In Session Practice Problems – Thermodynamics (EGN 3343)

April 2024

Hello everyone,

These are some problems that, in my experience, provide students with a wider understanding of the topics covered in the first third of the semester. I will go over these and other problems during my sessions. I highly recommend that you attend these sessions to solve any doubts.

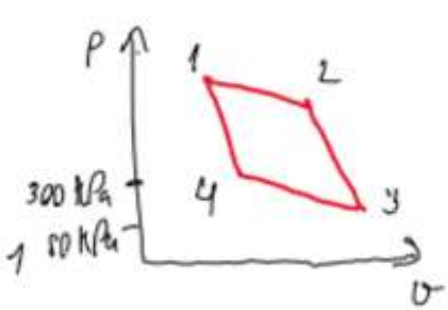
Disclaimer: There is no guarantee that any of these problems will be included in any exam, so the best way to approach these problems is like practice problems that will help you familiarize yourself with important concepts learned during the semester. Finally, do not use this guide as your ONLY study resource for the exams.

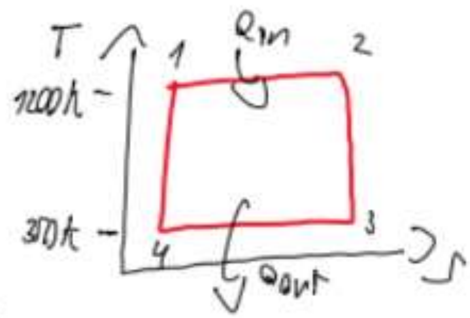
Important Note: All problems and diagrams presented here were extracted from Cengel, Yunus, et al. Thermodynamics: An Engineering Approach. Available from: Yuzu Reader, (9th Edition). McGraw-Hill Higher Education (US), 2018.

9-19. An air-standard Carnot cycle is executed in a closed system between the temperature limits of 350 and 1200 K. The pressures before and after the isothermal compression are 150 and 300 kPa, respectively. If the net work output per cycle is page 5290.5 kJ, determine (a) the maximum pressure in the cycle, (b) the heat transfer to air, and (c) the mass of air. Assume variable specific heats for air. Answers: (a) 30.0 MPa, (b) 0.706 kJ, (c) 0.00296 kg

9.19 $T_L = 350\,K$ $T_H = 1200\,K$ $W_{net} = 0.5\,kJ$

$P_1 = 150\,kPa$ $P_2 = 300\,kPa$





a. 4-1 is an isentropic process, so

$$\frac{P_1}{P_4} = \frac{P_{r,1}}{P_{r4}}$$ From table A-17 $P_{r4} = 2.379$ $P_{r1} = 238$

$$P_2 = \frac{238}{2.379}(300\,kPa) = 30012.61\,kPa$$

$$\boxed{P_2 \approx 30\,MPa}$$

b. $$\eta = 1 - \frac{T_L}{T_H} = 1 - \frac{350\,K}{1200\,K} = 0.708333$$

but η is also equal to

$$\eta = \frac{W_{net}}{Q_{in}}, \text{ so}$$

$$Q_{in} = \frac{W_{net}}{\eta} = \frac{0.5\,J}{0.708333} = 0.705882\,J$$

$$\approx 0.706\,J$$

c.

$$s = \frac{q}{T} \rightarrow q = T(s_2 - s_1)$$

$$q = \left[C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right) \right] T$$

$$q = 350 \left[1.005 \ln(1) - 0.2870 \ln\left(\frac{300 \text{ kPa}}{150 \text{ kPa}}\right) \right]$$

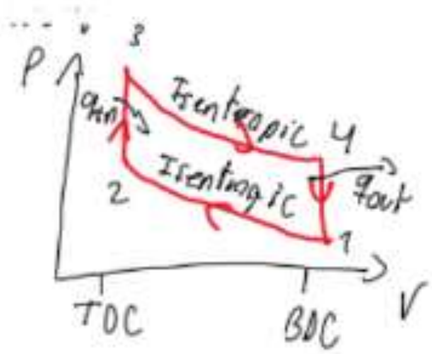
$$q = -69.6266 \text{ kJ/kg}$$

$$Q_{out} = 0.705882 - 0.5 = 0.205882 \text{ kJ}$$

$$m = \frac{Q}{q} = \frac{0.205882}{69.6266} = 0.00295694$$

$$m \approx 0.00296 \text{ kg}$$

9.34. An ideal Otto cycle has a compression ratio of 8. At the beginning of the compression process, air is at 95 kPa and 27°C, and 750 kJ/kg of heat is transferred to air during the constant volume heat-addition process. Taking into account the variation of specific heats with temperature, determine (a) the pressure and temperature at the end of the heat-addition process, (b) the net work output, (c) the thermal efficiency, and (d) the mean effective pressure for the cycle. Answers: (a) 3898 kPa, 1539 K, (b) 392 kJ/kg, (c) 52.3 percent, (d) 495 kPa



$BDC = 8 = \frac{v_1}{v_2}$

$P_1 = 95\ kPa \qquad T_1 = 27°C$

$q_{in} = 750\ \frac{kJ}{kg}$

a. $PV = RTm \rightarrow Pv = RT \rightarrow v_1 = \frac{RT}{P}$

$v_1 = \frac{0.287\ (300\ K)}{95\ kPa} = 0.906315\ m^3/kg$

$v_2 = \frac{v_1}{8} = 0.113289\ m^3/kg$

$v_{r1} = 621.2$

Since 1-2 is isentropic

$\frac{v_1}{v_2} = \frac{v_{1r}}{v_{2r}} \rightarrow v_{2r} = v_{1r}\left(\frac{v_2}{v_1}\right)$

$v_{2r} = 621.8\left(\frac{1}{8}\right) = 77.6375$

Interpolating table A-17

$T_2 = 673.1270\ K \qquad u_2 = 491.252\ kJ/kg$

$P_2 = \frac{RT}{v} = \frac{0.287\ (673.1270)}{0.113289} = 1705.26\ kPa$

$u_3 = q + u_2 = 750 + 491.252 = 1241.252\ kJ/kg$

Once again we interpolate table A-17

$T_3 = 1538.74 \approx \boxed{1539\ K}$ $\quad V_{3r} = 6.587088$

$$P_3 = \frac{RT_3}{v_3} = \frac{0.287\,(1538.73)}{0.113289} = 3898.13\ kPa$$

$$\boxed{P_3 \approx 3898\ kPa}$$

6. $T_3 = 1538.73\ K \qquad V_{3r} = 6.587088$

$$V_{4r} = V_{3r}\left(\frac{V_4}{V_3}\right) = 6.587088\,(8) = 52.6967$$

Interpolating table A-17

$T_4 = 774.581\ \frac{kJ}{kg} \qquad h_4 = 571.755\ \frac{kJ}{kg}$

$$q_{out} = h_4 - h_1 = 571.755 - 214.07$$

$$q_{out} = 357.688\ kJ/kg$$

$$w_{out} = q_{in} - q_{out} = 750 - 357.685$$
$$= \boxed{392.315\ \frac{kJ}{kg}}$$

c.

$$\eta = \frac{w_{out}}{q_{in}} = \frac{392.315}{750} = 0.523086$$
$$\boxed{\approx 52.3\%}$$

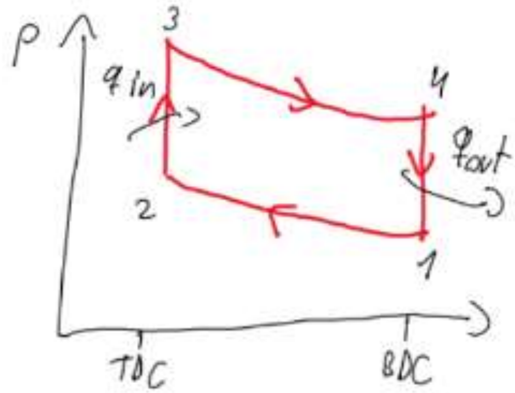
D $w = P_{mean} \Delta v \rightarrow P_{mean} = \frac{w}{\Delta v}$

$$P_{mean} = \frac{392.315}{0.406315 - 0.113289} = 494.706 \text{ kPa}$$

$$\boxed{P_{mean} \approx 495 \text{ kPa}}$$

9-38. An ideal Otto cycle has a compression ratio of 7. At the beginning of the compression process, P1 = 90 kPa, T1 = 27°C, and V1 = 0.004 m^3. The maximum cycle temperature is 1127°C. For each repetition of the cycle, calculate the heat rejection and the net work production. Also calculate the thermal efficiency and mean effective pressure for this cycle. Use constant specific heats at room temperature. Answers: 1.03 kJ, 1.21 kJ, 54.1 percent, 354 kPa

9.38



$$\frac{BDC}{TDC} = 7 = \frac{v_1}{v_2}$$

$P_1 = 90\ kPa$

$T_1 = 27\ °C$

$V_1 = 0.004\ m^3$

$T_3 = 1127\ °C$

$$PV = RTm \rightarrow m = \frac{PV}{RT}$$

$$m = \frac{90\ kPa\ (0.004\ m^3)}{0.287\ (300\ K)} = 0.00418118\ kg$$

1-2 and 3-4 are isentropic processes

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1}$$

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{k-1}$$

$$T_2 = 300\ K\ (7)^{1.4-1} = 653.371\ K$$

$$\frac{T_3}{\left(\frac{V_4}{V_3}\right)^{k-1}} = T_4$$

$$T_4 = \frac{1127+273}{7^{1.4-1}} = 642.819\ K$$

$$Q_{out} = m\,C_v\,\Delta T$$

$$Q_{out} = 0.00418118(0.718)(642.819 - 300)\ K$$

$$Q_{out} = 1.02917\ kJ \approx \underline{1.03\ kJ}$$

$$W = Q_{in} - Q_{out}$$

$$Q_{in} = 0.00418118\ (0.718)(1400 - 653.771)\ K$$

$$Q_{in} = 2.24144\ kJ$$

$$W = 2.24144\ kJ - 1.02917\ kJ$$

$$W = 1.21227\ kJ \simeq \underline{1.21\ kJ}$$

$$\eta = \frac{W_{out}}{q_{in}} = \frac{1.21227}{2.24144} = 0.540845$$

$$\eta \approx 54.1\%$$

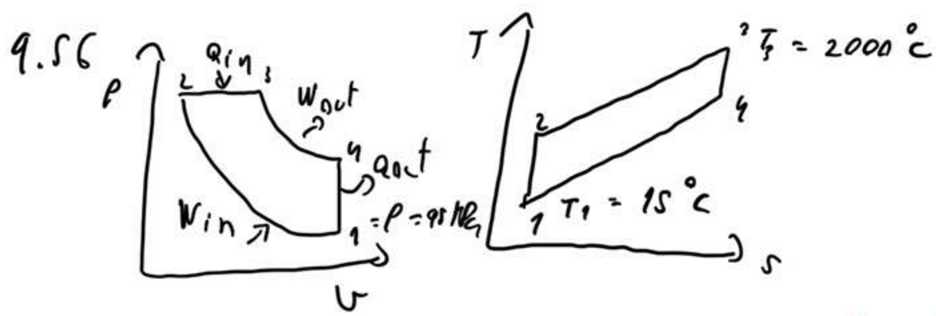
$$W = P_{mean} \cdot \Delta V \rightarrow P_{mean} = \frac{W}{\Delta V}$$

$$P_{mean} = \frac{1.21227}{V_1 - \frac{V_1}{7}} = \frac{1.21227(7)}{0.004(6)}$$

$$P_{mean} = 353.5787\ kPa \approx \underline{354\ kPa}$$

9-56 An ideal Diesel cycle has a maximum cycle temperature of 2000°C. The state of the air at the beginning of the compression is P1 = 95 kPa and T1 = 15°C. This cycle is executed in a four-stroke, eight-cylinder engine with a cylinder bore of 10 cm and a piston stroke of 12 cm. The minimum volume enclosed in the cylinder is 5 percent of the maximum cylinder volume. Determine the power produced by this engine when it is operated at 1600 rpm. Use constant specific heats at room temperature. Answer: 96.5 kW

9.56



Cylinder bore refers to the cylinder diameter

$$V_1 = \left(\frac{0.1}{2}\right)^2 \pi (0.12) = 9.4247 \times 10^{-4} m^3$$

$$V_2 = 0.05(9.4247 \times 10^{-4}) = 4.7124 \times 10^{-5} m^3$$

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{k-1} = (15+273)\left(\frac{1}{0.05}\right)^{1.4-1} = 954.56$$

$$PV = mRT$$

$$\frac{V}{T} = \frac{mR}{P} = \text{Constant} \xrightarrow{\text{So}} \frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$V_3 = \frac{T_3 V_2}{T_2} = \frac{2273(4.724 \times 10^{-5})}{954.56}$$

$$V_3 = 1.1248 \times 10^{-4} m^3$$

$$T_4 = T_3 \left(\frac{V_3}{V_4}\right)^{k-1} = 2273 \left(\frac{1.1248 \times 10^{-4}}{9.4247 \times 10^{-4}}\right)^{1.4-1}$$

$$T_4 = 971.25 \, K$$

$$PV = mRT \rightarrow m = \frac{PV}{RT}$$

$$m = \frac{95\,(1.1248 \times 10^{-}\,)}{0.287\,(15+273)} = 0.00108322 \text{ kg}$$

$$W = Q_{in} - Q_{out}$$

$$W = m\,(c_p(T_3 - T_2) - c_v(T_4 - T_1))$$

$$W = 0.00108322(1.005(2273 - 954.56) - 0.718(971.258 - 288))$$

$$W = 0.9058961 \text{ KJ}$$

$$1600 \frac{rev}{min}\left(\frac{1 min}{60 s}\right) = 26.6667 \frac{rev}{s}$$

We have 4 stroke, so the power should be multiplied by 4

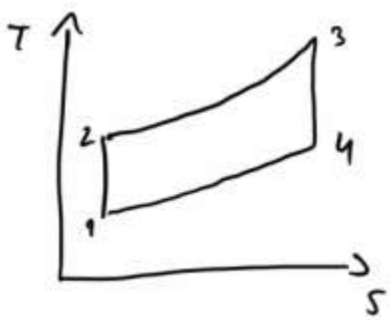
$$W = 0.90389673 * 4 = 3.61558$$

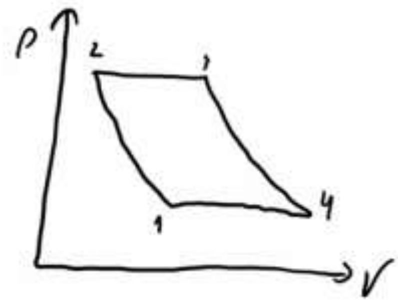
since this happens $26.\bar{6}$ times per second

$$P = 3.61558(26.6667) = 96.4155 \text{ KW}$$

$$\boxed{P = 96.4 \text{ KW}}$$

9-92 Air is used as the working fluid in a simple ideal Brayton cycle that has a pressure ratio of 12, a compressor inlet temperature of 300 K, and a turbine inlet temperature of 1000 K. Determine the required mass flow rate of air for a net power output of 70 MW, assuming both the compressor and the turbine have an isentropic efficiency of (a) 100 percent and (b) 85 percent. Assume constant specific heats at room temperature. Answers: (a) 352 kg/s, (b) 1037 kg/s





a. $T_1 = 300$ $T_3 = 1000\,K$ $c_p = 1.005\ \frac{kJ}{kg \cdot K}$

$$W_{out} = m\, c_p\left((T_3 - T_4) - (T_2 - T_1)\right)$$

$$\frac{P_2}{P_1} = \frac{P_3}{P_4} = 12$$

We need to find T_2 and T_4, and we can use isentropic relationships for this

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \rightarrow T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$T_2 = 300\,(12)^{\frac{1.4-1}{1.4}} = 610.181\,K$$

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}} \rightarrow T_4 = 1000\left(\frac{1}{12}\right)^{\frac{1.4-1}{1.4}}$$

$$T_4 = 491.657\,K$$

$$m = \frac{W_{out}}{c_p\left((T_3 - T_4) - (T_2 - T_1)\right)}$$

$$m = \frac{70000\ kW}{1.005\left((1000 - 491.657) - (610.181 - 300)\right)}$$

$$\boxed{m = 351.48 \simeq 351\ \frac{kg}{s}}$$

6.

In case our compressor is not ideal

$$W_{out} = \eta W_{out} - \frac{W_{in}}{\eta}$$

$$W_{out} = \eta c_p m (T_3 - T_4) - \frac{m c_p (T_2 - T_1)}{\eta}$$

$$W_{out} = m \left(\eta c_p (T_3 - T_4) - \frac{c_p}{\eta} (T_2 - T_1) \right)$$

$$m = \frac{70000}{(0.85(1.005)(1000 - 491.657) - \frac{1.005}{0.85}(610.81 - 300))}$$

$$m = 1036.90$$

$$\boxed{m \approx 1037 \text{ kg/s}}$$

10-15 A simple ideal Rankine cycle with water as the working fluid operates between the pressure limits of 3 MPa in the boiler and 30 kPa in the condenser. If the quality at the exit of the turbine cannot be less than 85 percent, what is the maximum thermal efficiency this cycle can have? Answer: 29.7 percent

10.15 $Q_{in} = h_3 - h_2$

$Q_{out} = h_4 - h_1$

at 30 kPa (Table A5)

$h_f = h_1 = 289.27 \frac{kJ}{kg}$ $s_1 = 0.9441$

$v_1 = 0.001022$

$h_4 = h_f + x h_{fg} = 289.27 + 0.85(2335.3)$

$h_4 = 2274.27 \frac{kJ}{kg}$

$s_4 = 0.9441 + 0.85(6.8234)$

$s_4 = 6.74399$

at 30 MPa

Using the formula for the work of a pump

$w = v(P_2 - P_1) = h_2 - h_1 \rightarrow h_2 = v(P_2 - P_1) + h_1$

$h_2 = 0.001022(3000 - 30) + 289.27 = 292.305 \text{ kJ/kg}$

Using entropy as reference and interpolating table A-6

$h_3 = 3115.49$ kJ/kg

$q_{in} = 3115.49 - 292.305$

$q_{in} \approx 2823.18$

$q_{out} = 2274.27 - 289.27$

$q_{out} = 1985$

$\eta = 1 - \frac{1985}{2823.18} \approx 0.296843$

$\boxed{\eta \approx 29.7\%}$