Thermodynamics 4
Tutorial 2 – Power Cycles 1 (Questions)

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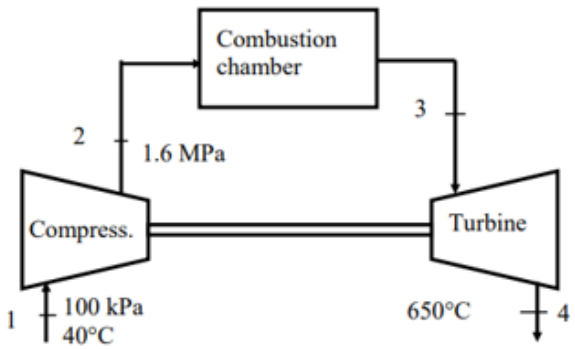
1) **What is the back work ratio? What are typical back work ratio values for gas-turbine engines?**

2) **Why are the back work ratios relatively high in gas- turbine engines?**

3) **How do the inefficiencies of the turbine and the compressor affect (a) the back work ratio and (b) the thermal efficiency of a gas-turbine engine?**

4) **Consider a simple Brayton cycle using air as the working fluid; it has a pressure ratio of 12; has a maximum cycle temperature of 600°C; and operates the compressor inlet at 100 kPa and 15°C. Which will have the greatest impact on the back work ratio: a compressor isentropic efficiency of 80 percent or a turbine isentropic efficiency of 80 percent? Use constant specific heats at room temperature.**

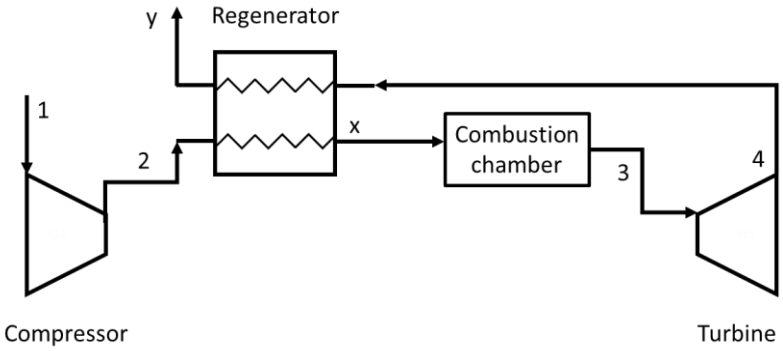
5) **A gas-turbine power plant operates on the simple Brayton cycle between the pressure limits of 100 and 1600 kPa. The working fluid is air, which enters the compressor at 40°C at a rate of 850 m3/min and leaves the turbine at 650°C. Assuming a compressor isentropic efficiency of 85 percent and a turbine isentropic efficiency of 88 percent, determine (a) the net power output, (b) the back work ratio, and (c) the thermal efficiency. Use constant specific heats with c_v = 0.821 kJ/kg·K, c_p = 1.108 kJ/kg·K, and k = 1.35.**

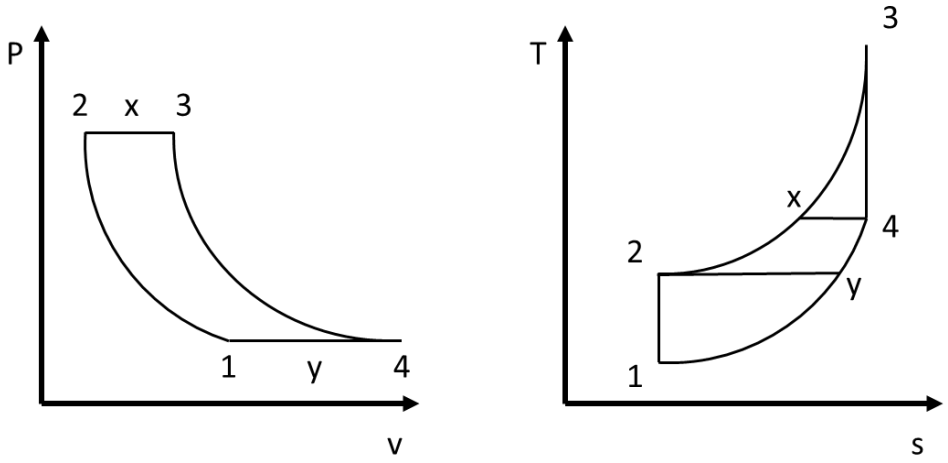


(a) 6488 kW, (b) 0.511, (c) 37.8 percent

6) A Brayton cycle with an ideal regenerator has inlet conditions of 290 K and 90 kPa. The highest pressure and temperature are 1170 kPa and 1800 K, respectively.

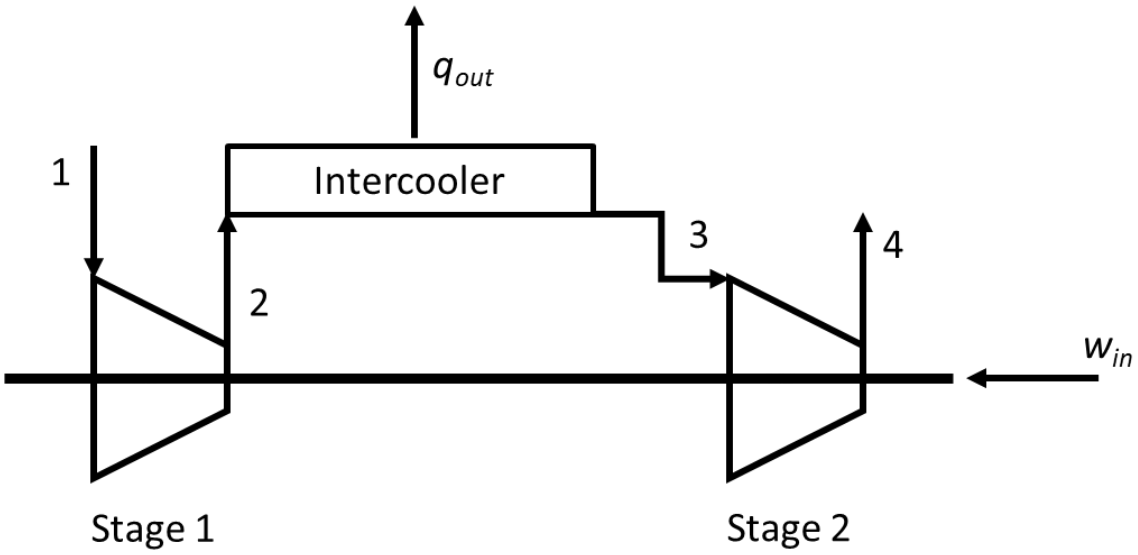
Using the cold air value for heat capacity C_p = 1.004 kJ/kgK, find the specific heat transfer and the cycle efficiency.





$q = 938.7\ kJ/kg,\ \eta = 0.666$

7) A two-stage air compressor has an intercooler between the two stages as shown below. The inlet state is 100 kPa, 290 K and the final exit pressure is 1.6 MPa. Assume that the constant-pressure intercooler cools the air to the inlet temperature so that $T_1 = T_3$. It can be shown that the optimal pressure P_2 for minimum total compressor work is given by $P_2 = (P_1P_4)^{1/2}$ (you may assume this without the need of proof).



Find the specific compressor work for both stages and the intercooler heat transfer that would give optimal P_2.

$w_{c1} = 141.5$ kJ/kg, $w_{c2} = 141.5$ kJ/kg, $q_{out} = 141.5$ kJ/kg

8) A two-stage compressor in a gas turbine brings atmospheric air at 100 kPa, 17°C to 500 kPa, then cools it in an intercooler to 27°C at constant pressure. The second stage brings the air to 2500 kPa. Assume both stages are adiabatic and reversible.

Find the combined specific work for the compressor stages. Compare that to the specific work for the case of no intercooler (only one compression from 100 kPa to 2500 kPa)

$w_{total} = 345.8$ kJ/kg, $w_{\text{no intercooler}} = 439$ kJ/kg

9) **Show that $dh = vdP$ for an adiabatic, reversible process.**

10) **Recalling that $C_p - C_v = R$ and that $k = C_p/C_v$, show that $(k*R)/(k-1) = C_p$, where C_p is the specific heat capacity at constant pressure, C_v is the specific heat capacity at constant volume, k is the specific heat ratio and R is the universal gas constant.**

11) **Using the development for an intercooled compressor in the lecture slides, demonstrate that for two consecutive turbines with reheating, the overall turbine work is maximised when the pressure ratio across the turbines is identical, assuming reheating to the high-pressure turbine inlet temperature in an isobaric steady flow process.**

12) **Assuming isobaric combustion and isentropic compression and expansion, demonstrate the thermal efficiencies of the standard and regenerative Brayton cycles are:**

$$\eta_{th} = 1 - \frac{1}{r_p^{\frac{k-1}{k}}}$$

$$\eta_{th,\text{regen}} = 1 - \frac{T_1}{T_a} * r_p^{\frac{k-1}{k}}$$

where r_p is the pressure ratio across the compression stage, k is the specific heat ratio of the working fluid, T_1 is the compressor inlet temperature and T_a is the turbine inlet temperature.

13) **For a standard, ideal Brayton cycle, show that maximum work is achieved when $T_2 = (T_1T_3)^{1/2}$. Then show that this corresponds to a pressure ratio r_p such that:**

$$r_p = \left(\frac{T_3}{T_1}\right)^{\frac{k}{2*(k-1)}}$$

where T_1, T_2 and T_3 are the temperatures of the compressor inlet, compressor outlet and turbine inlet respectively; r_p is the pressure ratio across the compression stage and k is the specific heat ratio of the working fluid.

Note: Start by writing the work output of the cycle as a function of T_2 and then derive with respect to T_2.

14) **An intercooled gas turbine has ambient conditions 1.013 bar, 15°C, compressor isentropic efficiency 87%, turbine isentropic efficiency 90%, compressor stage ratio 6.6, constant air flow 200 kg/s, firing temperature 1400°C, temperature after intercooler 15 K above air inlet temperature, pressure drop in intercooler 0.15 bar, pressure drop in combustor 1% of inlet pressure. Effective air properties are C_p = 1.15 kJ/kgK, k = 1.333.**

What are the compressor work, turbine work, combustor heat input, and efficiency for:

a) The above configuration?

94.1 MW, 210 MW, 266.8 MW, 43.5 %

b) When a regenerator is added that heats the air to within 150 K of the maximum possible value?

94.1 MW, 210 MW, 245 MW, 47.3 %

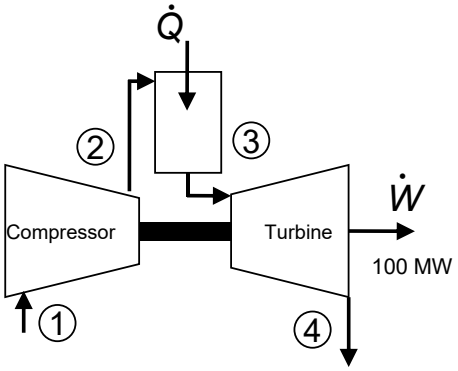
c) With a single-stage compressor with the same exit pressure and no regenerator?

119.3 MW, 210 MW, 199.2 MW, 45.5 %

d) If the firing temperature of the gas turbine in c) is reduced to 1150°C?

119.3 MW, 179.5 MW, 141.7 MW, 42.6 %

15) A large stationary Brayton cycle gas-turbine power plant delivers a power output of 100 MW to an electric generator. The minimum temperature in the cycle is 300 K, and the exhaust temperature is 750 K. The minimum pressure in the cycle is 100 kPa, and the compressor pressure ratio is 18:1. Calculate the power output of the turbine. What fraction of the turbine output is required to drive the compressor? What is the thermal efficiency of the cycle?



166.64 MW, 0.4, 56.2%

16) Repeat the previous problem, but assume the compressor has an isentropic efficiency of 85% and the turbine has an isentropic efficiency of 88%.

214.9 MW, 0.535, 41%