Rhiley Silvis | MET 350

Problem 9-13

An Air Standard cycle with variable specific heats is executed in a closed system and is composed of the following four processes:

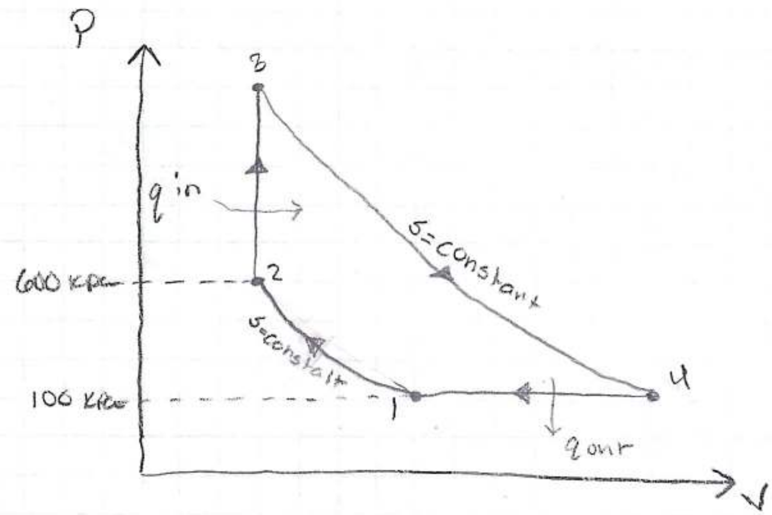
1 - 2 Isentropic compression from 100 kPa and 22 C° (295 K) to 600 kPa.

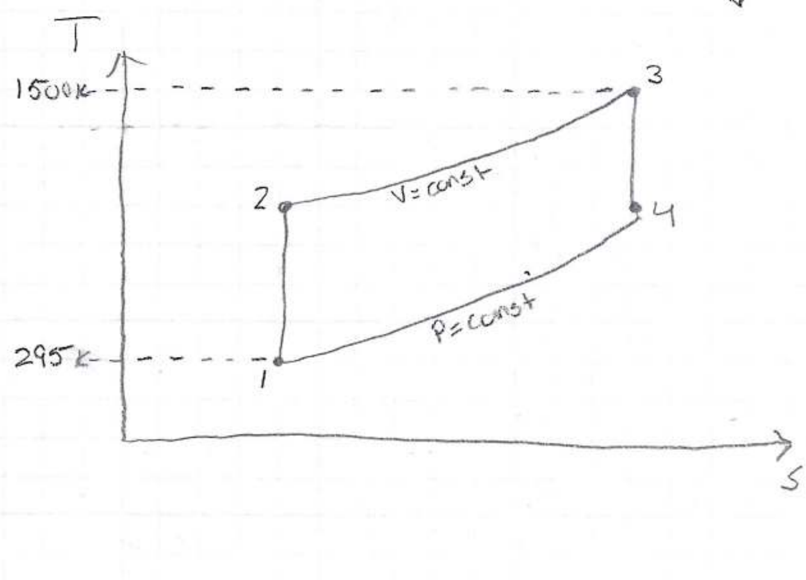
2 - 3 V = constant heat addition to 1500 K

3 - 4 Isentropic expansion to 100 kPa

4 - 1 P = constant heat rejection to inial state

a) Show the cycle on P-V and T-s diagrams





b) Calculate net work per unit mass

From A-17 @ 295 K : $P_{r1} = 1.3068$

$u_1 = 210.49$ kJ/kg

1-2) Isentropic, Ideal gas, var cp,cv

$$\frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}} \longrightarrow \frac{600 \text{ kPa}}{100 \text{ kPa}} = \frac{P_{r2}}{1.3068}$$

– $P_{r2} = 7.8408$

P_r	T
8.411	500
7.8408	T_2
7.824	490

$$\frac{7.8408-8.411}{7.824-8.411} = \frac{T_2 - 500}{490-500}$$

– $T_2 = 490.29$ K

P_r	u
8.411	359.49
7.8408	u_2
7.824	352.08

$$\frac{7.8408-8.411}{7.824-8.411} = \frac{u_2 - 359.49}{352.08-359.49}$$

– $u_2 = 352.29$ kJ/kg

2-3) contant V

– $T_2 = 490.29$ K

– $P_2 = 600$ kPa

– $T_3 = 1500$ K

$$P_3 = P_2\left(\frac{T_3}{T_2}\right)$$

– $P_3 = 600\left(\frac{1500 \text{ K}}{490.29 \text{ K}}\right) = 1835.65$ kPa

From A-17 @ 1500 K – $P_{r3} = 601.9$

– $u_3 = 1205.41$ kJ/kg

3-4) Isentropic process – $P_4 = 100$ kPa

$$\frac{P_4}{P_3} = \frac{P_{r4}}{P_{r3}} \longrightarrow \frac{100 \text{ kPa}}{1835.65 \text{ kPa}} = \frac{P_{r4}}{601.9} \qquad P_{r4} = 32.79$$

P_r	h
32.02	734.82
32.79	h_4
33.72	746.62

$$\frac{32.79-32.02}{33.72-32.02} = \frac{h_4 - 734.82}{746.62-734.82}$$

$$h_4 = 739.71 \text{ kJ/kg}$$

h_1 From A-17 @ 295 K = 295.17 kJ/kg

Process 2-3 const volume (u)

$q_{in} = u_3 - u_2 = 1205.41 - 352.29$

$q_{in} = 853.12$ kJ/kg

Process 4-1 const pressure (h)

$q_{out} = h_4 - h_1 = 739.71 - 295.17$

$q_{out} = 444.54$ kJ/kg

$W_{net} = q_{in} - q_{out} = 853.12 - 444.54$

$W_{net} = 408.58$ kJ/kg

c) Determine Thermal efficiency

$$\eta_{Th} = \frac{W_{net}}{q_{in}} = \frac{408.58}{853.12}$$

$\eta_{Th} = 47.89\%$

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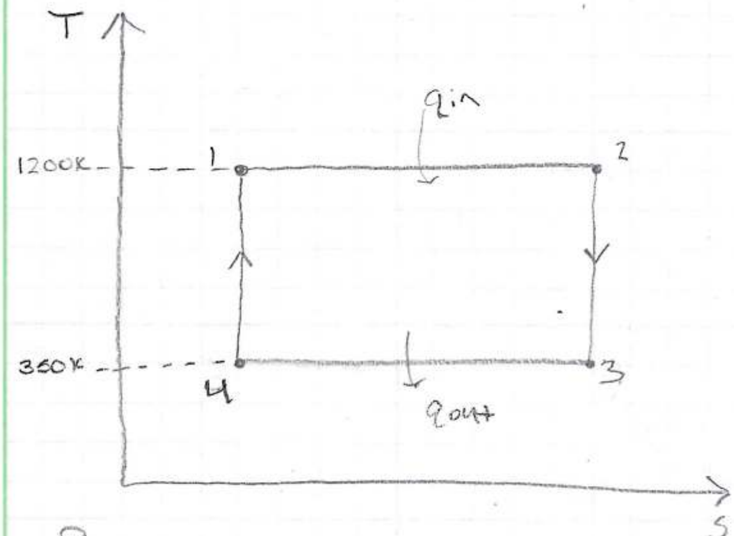
Problem 9-18

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 isothermal compression are 150 and 300 kPa. If the Net-work output per cycle is 0.5 kJ, determine:

a) Maximum pressure in the cycle
b) the heat transfer to air
c) the mass of the air

(Assume Variable Specific heats)

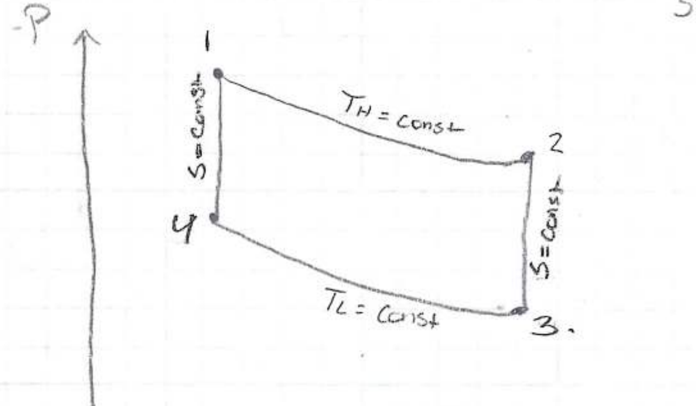


given:

T_1 & T_2 = 1200 K

T_3 & T_4 = 350 K

W_{net} = 0.5 kJ



P_3 = 150 kpa

P_4 = 300 kpa

P_1 & P_2 = ?

a) Maximum pressure (P_1)

$$\frac{P_1}{P_4} = \frac{P_{r1}}{P_{r4}}$$

From A-17 @ 1200 k $p_{r1} = 238$

From A-17 @ 350 k $p_{r4} = 2.379$

$P_4 = 300$ kpa

$$P_1 = P_4 \left(\frac{P_{r1}}{P_{r4}}\right) = 300 \left(\frac{238}{2.379}\right) = \boxed{30 \text{ Mpa}}$$

b) The heat transfer to air (q_{in})

$$\eta_{Th(carnot)} = 1 - \frac{T_L}{T_H} = \frac{W_{net}}{q_{in}}$$

$$\frac{W_{net}}{q_{in}} = 1 - \frac{T_L}{T_H} \qquad \frac{0.5 \text{ kJ}}{q_{in}} = 1 - \left(\frac{350}{1200}\right)$$

$$q_{in} = \frac{0.5}{0.7083} = \boxed{0.7058 \text{ kJ}}$$

c) The mass of air (m)

$$m = \frac{W_{net\ out}}{W_{net}}$$

$$W_{net} = (s_3 - s_4) \cdot (T_H - T_L)$$

From Chap 7 $\quad s_2 - s_1 = c_{p\,avg} \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$ (Same)

$$s_4 - s_3 = \cancel{c_{p\,avg} \ln(1)} - 0.287 \left(\frac{P_4}{P_3}\right)$$

$$s_4 - s_3 = -0.287 \left(\frac{300}{150}\right) =$$

$$s_4 - s_3 = -0.1989$$

$$s_3 - s_4 = 0.1989$$

$$W_{net} = (0.1989 \text{ kJ/kg-K}) \cdot (1200K - 350K)$$

$$= 169.065 \text{ kJ/kg}$$

$$m = \frac{0.5 \text{ kJ}}{169.065 \text{ kJ/kg}} = \boxed{0.00296 \text{ kg}}$$

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Problem 9-22

An Ideal gas is contained in a piston-cylinder device and under goes a power cycle as follows:

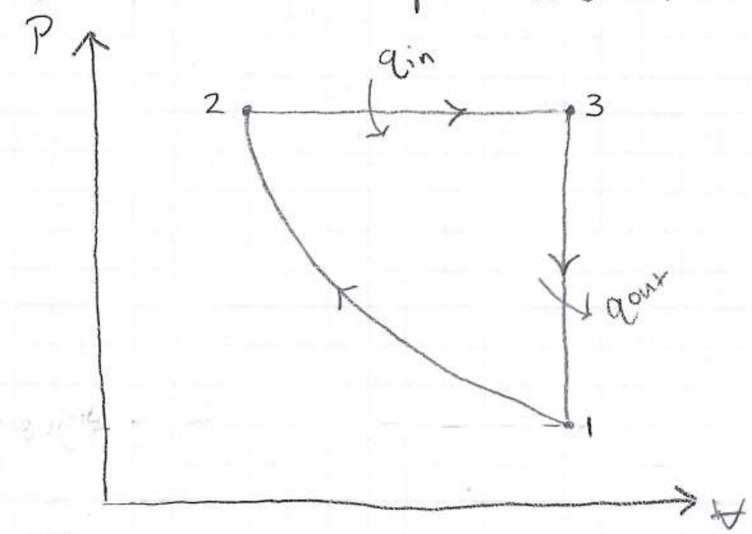
1-2 Isentropic compression from an initial temp $T_1 = 20°c$ with a compression ratio $r=5$

2-3 contant pressure heat addition

3-1 constant volume heat rejection

The gas has constant specific heats with $c_v = 0.7$ kJ/kg·K and $R = 0.3$ KJ/kg·K

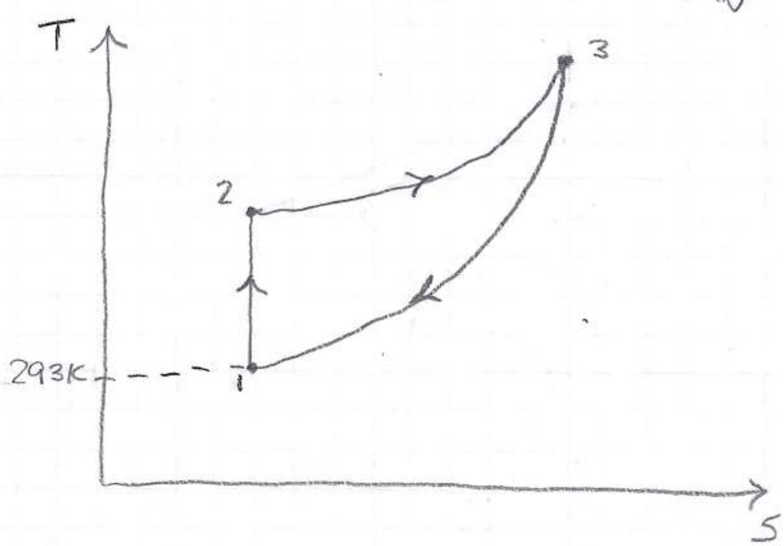
a) sketch the p-v and t-s diagrams for the cycle



given:

$T_1 = 293$ K

$r = 5$



b) Determine the heat and work interactions for each process, in kJ/kg

(const specific heats, $c_v = 0.7 \frac{kJ}{kg \cdot K}$, $R = 0.3 \frac{kJ}{kg \cdot K}$

$$C_p = C_v + R = 0.7 \frac{kJ}{kg \cdot K} + 0.3 \frac{kJ}{kg \cdot K} = 1 \frac{kJ}{kg \cdot K}$$

$$k = \frac{c_p}{c_v} = \frac{1}{0.7} = 1.429$$

Process 1→2) Isentropic compression ($s = const$)

$$\frac{V_1}{V_2} = \frac{V_3}{V_2} = 5$$

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

$$T_2 = 293\,K\,(5)^{1.429-1} = 584.42\,K$$

Isentropic $\boxed{q_{1\to2} = 0}$

$$\Delta U = C_v \Delta T = 0.7 \frac{kJ}{kg \cdot K} (293\,K - 584.42\,K)$$

$$\Delta U = -203.99 \frac{kJ}{kg}$$

$$\Delta U = \cancel{q_{in}} - \cancel{q_{out}} + W_{in} - W_{out}$$

$$\boxed{\Delta W_{1\to2} = -203.99 \frac{kJ}{kg}}$$

Process 2-3) constant pressure, q_{in}

$$\frac{V_3}{V_2} = \frac{T_3}{T_2} \qquad T_3 = T_2 \left(\frac{V_3}{V_2}\right) = 584.42\,K\,(5)$$

$$T_3 = 2922.1\,K$$

$$q_{in} = C_p (T_3 - T_2) = 1\,(2922.1\,K - 584.42\,K)$$

$$q_{in} = \boxed{q_{2\to3} = 2337.68 \frac{kJ}{kg}}$$

$$\Delta U = q_{in} - \cancel{q_{out}} + W_{in} - W_{out}$$

$$\Delta W = q_{in} - \Delta u = q_{in} - c_v (T_3 - T_2)$$

$$2337.68 \frac{kJ}{kg} - 0.7\,(2922.1\,K - 584.42\,K)$$

$$\Delta W_{2\to3} = 2337.68\ kJ/kg - 1636.376\ kJ/kg$$

$$\boxed{\Delta W_{2\to3} = 701.3\ kJ/kg}$$

Process $3\to1$) constant volume, q_{out}

$$q_{out} = C_v(T_1 - T_3) = 0.7(293K - 2922.1K)$$

$$\boxed{q_{3\to1} = -1840.37\ \frac{kJ}{kg}}$$

contant volume $\boxed{\Delta W_{3\to1} = 0}$

c) Determine Thermal effienay

$$\eta_{Th} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{1840.37}{2337.68} = \boxed{21.27\%}$$

d) Obtain the expression for the cycle thermal efficeincy as a function of the compression ratio r of specific heats k

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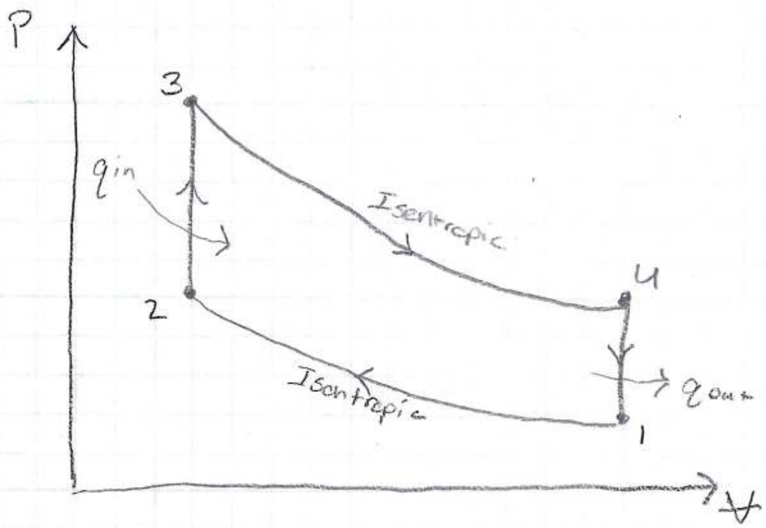
Problem 9-31

An Ideal Otto cycle has a compression ratio of 10.5, takes in air at 90 kPa and 40°C, and is repeated 2500 times per minute. Using constant specific heats at room temperature, determine the thermal efficency of this cycle and the rate of heat input if the cycle is to produce 90 kW of power.



given:

$r = 10.5$

$P_1 = 90$ kPa

$T_1 = 313$ K

rpm = 2500

constant specific heats @ 300K

From lecture part 2 $\eta_{Th} = 1 - \left(\frac{1}{r^{k-1}}\right)$

From A-2 Air @ 300K $\longrightarrow$ $k = 1.4$

$$\eta_{Th} = 1 - \left(\frac{1}{r^{1.4-1}}\right) = 1 - \left(\frac{1}{10.5^{0.4}}\right) = \boxed{60.96\%}$$

$$\eta_{Th} = \frac{\text{Desired output}}{\text{Required input}}$$

$$\text{Required input} = \frac{\text{Desired output}}{\eta_{Th}} = \frac{90\text{ kW}}{60.96\%} = \boxed{147.64\text{ kW}}$$