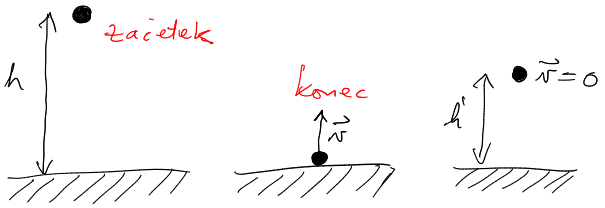
9.17 $h = 20\,m$

$v = 3\,m/s$

$c = 130\,J/kgK$

$\Delta T = ?$



energijski zakon: $\Delta W = A' + Q$ (toplota)

$\Delta W_k + \Delta W_p + \Delta W_{pr} + \Delta W_n + \dots$ (notranja energija)

Hitrost, s katero se krogla zaleti v tla:

pokaže: $\Delta W_p + \Delta W_k = 0$

$-mgh + \frac{1}{2} m v_0^2 = 0 \rightarrow v_0 = \sqrt{2gh} \sim 20\,m/s$

$\Delta W_k + \Delta W_p + \Delta W_n = 0$

$\frac{1}{2} m v^2 - mgh + \Delta W_n = 0$

$mc\Delta T = \Delta W_n = mgh - \frac{1}{2} m v^2$

$\Delta T = \frac{gh - \frac{1}{2} v^2}{c} = \frac{9{,}81\,\frac{m}{s^2} \cdot 20\,m - \frac{1}{2}(3\,m/s)^2}{130\,J/kgK}$

$= 1{,}5\,K = 1{,}5\,°C$

$\frac{m^2/s^2}{J/kgK} = \frac{m^2 s^2 kgK}{s^2 \cdot kg\, m^2} = K$

9.26

$m = 1\ kg$
$V_1 = 1\ m^3$
$p_1 = 10^5\ Pa$
$V_2 = 2\ m^3$
$p_2 = 1{,}5\ bar$
$A_{opr} = 0{,}1\ MJ$

$Q_{pr} = ?$

$\Delta W_n = A + Q$ (A … prejeto delo, Q … prejeta toplota)

$Q_{pr} = -Q = \Delta W_n - A = \Delta W_n + A_{opr}$

$A = -A_{opr}$

idealen plin: $\Delta W_n = m c_v \Delta T$

$Q_{pr} = m c_v (T_2 - T_1) + A_{opr}$

$dW_n = dA + dQ = -p dV + dQ$

V konst. $\rightarrow dV = 0$ $\quad dW_n = dQ = m c_v dT$

p konst. $\rightarrow$ $\quad m c_v dT = dW_n = -p dV + dQ = -p dV + m c_p dT$

$pV = \frac{m}{M} RT$

p konst.: $p dV = \frac{m}{M} R\, dT$

za idealen plin

$m c_v dT = -\frac{m}{M} R\, dT + m c_p dT \rightarrow c_v = -\frac{R}{M} + c_p$

$\frac{c_p}{c_v} = \kappa$

za dvoatomne molekule (npr. O_2, N_2): $\kappa = \frac{7}{5} = 1{,}4$

$c_v = -\frac{R}{M} + \kappa c_v$

$c_v (\kappa - 1) = \frac{R}{M}$

$c_v = \frac{R}{M(\kappa - 1)}$

$Q_{pr} = m c_v (T_2 - T_1) + A_{opr}$

$Q_{pr} = m \frac{R(T_2 - T_1)}{M(\kappa - 1)} + A_{opr}$

$Q_{pr} = \frac{1}{\kappa - 1} (p_2 V_2 - p_1 V_1) + A_{opr}$

$Q_{pr} = \frac{1}{0{,}4} (1{,}5 \cdot 10^5\ Pa \cdot 2\ m^3 - 10^5\ Pa \cdot 1\ m^3) + 0{,}1\ MJ =$

$= \frac{1}{0{,}4} \cdot 2 \cdot 10^5\ J + 0{,}1\ MJ = 5 \cdot 10^5\ J + 0{,}1\ MJ = \underline{\underline{0{,}6\ MJ}}$

$Pa\,m^3 = \frac{N}{m^2} \cdot m^3 = N m = J$

9.29

$m = 1\,kg$

$T_1 = 20°C$

$p_1 = 10^5\,Pa$ ← hitro razpremo (adiabatna)

$p_2 = 8 \times 10^4\,Pa$ ← stisnemo pri konstantni temperaturi (izotermno)

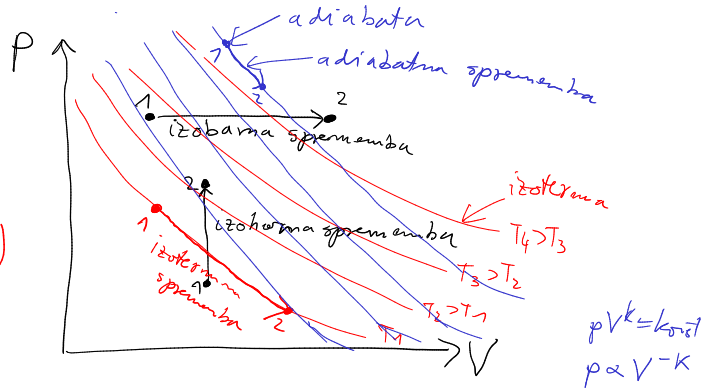
$p_3 = p_1 = 10^5\,Pa$

$T_2 = T_3$

$\Delta W_m = ?$

$A_{pr} = ?$

$Q_{odd} = ?$



$T = konst.$ izotermna sprememba

za idealni plin:

$pV = \frac{m}{M} RT \rightarrow \frac{pV}{T} = \left(\frac{m}{M} R\right) = konst.$

$T = konst. \rightarrow pV = konst.$

$dQ = 0$ adiabatna sprememba

za idealni plin:

$dW_m = m c_V dT = -p dV$

$c_V = \frac{R}{M(k-1)}$

$\frac{m R}{M(k-1)} dT = -p dV$

$pV = \frac{m}{M} RT \rightarrow dpV + pdV = \frac{m}{M} R dT$

$\frac{dpV + pdV}{k-1} = -pdV \quad / \cdot (k-1)$

$dpV + pdV = (1-k)\,pdV$

$dpV = -k\,pdV$

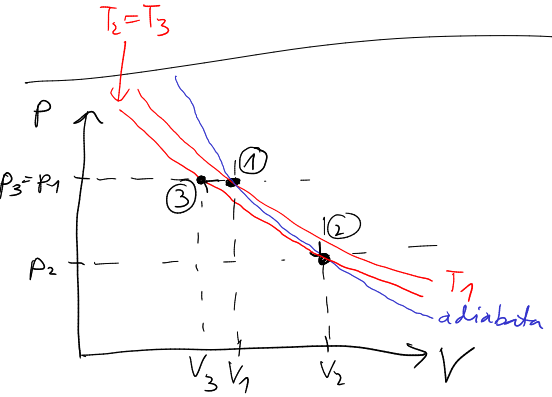
$\frac{dp}{p} = -k \frac{dV}{V} \quad / \int$

$\int_{p_1}^{p_2} \frac{dp}{p} = \ln \frac{p_2}{p_1} = -k \int_{V_1}^{V_2} \frac{dV}{V} = -k \ln \frac{V_2}{V_1} \quad / e^{\square}$

$\frac{p_2}{p_1} = \left(\frac{V_2}{V_1}\right)^{-k}$

$p_1 V_1^k = p_2 V_2^k$

$pV^k = konst.$



$\Delta W_m = \Delta W_m^{1\to2} + \Delta W_m^{2\to3} =$

$= m c_v (T_2 - T_1) + 0 =$

$= m \frac{R(T_2 - T_1)}{M(k-1)}$

adiabatna:

$p_1 V_1^k = p_2 V_2^k$

$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \quad / \square^k$

$\frac{p_1^k V_1^k}{T_1^k} = \frac{p_2^k V_2^k}{T_2^k}$

$p_1^{1-k} T_1^k = p_2^{1-k} T_2^k$

$T_2 = T_1 \left(\frac{p_1}{p_2}\right)^{\frac{1-k}{k}}$

$\Delta W_m = m \frac{R T_1}{M(k-1)} \left(\left(\frac{p_1}{p_2}\right)^{\frac{1-k}{k}} - 1\right) =$

$= \frac{1\,kg \cdot 8300\,J \cdot 293\,K}{kmol\,K \cdot 0{,}4 \cdot 29\,kg/kmol} \left(\left(\frac{10^5\,Pa}{8 \times 10^4\,Pa}\right)^{\frac{1-1{,}4}{1{,}4}} - 1\right) =$

$= -13\,kJ$

zrak: O_2 20% $M_{O_2} = 32\,kg/kmol$

N_2 80% $M_{N_2} = 28\,kg/kmol$

$\rightarrow M = 20\% M_{O_2} + 80\% M_{N_2} \doteq 29\,kg/kmol$

$Q_{pr} = Q_{pr}^{1\to2} + Q_{pr}^{2\to3} = 0 + Q_{pr}^{2\to3}$

$0 = \Delta W_m^{2\to3} = A^{2\to3} + Q^{2\to3} \rightarrow Q^{2\to3} = -A^{2\to3}$

$dQ = -dA = pdV$

$Q_{pr} = Q_{pr}^{2\to3} = -A_{pr}^{2\to3} = \int_{V_2}^{V_3} pdV = \frac{m}{M} RT_2$

$= p_2 V_2 \int_{V_2}^{V_3} \frac{dV}{V} = p_2 V_2 \ln \frac{V_3}{V_2} = p_2 V_2 \ln \frac{p_2}{p_3} =$

$\frac{V_3}{V_2} = \frac{p_2}{p_3}$

izotermna $\rightarrow pV = p_2 V_2 = p_3 V_3$

$p = \frac{p_2 V_2}{V}$

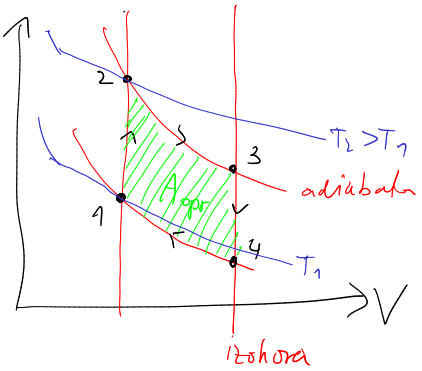
$= \frac{m}{M} R T_2 \ln \frac{p_2}{p_3} = \frac{m}{M} R T_1 \left(\frac{p_1}{p_2}\right)^{\frac{1-\kappa}{\kappa}} \ln \frac{p_2}{p_3}$

$Q_{pr} = \frac{1\,\text{kg} \cdot 8300\,\text{J} \cdot 293\,\text{K}\ \text{kmol}}{\text{kmol K} \cdot 29\,\text{kg}} \left(\frac{1}{0.8}\right)^{\frac{1-1,4}{1,4}} \ln \frac{0.8}{1} = \underline{\underline{-18\ \text{kJ}}}$

$\Delta W_m = Q_{pr} + A_{pr}$

$A_{pr} = \Delta W_m - Q_{pr} = -13\,\text{kJ} - (-18\,\text{kJ}) = \underline{\underline{5\,\text{kJ}}}$

3.40



$\kappa = \frac{7}{5} = 1{,}4$ | $\frac{V_3}{V_2} = 4{,}1 = \lambda$ | $V_1 = V_2$, $V_3 = V_4$

$\eta = ?$ iz koristek

$A_{opr} > 0$

$A_{opr} = -A_{pr} = \int p\,dV$

$A_{opr}^{1\to2} = 0 \quad dV = 0$

$A_{opr}^{2\to3} = \int_{V_2}^{V_3} p\,dV > 0$

$A_{opr}^{3\to4} = 0 \quad dV = 0$

$A_{opr}^{4\to1} = \int_{V_4}^{V_1} p\,dV < 0 \qquad \left|A_{opr}^{4\to1}\right| = \int_{V_1}^{V_4} p\,dV < A_{opr}^{2\to3}$

$A_{opr} = A_{opr}^{2\to3} + A_{opr}^{4\to1} > 0$

$\Delta W_{1\ldots} = A + Q = -A_{opr} + Q_{dov} + Q_{odv}$

$\eta = \frac{A_{opr}}{Q_{dov}}$

$Q^{1\to2} = \Delta W_m^{1\to2} = m c_v (T_2 - T_1) > 0$ dovedena toplota

$Q^{2\to3} = 0$ (adiabata)

$Q^{3\to4} = \Delta W^{3\to4} = m c_v (T_4 - T_1) < 0$ odvedena toplota

$Q^{4\to1} = 0$ (adiabata)

$A_{opr}^{2\to3} = \int_{V_2}^{V_3} p\,dV = -mc_v(T_3 - T_2)$

$\Delta W_m^{2\to3} = A^{2\to3} = -A_{opr}^{2\to3}$ ($Q = 0$, ker je sprememba adiabatna)

$A_{opr}^{4\to1} = -mc_v(T_1 - T_4)$

$\eta = \frac{A_{opr}^{2\to3} + A_{opr}^{4\to1}}{Q^{1\to2}} = \frac{-mc_v(T_3 - T_2) - mc_v(T_1 - T_4)}{mc_v(T_2 - T_1)} = \frac{T_2 - T_1 + T_4 - T_3}{T_2 - T_1} =$

$= 1 - \frac{T_3 - T_4}{T_2 - T_1}$

$2 \to 3$ adiabata

$p_2 V_2^{\kappa} = p_3 V_3^{\kappa}$

$\frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3}$:

$V_2^{\kappa-1} T_2 = V_3^{\kappa-1} T_3$

$T_3 = T_2 \left(\frac{V_2}{V_3}\right)^{\kappa-1}$

$T_3 = T_2 \left(\frac{1}{\lambda}\right)^{\kappa-1}$

$T_2 = T_3 \lambda^{\kappa-1}$

$4 \to 1$ adiabata

$T_1 = T_4 \left(\frac{V_4}{V_1}\right)^{\kappa-1}$

$T_1 = T_4 \lambda^{\kappa-1}$

$\eta = 1 - \frac{T_3 - T_4}{T_3 \lambda^{\kappa-1} - T_4 \lambda^{\kappa-1}} =$

$= 1 - \frac{T_3 - T_4}{\lambda^{\kappa-1}(T_3 - T_4)} =$

$= 1 - \lambda^{1-\kappa} = 1 - (4{,}1)^{-0{,}4} =$

$= 0{,}43 = 43\,\%$