School of Engineering, University of Edinburgh
Engineering Thermodynamics 2

THE UNIVERSITY *of* EDINBURGH
School of Engineering

Tutorial 9 – Rankine and Otto Cycles

Note: numerical solution are based on one approach to solving the tutorial questions. Other approaches can also be correct and could lead to slightly different numerical answers.

Conceptual Questions:

1. How does an Otto cycle deviate from the Carnot cycle?

2. What simplifications or assumptions are made when treating a gasoline internal combustion engine as an ideal Otto cycle?

3. Why are there limitations on the allowable compression ratios for internal combustion engines?

Problem Solving Questions

4. A small power plant operates on the ideal Reheat Rankine cycle. Steam flows at 25 kg/s in the boiler to produce steam at 3 MPa, 600°C that enters the high-pressure turbine. The steam exits the high-pressure turbine and re-enters the boiler where it is reheated to 400°C at 500 kPa and then is sent to the low-pressure turbine. The steam/water is sent to the condenser where it exits the condenser at a temperature of 45°C.

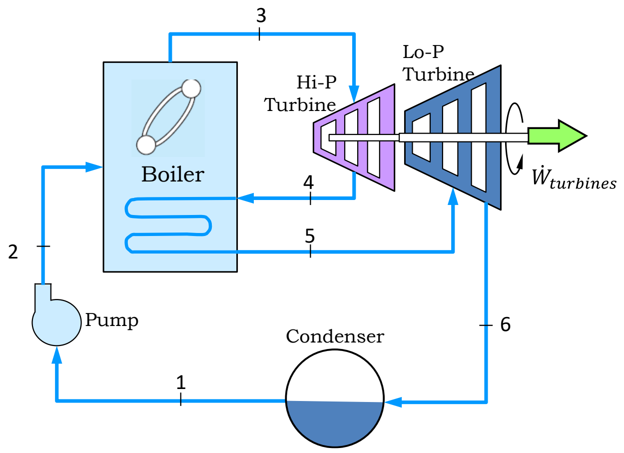
a. Determine the quality of the steam exiting the low-pressure turbine.

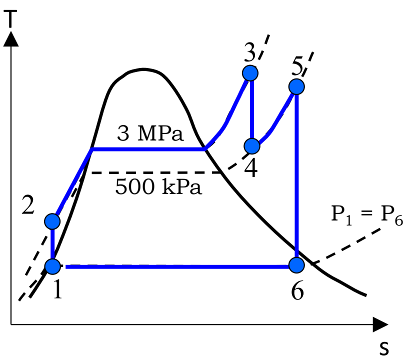
b. Determine the cycle efficiency.

c. Now assume that the low-pressure turbine is not reversible and the steam exits as a saturated vapor at 45°C

 i. Determine the cycle efficiency.

 ii. Determine the rate of entropy generation in the low-pressure turbine.





[ans: a) $x_6 = 0.9507$, b) $\eta_{th} = 38\%$ c) i) $\eta_{th} = 34.7\%$, ii) $\dot{S}_{gen,65} = 9.275 \frac{kW}{K}$]

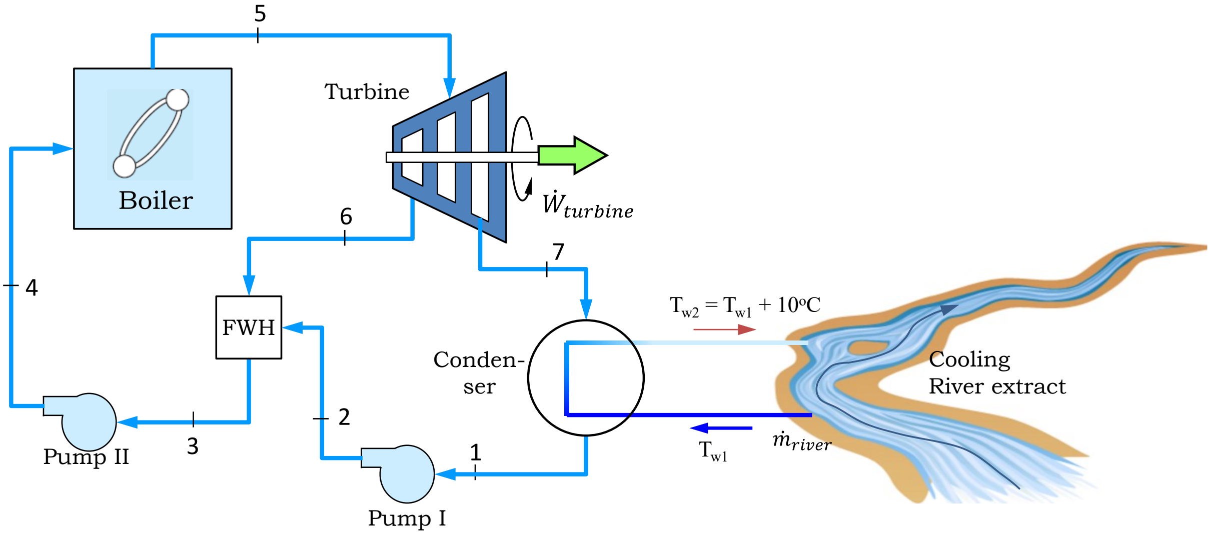
5. An _ideal_ steam power plant has high and low working pressures of 20 MPa and 10 kPa. It operates with an open feedwater heater at 1 MPa. The water exiting the FWH is a saturated liquid at 1 MPa. The maximum working temperature is 800°C and the turbine has a total power output of 5 MW.

a. Find the flow rate of steam sent into the FWH.

b. Determine the cycle efficiency.

c. Draw the T-s diagram for this open feedwater heater cycle.

d. To reject the heat in the condenser, a fraction of a river flow is extracted and sent through piping in the condenser in a heat exchanger arrangement. If the government will not allow the heating of the river to exceed 10°C, determine the flow rate of the river allowed to pass through the condenser. Assume the river water to have a constant specific heat of C_P = 4.184 kJ/kgK.



[ans: a) $\dot{m}_6 = 0.60\frac{kg}{s}$, *b)* $\eta_{th} = 50.3\%$ *d)* $\dot{m}_{river} = 116.16\frac{kg}{s}$*]*

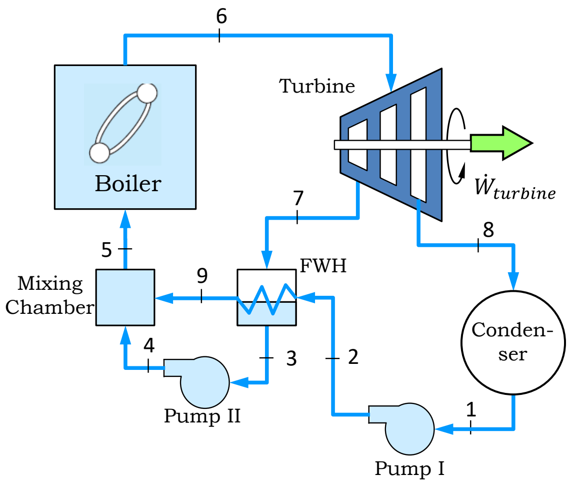
6. A steam power plant operates on an *ideal* regenerative Rankine cycle with closed feedwater heater. Steam enters the turbine at 10 MPa and 550°C. Steam is condensed in the condenser at 20 kPa. Steam is extracted from the turbine at 1000 kPa and sent through the closed feedwater heater. This extracted steam leaves the FWH as a saturated liquid at 1000 kPa. The turbine produces 14 MW of power, while the condenser removes 19.5 MW of heat in the condenser.

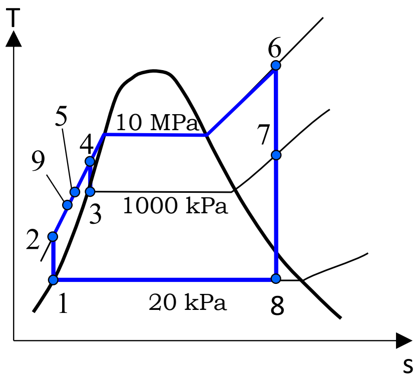
a. Determine the total mass flow rate of steam through the cycle.

b. Determine the quality of the steam exiting the turbine.

c. Determine the flow rate of steam extracted into the FWH.

d. Determine the cycle efficiency.





[ans: a) x_8 = 0.837, *b)* $\dot{m}_{total} = 12.06\frac{kg}{s}$ *c)* $\dot{m}_7 = 2.18\frac{kg}{s}$, *d)* $\eta_{th} = 41.6\%$*]*

7. Consider an ideal, air-standard Otto cycle with a compression ratio of 9. Before compression, the air exists at P_1 = 95 kPa, T_1 = 17°C and occupies V_1 = 3.8 Litres. During the constant volume heat addition, 7.5 kJ of heat is transferred to the air. Assume constant specific heats with R_{air} = 0.287 kJ/kgK, C_v = 0.717 kJ/kgK.

a) Determine the maximum temperature and pressure in the cycle.

b) Calculate the thermal efficiency.

c) Calculate the mean effective pressure.

[ans: a) T_3 = 3111.7 K, P_3 = 9169 kPa , b) $\boldsymbol{\eta_{th}} = \mathbf{58.5}\%$*, c) MEP = 1298.4 kPa]*

8. A gasoline engine operates on the ideal Otto cycle. Before compression, the air exists at P_1 = 90 kPa and T_1 = 290K. The combustion adds 1000 kJ/kg to the air after which the temperature is 2050K. Assume constant specific heats with R_{air} = 0.287 kJ/kgK and C_v = 0.717 kJ/kgK.

a) Determine the compression ratio.

b) Determine the highest pressure in the cycle.

c) Determine the exhaust temperature (T_4).

d) Determine the specific net work output in kJ/kg.

[ans: a) r = 7.67, b) P_3 = 4883 kPa, c) T_4 = 907.2K, d) w_{net} = 557.5 kJ/kg]