General Information

- Exam resources: property tables in book and four pages (front and back) of your own notes.
- There will be three problems on the exam. All three will involve cycle analysis (similar to the homework problems), and all will be given the same weight in the final grade. The problems will cover
  1. A vapor power cycle (Rankine cycle, possibly with reheat and/or FWH),
  2. A gas turbine power or propulsion cycle,
  3. A spark or compression ignition IC cycle.
- The exam will begin at 8:55 and end at 9:55.
- Please spread out when you arrive in the classroom. There should be an empty seat between yourself and your neighbors.

Problem-Solving advice

1. Your first step should be to identify precisely what the problem is asking for. Don’t simply read the first couple of sentences – which typically describe the cycle – and then go about a shotgun approach of determining every state or process in the cycle. More often than not, most of this information will not be needed to solve the problem as stated.

2. Once you understand what the required quantities are in the problem, then you can identify the required formulas and property information needed to obtain the quantities.

3. Often there is a shortcut to the answer. You may see one if you are clear about what is required in the problem. I give some examples of shortcuts in the review problems.

4. Formulate the problem first, get the property information last.

5. Even better, formulate all of the problems first, then get the property information and do the arithmetic to get the answer(s). Refer to the following piece of advice:

6. You will earn a substantial number of marks on a problem (say 7-8 out of 10) if you provide a correct road map (i.e., formulation) to the problem yet have left out the property information and/or calculations. On the other hand, a blank problem will earn a blank.

Review Problems

1. A single-cylinder, 4-stroke spark-ignition engine has a displacement of 400 cc (1 cc = 10^{-6} m^3) and a compression ratio of 6. At the beginning of the compression stroke the air in the cylinder is at 300 K and 95 kPa. The maximum temperature in the cycle is 1600 K. Determine:
   (a) The heat input per unit mass during a cycle \( q_H \).
   (b) The cycle thermal efficiency.
   (c) The net work per unit mass produced during a cycle \( w_{net} \).
   (d) The engine RPM required to produce a power output of 4 kW.

Use the air-standard Otto cycle and assume constant specific heats in your analysis, with \( c_v = 0.75 \) kJ/kg·K, \( k = 1.4 \), and \( R = 0.287 \) kJ/kg·K.

Some advice: the net work can be obtained from \( w_{net} = \eta \cdot q_H \), and both \( \eta \) and \( q_H \) are relatively simple to find. This approach is computationally quicker than calculating the net work as the difference between the expansion and compression works. For the 4-cycle: \( \dot{W} = mw_{net} \cdot RPM/60/2 \), and \( V_{disp} = m(v_1 - v_2) = mv_1(1 - 1/r) \) can be used to find \( m \). Solution to d) RPM = 2\cdot60\cdot\dot{W}/(wm) = 2396 \text{ rev/s.}
2. Air enters the compressor of a regenerative gas turbine engine at 300 K and 100 kPa, where it is compressed to 800 kPa and 580 K. The inlet temperature of the turbine is 1200 K. The regenerator is ideal and the turbine has an isentropic efficiency of $\eta_T = 0.8$. Determine:

(a) The net work per unit mass.
(b) The cycle thermal efficiency.

Assume constant specific heats, with $c_p = 1.01$ kJ/kg·K. Solution to b) $\eta = \frac{w_{net}}{q_H} = 0.349$

3. A diesel cycle uses a compression ratio of 18, and the end of the constant–pressure combustion process occurs at a cutoff ratio of $V_3/V_2 = 3$. The conditions at the beginning of the compression stroke are $P_1 = 95$ kPa, $T_1 = 320$ K. Find the maximum temperature in the cycle and the cycle thermal efficiency. Answers: Constant specific heat model gives $\eta = 0.59$, $T_3 = r_CT_2 = r_CT_1 r^{k-1} = 3051$ K. The second answer is not very realistic; a more accurate result would use the air tables.

4. A simple gas turbine (no regeneration) generates a power output of $W = 2$ MW. The compressor and turbine have isentropic efficiencies of 0.85, and the heat added, per unit mass flow, is $q_H = 1400$ kJ/kg.

The pressure ratio is $r_P = 10$. Calculate

(a) The maximum temperature in the cycle.
(b) The air mass flow rate.

Assume constant specific heats, with $c_p = 1.01$ kJ/kg·K and $k = 1.4$. Answers (assuming $T_1 = 300$ K): $T_{2a} = 628$ K, $T_3 = 2015$ K, $w_{net} = 502$ kJ/kg, $\dot{m} = 3.98$ kg/s.

5. A simple Rankine cycle operates between the pressures of 50 kPa and 2 MPa. Both the turbine and the pump can be considered isentropic. The inlet to the pump is a saturated liquid, and the exit of the turbine is a saturated vapor, both at 50 kPa. Find

(a) The turbine inlet temperature,
(b) The cycle thermal efficiency, and
(c) the mass flow rate needed to provide a net power output of $\dot{W}_{net} = 50$ MW.

Advice: the turbine exit state is specified ($x_4 = 1, P_4 = 50$ kPa, and the turbine is isentropic, so $s_3 = s_4$ and $P_3 = 2$ MPa fix state 2. The isentropic pump work can be estimated as $w_p = v_1(P_2 - P_1)$, and $h_2 = h_1 + w_p$. Answers: $T_3 = 559^\circ$C, $\eta = 0.29$, $w_{net} = 950$ kJ/kg, $\dot{m} = \dot{W}/w_{net} = 52.6$ kg/s.

6. A Rankine cycle has a condenser pressure of 50 kPa and a boiler pressure of 5 MPa. The pump and the turbine can be considered isentropic, and the maximum temperature in the cycle is 450°C. The cycle employs a single open FWH which operates at 500 kPa. Find:

(a) The fraction of the mass flow through the boiler that is split from the turbine and sent to the FWH.
(b) The net work per unit mass, and the cycle thermal efficiency.

Solution (the H2O code was used to get properties):

$P_1 = P_6 = 50$ kPa, $P_2 = P_3 = P_7 = 500$ kPa, $P_4 = P_5 = 5$ MPa

$h_1 = 340.5 \text{ kJ/kg}, \quad w_{p_1} = v_1(P_2 - P_1) = 0.45 \text{ kJ/kg}, \quad h_2 = h_1 + w_{p_1} = 341 \text{ kJ/kg}

h_3 = h_f(500 \text{ kPa}) = 640.3 \text{ kJ/kg}, \quad w_{p_2} = v_3(P_4 - P_3) = 5 \text{ kJ/kg} \quad h_4 = h_3 + w_{p_2} = 645.3 \text{ kJ/kg}

h_5 = 3316 \text{ kJ/kg}, \quad s_5 = 6.818 \text{ kJ/kg·K} \quad K = s_6 = s_7

h_6(50 \text{ kPa}, s_6) = 2371 \text{ kJ/kg}, \quad h_7(50 \text{ kPa}, s_7) = 2748 \text{ kJ/kg}

y = \frac{h_3 - h_2}{h_7 - h_2} = 0.124

w_t = h_5 - (1 - y)h_6 - yh_7 = 898 \text{ kJ/kg}, \quad w_p = (1 - y)w_{p_1} + w_{p_2} = 5.3 \text{ kJ/kg}

w_{net} = w_t - w_p = 893 \text{ kJ/kg}, \quad q_H = h_5 - h_4 = 2671 \text{ kJ/kg}, \quad \eta = \frac{w_{net}}{q_H} = 0.334