9-13 An air-standard cycle w/ variable specific heats is executed in a closed system and is composed of the following four processes:

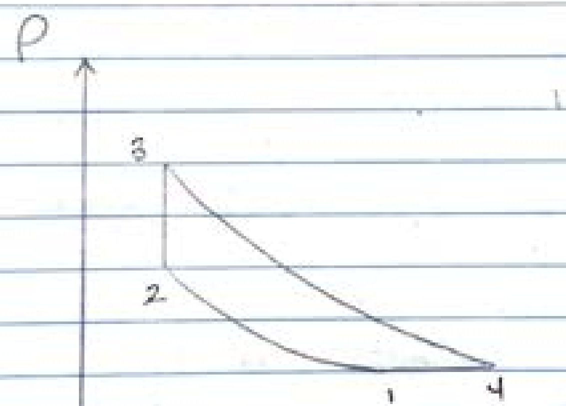
1-2 Isentropic compression from 100 kPa and 22°C to 600 kPa

2-3 V = constant heat addition to 1500K

3-4 Isentropic expansion to 100 kPa

4-1 P = constant heat rejection to initial state

a.

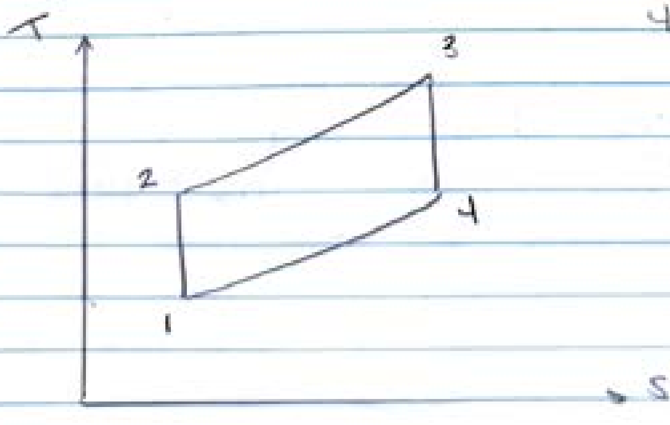


1-2 $P_1 = 100\text{ kPa}$
$T_1 = 22°C = 295.15K$
$P_2 = 600\text{ kPa}$

2-3 $T_3 = 1500K$

3-4 $P_4 = 100\text{ kPa}$

4-1 $V = \text{const.}$



$\xrightarrow{} 1 \xrightarrow{\text{ISENTROPIC}} 2 \xrightarrow{V = \text{CONST.}} 3 \xrightarrow{\text{ISENTROPIC}} 4 \xrightarrow{V = \text{CONST.}}$

$P_1 = 100 kPa$ $P_2 = 600 kPa$ $T_3 = 1500 K$ $P_4 = 100 kPa$

$T_1 = 22°C \to 295 K$

1-2 $$T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \cdot (T_1)$$

$$= \left(\frac{600}{100}\right)^{\frac{0.4}{1.4}} (295)$$

$$T_2 = 492.21 K$$

2-3 $V = c$

$\underline{W_{2-3} = 0}$

$$\Delta Q = \Delta U + \Delta W$$

$$Q_{2-3} = U_{2-3} = C_v \Delta T = C_v (T_3 - T_2)$$

$$= 0.718 (1500 - 492.21)$$

$$Q_{2-3} = 723.59 \ kJ/kg$$

$\underline{V = c}$

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

$$= \frac{600}{492.21}(1500)$$

$$P_3 = 1828.49 kPa$$

3-4 $$T_4 = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} (T_3)$$

$$= \left(\frac{100}{1828.49}\right)^{\left(\frac{0.4}{1.4}\right)} (1500)$$

$$T_4 = 653.87 K$$

$Q_{out} = C_p \Delta T = C_p (T_4 - T_1)$

$= 1.005 (653.87 - 295)$

$= 360.66 \ kJ/kg$

$W_{3-4} = \dfrac{mR (T_3 - T_4)}{\gamma - 1}$

$= \dfrac{0.287 (1500 - 653.87)}{0.4}$

$W_{3-4} = 607.09 \ kJ/kg$

$W_{1-2} = \dfrac{mR (492.21 - 295)}{0.4}$

$W_{1-2} = 141.491 \ kJ/kg$

$W_{NET} = W_{3-4} - W_{1-2}$

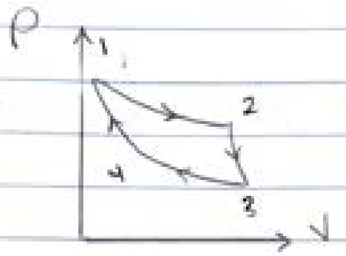
$= 607.09 - 141.49$

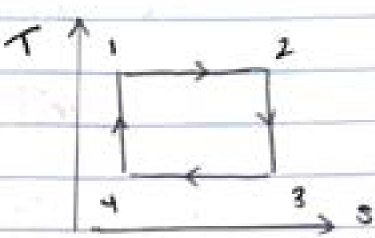
$W_{NET} = 465.60 \ kJ/kg$

$\eta = \dfrac{W_{NET}}{Q_{IN}} = \dfrac{465.6}{723.89} (100)$

$\eta = 64.34\%$

9-18 An air-standard Carnot cycle is executed in a closed system between the temp. 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 0.5





$\xrightarrow{}$ ① $\xrightarrow{T_H = \text{CONST.}}$ ② $\xrightarrow{\text{ISENTROPIC}}$ ③ $\xrightarrow{T_L = \text{CONST.}}$ ④ $\xrightarrow{\text{ISENTROPIC}}$

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

$W_{NET} = 0.5\,kJ$

a) maximum pressure in the cycle

$$P_1 = P_1\left(\frac{P_{r,1}}{P_{r,1}}\right)$$

$$= 300\left(\frac{238}{2.379}\right)$$

$$P_1 = 30.01\,mPa$$

$$P_{MAX} = P_1 = 30.01\,mPa$$

b) The heat transfer to air

$$\eta_c = 1 - \frac{T_L}{T_H}$$

$$= 1 - \left(\frac{350}{1200}\right)$$

$$\eta_c = 0.7083$$

$$\eta_c = \frac{W_{out}}{Q_s} \rightarrow 0.7083 = \frac{0.5}{Q_s}$$

$$Q_{out} = 0.706 \text{ kJ}$$

c) $$ds = \frac{dQ}{T} \rightarrow dQ = T\,ds$$

isothermal : $dQ = dW$

$$dW = (T_H - T_L)(s_4 - s_3)$$

$$(s_4 - s_3) = -(s_3 - s_4)$$

$$= -\left[-R \ln\left(\frac{P_4}{P_3}\right)\right]$$

$$= R \ln\left(\frac{P_4}{P_3}\right)$$

$$= 0.2870 \ln\left(\frac{300}{150}\right)$$

$$= 0.1989 \text{ kJ/kg}\cdot\text{K}$$

$$dW = (T_H - T_L)(s_4 - s_3)$$
$$= (1200 - 350)(0.1989)$$
$$dW = 169.065 \text{ kJ/kg}$$

mass of air:

$$m = \frac{W_{out}}{dw} = \frac{0.5}{169.065}$$

$$m = 0.002957 \text{ kg}$$
$$= 0.00296 \text{ kg}$$

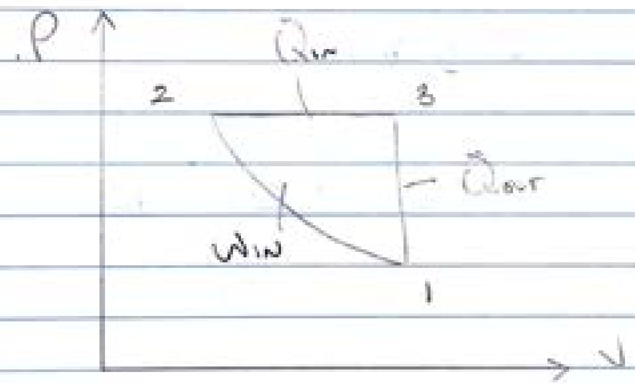
9-22 An ideal gas is contained in a piston-cylinder device and undergoes a power cycle as follows:

1-2 Isentropic compression from an initial temp. $T_1 = 20°C$ w/ a compression ratio $r = 5$

2-3 Constant pressure heat addition

3-1 Constant volume heat rejection.

The gas has constant specific heats w/ $C_v = 0.7\ kJ/kg \cdot K$ and $R = 0.3\ kJ/kg \cdot K$



$T_1 = 20°C \rightarrow 293K$

$r = 5$

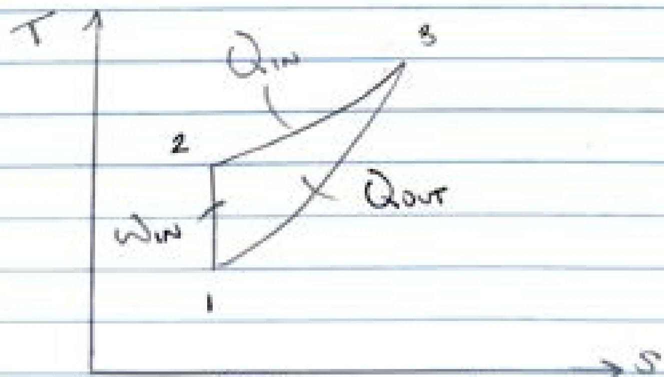
$C_v = 0.7\ kJ/kg \cdot K$

$R = 0.3\ kJ/kg \cdot K$

$C_p = 1\ kJ/kg \cdot K$

$k = \frac{C_p}{C_v} = \frac{1}{0.7}$

$= 1.428$



1 $\xrightarrow{\text{ISENTROPIC}}$ 2 $\xrightarrow{P = \text{CONST.}}$ 3 $\xrightarrow{V = \text{CONST}}$ 1

$T_1 = 20°C \rightarrow 293K$

1-2 $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} = r^{k-1}$

$T_2 = T_1 (r^{k-1})$

$= 293(5^{1.42857-1})$

$T_2 = 584.02\ K$

$q_{1-2} = 0\ kJ/kg$

$w_{1-2} = \frac{R(T_1 - T_2)}{k-1}$

$= \frac{0.3(293 - 583.48)}{1.42857-1}$

$w_{1-2} = -203.72\ kJ/kg$

2-3 $\frac{V_2}{T_2} = \frac{V_3}{T_3}$

$T_3 = T_2\left(\frac{V_3}{V_2}\right) = T_2\left(\frac{V_1}{V_2}\right) = T_2 \cdot r$

$= 584.02(5)$

$T_3 = 2920.1\ K$

$q_{2-3} = c_p(T_3 - T_2)$

$= 1(2920.1 - 584.02)$

$q_{2-3} = 2336.08$

$$\Delta U_{2-3} = U_3 - U_2 = C_v(T_3 - T_2)$$

$$= 0.7(2920.1 - 584.02)$$

$$= 1635.26 \ kJ/kg$$

$$W_{2-3} = q_{2-3} - \Delta U_{2-3}$$

$$= 2336.08 - 1635.26$$

$$W_{2-3} = 700.82 \ kJ/kg$$

3-1 $\quad q_{3-1} = C_v(T_1 - T_3)$

$$= 0.7(293 - 2920.1)$$

$$q_{3-1} = -1838.97 \ kJ/kg$$

$$W_{3-1} = 0 \ kJ/kg$$

Cycle Efficiency

$$\eta_{TH} = 1 - \frac{q_{OUT}}{q_{IN}}$$

$$= 1 - \frac{1838.97}{2336.08} (100)$$

$$= .2128 \rightarrow 21.28\%$$

Thermal Efficiency

$$\eta_{TH} = 1 - \frac{q_{OUT}}{q_{IN}}$$

$$= 1 - \frac{C_v(T_3 - T_1)}{C_p(T_3 - T_2)}$$

$$= 1 - \frac{1}{k}\left[\frac{T_3\left(1 - \frac{T_1}{T_3}\right)}{T_2\left(1 - \frac{T_2}{T_3}\right)}\right]$$

$$= 1 - \frac{1}{k}\left[\frac{1 - \frac{T_1}{T_2}\frac{T_2}{T_3}}{1 - \frac{T_2}{T_3}}\right]$$

$$= 1 - \frac{1}{k}\left[\frac{1 - \frac{1}{r^{k-1}}\frac{1}{r}}{1 - \frac{1}{r}}\right]$$

$$= 1 - \frac{1}{k}\left[\frac{1 - \frac{1}{r^k}}{1 - \frac{1}{r}}\right]$$

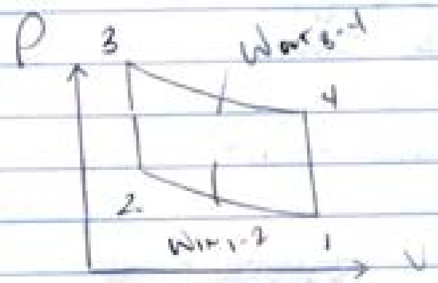
$$\eta_{TH} = 1 - \frac{1}{k} \cdot \frac{1}{r^{k-1}} \cdot \frac{r^k - 1}{r - 1}$$

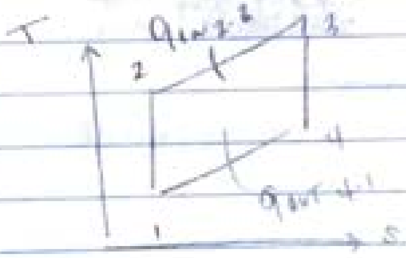
$1 \xrightarrow{\text{ISENTROPIC}} 2 \xrightarrow{V = \text{CONST}} 3 \xrightarrow{\text{ISENTROPIC}} 4 \xrightarrow{V = \text{CONST}}$

$P_1 = 90\,kPa$

$T_1 = 40°C \rightarrow 313K$

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 efficiency of this cycle and the rate of heat input if the cycle is to produce 90kW of power.





$r = 10.5$

$P_1 = 90\,kPa$

$T_1 = 40°C \rightarrow 313K$

$W_{NET} = 90\,kPa$

Constant Specific Heat at room temp.

$C_v = 0.718$

$C_p = 1.005$

$k = \frac{C_p}{C_v} = 1.4$

Thermal Efficiency (η_{TH})

$$\eta_{TH} = 1 - \frac{1}{r^{k-1}}$$

$$= 1 - \frac{1}{10.5^{1.4-1}}$$

$$= 0.621 = 62.1\%$$

Rate of Heat Input (Q_{in})

$$W_{NET} = \eta_{TH} \cdot Q_{in}$$

$$Q_{in} = \frac{W_{NET}}{\eta_{TH}} = \frac{90}{0.621} = 144.9\,kW$$