 300 K and 1 atm at a rate of 13 kg/s and is heated to 1500 K in the combustion chamber. The combustion gases leaving the gas turbine are used to heat the steam to 400 ˚C at 10 MPa in a heat exchanger. The combustion gases leave the heat exchanger at 420 K. The steam leaving the turbine is condensed at 15kPa. Assuming all the compression and expansion processes to be isentropic, determine, (a) the mass flow rate ($\dot{m}$) of steam, (b) the net power output ($\dot{W}_{net}$) and (c) the thermal efficiency (η_{th}) of the combined cycle. (d) *What-if scenario:* What would the thermal efficiency be if the compression ratio increased to 17?
   [Ans: (a) 1.6 kg/s, (b) 8.3 MW, (c) 64.7 %, (d) 65.6 %]

2. In a combined gas turbine-steam turbine power plant, the exhaust gas from the open cycle gas turbine is the supply gas to the steam generator of the steam cycle at which additional fuel is burned in the gas. The pressure ratio for the gas turbine is 7.5, the air inlet temperature is 15 ˚C and the maximum cycle temperature is 750 ˚C. Combustion of additional fuel raises the gas temperature to 750 ˚C and the gas leaves the steam generator at 100 ˚C. The steam is supplied to the turbine at 50 bar, 600 ˚C and the condenser pressure is 0.1 bar. The total power output of the plant is 200 MW. The calorific value of the fuel burned is 43.3 MJ/kg. Neglecting the mass flow rate of fuel on the air flow, determine, (a) the flow rates of air and steam required, (b) the power outputs of the gas turbine and steam turbine, (c) the thermal efficiency of the combined plant, (d) the air fuel ratio. Take c_p = 1.005 kJ/kg K and γ = 1.4 for air. Neglect pump work.
   [Ans: (a) $\dot{m}_a$ = 398.34 kg/s, $\dot{m}_s$ = 81.9 kg/s, (b) W_{GT} = 88.22 MW, W_{ST} = 111.78 MW, (c) 50 %, (d) 42.7]

3. A combined cycle power plant has a total power output of 300 MW. The gas turbine operates with a pressure ratio of 10, air inlet temperature of 30 ˚C and the maximum gas temperature of 1000 ˚C. There is the provision for supplementary firing in which the combustion of additional fuel raises the gas temperature to 900 ˚C. The exhaust gas from the GT flows to a HRSG from which the gas leaves at 110 ˚C. in the bottoming steam plant the steam is supplied to the turbine at 80 bar, 500 ˚C and the condenser pressure is 0.1 bar. The calorific value of fuel is burned is 43.3 MJ/kg. Neglect the effect of mass flow rate of fuel on the air flow rate and take c_p = 1.11 kJ/kg K and γ = 1.33 for combustion gases and c_p = 1.005 kJ/kg K and γ = 1.4 for air. Neglect pump work. Determine (a) the flow rates of air and steam required, (b) the power outputs of the gas turbine and steam turbine, (c) the overall efficiency of the combined plant and (d) the air-fuel ratio. Draw the flow and T-s diagrams.

[Ans: (a) $\dot{m}_a$ = 442.62 kg/s, $\dot{m}_s$ = 121.056 kg/s, (b) W_{GT} = 146.47 MW, W_{ST} = 153.53 MW, (c) 53.5 %, (d) 34.1]

4. A combined power plant consisting of a closed cycle GT unit (Brayton cycle), using air as the working fluid and a ST unit (Rankine cycle) is to be designed such that the heat rejected at the GT unit is to be utilized to produce steam at the generator for the ST. The air leaving the generator is at 200 ˚C and it is cooled to the compressor inlet temperature by a second cooler which rejects the heat to waste. Draw the flow and T-s diagram of the plant and calculate on the basis of ideal cycles, neglecting the feed pump work of the Rankine cycle, (a) the mass flow rate of steam per kg/s of air flow, (b) the total power output per kg/s of air flow and (c) the overall efficiency of the plant. Take c_p = 1.005 kJ/kg K and γ = 1.4 for air. The particulars of each cycle are as follows:

		Gas cycle (Brayton)	ST cycle (Rankine)
Pressure (bar)	min	1	0.07
	max	5	30
Temperature (˚C)	min	20	-
	max	830	300

[Ans: (a) 0.0762 kg/s, (b) 314.78 KJ/kg, (c) 49 %]