TERMODINAMIKA

Glava 1

1-2-1

$P_{atm} = 720$ mmHg $\Rightarrow$ atm, lb/in^2

1 kPa $= 10^{-2}$ bar $= 0,14504$ lb/in^2 $= 7,501$ mmHg

1 atm $= 101,325$ kPa

1000 Pa $= 7,501$ mmHg

1 Pa $= \frac{7,501}{1000}$ mmHg

1 Pa $= 0,007501$ mmHg

$\frac{1}{0,007501}$ Pa $= 1$ mmHg

133,3 Pa $= 1$ mmHg

720 mmHg $= 720 \cdot 133,3$ Pa $= 95987,2$ Pa $= 96$ kPa

1 atm $= 101,325$ kPa

$\frac{1}{101,325}$ atm $= 1$ kPa

$10^{-2} = 0,01$

96 kPa $= 0,96$ bar

0,009869 atm $= 1$ kPa

96 kPa $= 0,009869 \cdot 96$ atm $= 0,94$ atm

0,01 bar $= 0,14504$ lb/in^2

1 bar $= \frac{0,14504}{0,01}$ lb/in^2

1 bar $= 14,504$ lb/in^2

0,96 bar $= 14,504 \cdot 0,96$ lb/in^2 $= 13,92$ lb/in^2

1-2-2

$p_v = 28,22$ in Hg

$p_b = 29,32$ in Hg

$p_{aps,k} = ?$

$p_{aps,kond} = p_b - p_v = 29,32 - 28,22 = 1,1$ in Hg

29,92 in Hg = 101,325 kPa

1 in Hg = $\frac{101,325}{29,92}$ kPa

1 in Hg = 3,3865 kPa

1,1 in Hg = 1,1 · 3,3865 kP = 3,72515 kPa = 3725,15 Pa

1 kPa = 0,14504 lb/in²

3,72515 kPa = 0,14504 · 3,72515 lb/in² = 0,54029 lb/in²

1-2-3

$R_0 = 8\,314$ J/kmol·K

) $R_0 = 8,314$ kJ/kmol K

1 kJ = 0,9478 Btu

1 kJ/kg = 0,4299 Btu/lbm

) $R_0 = 8\,314$ Nm/kmol·K

1 Btu/lbm·mol·°R ?

1 J = 1 Nm

1 kJ/kgK = 9238,8 Btu/lbm·°R

1,8 T[K] = T[°R]

1-2-4

$P = 2{,}5\ kW$

Btu/h, Btu/s, hp, ks, $ft \cdot lb_f/s^2$

$1\ kW = 1{,}3410\ hp = 344\ Btu/h = 737{,}56\ ft\,lb_f/s$

$1\ lb_f = 32{,}174\ lb_m \cdot ft/s^2$

$2{,}5\ kW = 2{,}5 \cdot 1{,}3410\ hp = 3{,}3525\ hp$

$2{,}5\ kW = 2{,}5 \cdot 344\ Btu/h = 8535\ Btu/h$

$2{,}5\ kW = \frac{8535}{3600}\ Btu/s = 2{,}37\ Btu/s$

$2{,}37\ Btu/s = 2{,}37 \cdot \frac{737{,}56}{3600}\ ft\,lb_f/s = 0{,}48556\ ft\,lb_f/s^2$

ks ??

1-2-5

$t = 150°C$

$T[K] = 150 + 273{,}15 = 423{,}15\ K$

$T[°Re] = 1{,}8 \cdot T[K] - 1{,}8 \cdot 423{,}15 = 761{,}67\ °Re$? R_a ?

$t[°C] = \frac{5}{9}\{t[°F] - 32\}$

$\frac{9}{5}t[°C] + 32 = t[°F]$

$\frac{9}{5} \cdot 150 + 32 = t[°F]$

$t[°F] = 302\ °F$

1-2-6

$t_0 = 0°C$

$t[K] = 273,15\ K$

$t_s = -\frac{273,15}{2} = -136,575\ K$

$t[°K] = t[°C] \cdot \frac{9}{5} + 32$

$t[°F] = 32$

$t_s = 32/2 = 16°F$

$t_s[°C] = \frac{5}{9} \cdot 16 - 32 = -23,11°C$??

$t_s[°C] = T[K] - 273,15 = -136,575°C$??

1-27

$\dot{m} = 1,7$ liter/s

$m^3/h,\ m^3/s,\ ft^3/h,\ ft^3/min,\ gal/min$

1 liter = 0,001 m^3

1 ft^3 = 0,02832 m^3

1 ft^3 = 28,32 l

1 gal = 3,7854 l

1,7 l = 1,7 · 0,001 = 0,0017 m^3

$\dot{m} = 0,0017\ m^3/s$ $\quad \dot{m} = 0,0017 \cdot 3600\ m^3/h$

$\dot{m} = 6,12\ m^3/h$

$1\,m^3 = \frac{1}{0{,}02832}\,ft^3 = 35{,}31\,ft^3$

$\dot{m} = 6{,}12 \cdot 35{,}31\ ft^3/h = 216{,}097\ ft^3/h$

$\dot{m} = \frac{216{,}097}{60}\ ft^3/min = 3{,}6\ ft^3/min$

$1\,L = \frac{1}{28{,}32}\,ft^3 = 0{,}0353\,ft^3$

$1\,L = \frac{1}{3{,}7854}\,gal = 0{,}2642\,gal$

$0{,}0353\,ft^3 = 0{,}2642\,gal$

$1\,ft^3 = \frac{0{,}2642}{0{,}0353}\,gal$

$1\,ft^3 = 7{,}483\,gal$

$\dot{m} = 3{,}6 \cdot 7{,}483\ gal/min$

$\dot{m} = 26{,}94\ gal/min$

1-2-8

$p_m = 1{,}5\ MPa = 1\,500\,000\ Pa = 1\,500\ kPa$

atm, bar, mmHg, mmH_2O, lb_f/in^2

$p_m = 1500\ kPa = 0{,}14504 \cdot 1500\ lb_f/in^2 = 217{,}56\ lb_f/in^2$

$1\ lb_f/in^2 = \frac{4{,}015}{0{,}14504}\ inH_2O = 27{,}682\ inH_2O = 27{,}682 \cdot 25{,}445\ mmH_2O = 704{,}37\ mmH_2O$

$1\ m = 1000\ mm$ $\qquad 1\ in = \frac{1}{0{,}0393}\ mm$

$1\ m = 39{,}370\ in$ $\qquad 1\ in = 25{,}445\ mm$

$1\ mm = \frac{39{,}370}{1000}\ in = 0{,}0393\ in$

$p_m = 217,56 \cdot 704,37 \text{ mm } H_2O = 153244,171 \text{ mm } H_2O$

$p_m = 15 \text{ bar}$

$1 \text{ atm} = 101,325 \text{ kPa}$

$\frac{1}{101,325} \text{ atm} = 1 \text{ kPa}$

$0,0098692 \text{ atm} = 1 \text{ kPa}$

$p_m = 1500 \text{ kPa} = 1500 \cdot 0,0098692 = 14,8 \text{ atm}$

$1 \text{ atm} = 29,92 \text{ in Hg}$

$14,8 \text{ atm} = 14,8 \cdot 29,92 \text{ in Hg} = 442,93 \text{ in Hg} = 442,93 \cdot 25,445 =$

$= 11270,38 \text{ mm Hg}$?

$10^{-2} \text{ bar} = 7,501 \text{ mm Hg}$

$0,01 \text{ bar} = 7,501 \text{ mm Hg}$

$1 \text{ bar} = \frac{7,501}{0,01} \text{ mm Hg} = 750,1 \text{ mm Hg}$

$p_m = 15 \text{ bar} = 15 \cdot 750,1 = 11251,5 \text{ mm Hg}$

1-2-9

$m_z = 76\ kg$ $\quad m_M = ?$

$G_z = 740\ N$ $\quad G_M = ?$

masa je ista

$G = 76 \cdot 1,67 = 125,25\ N$

1-2-10

$V = 5\ m^3$

$t = 25°C$

$p = 1\ bar$

$m = 4,985\ kg$

$g = 9,75\ m/s^2$

$\rho = ?\ kg/m^3,\ lb_f/ft^3$

$$\rho = \frac{4,985}{5} = 0,997\ kg/m^3$$

$m = 4,985\ kg$

$1000\ kg/m^3 = 62,428\ lb_m/ft^3$

$1\ kg/m^3 = \frac{62,428}{1000}\ lb_m/ft^3 = 0,062428\ lb_m/ft^3$

$m = 4,985 \cdot 0,062428\ lb_m/ft^3 = 0,3112\ lb_m/ft^3$

1-2-11

$V = 3\ ft^3$

$t = 60°F$

$p = 14{,}7\ psi$

$m = 187\ lbm$

$g = 32{,}8\ ft/s^2$

2-2-1 2 Prvi Zakon termodinamike

U mjehu se nalazi 3,5 kg vode početne temp. 19°C na pritisku 1 bar. Pomoću mješalice s rotorom unosi se energija 195 kJ rada. Sistem i okolina razmjenjuju toplotu. Potrebno je odrediti prijenos topline u procesu kada se postigne ravnotežno stanje temp. 29°C na istom pr.

$m = 3,5\ kg$

$t_1 = 19°C$

$p_1 = 1\ bar$

$L = 195\ kJ$

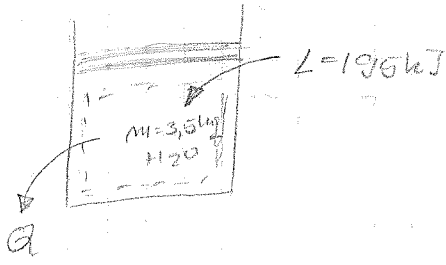
$t_2 = 29°C$

$p_2 = 1\ bar$

$\Delta U = Q - L$

$L = pV$

$\rho = 1000\ kg/m^3$



p=const.

$\Delta t = t_2 - t_1 = 29 - 19 = 10°C = 10 + 273,15 = 283,15\ K$

$\Delta U = m c_p \Delta t = c \cdot 3,5 \cdot 283,15 = 991,025\ c_v\ kgK$

$991,025 c_p = Q + 195\,000\ J$

$991,025 \cdot 2,318 = Q + 195$

($c_p = 4,614 - 103 \cdot T^{-0,5} + 967 \cdot T^{-1}\ kJ/kgK$ (P-2-2)

$c_p = 4,614 - \frac{103}{31,480} + \frac{967}{991,025} = 4,614 - 3,272 + 0,976 = 2,318\ kJ/kgK$)

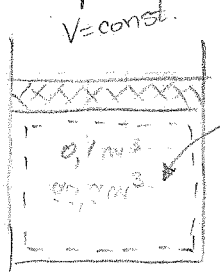
$2297,196 = Q + 195$

$2297,196 - 195 = Q$

$\boxed{Q = 2102,196\ kJ}$

2-2-2 ✱

U zatvorenoj posudi nalazi se mješavina 0,1 m³ vrele vode i 99,9 m³ zasićenog vodenog pora na tlaku 200 kPa. Zagrijavanjem, odnosno dovođenjem topline u posudu, stanje sustava se mijenja i tlak se u posudi povećava za 300 kPa. Potrebno je odrediti količinu dovedene topline u posudu i temperaturu na kraju tog procesa.



P-3-2

$p_1 = 200\,000$ $P_a = 2$ bar $V = 100\ m^3$ vlažan par

$p_2 = 300\,000$ $P_a = 3$ bar

$v_{t_1} = 1{,}0605\ dm^3/kg$ $u_{t_1} = 504{,}8\ kJ/kg$

$v_{p_1} = 0{,}8854\ m^3/kg$ $u_{p_1} = 2707\ kJ/kg$

$v_{t_2} = 1{,}0733\ dm^3/kg$ $u_{t_2} = 561{,}4\ kJ/kg$

$v_{p_2} = 0{,}6057\ m^3/kg$ $u_{p_2} = 2725\ kJ/kg$

$v_x = (1-x)\,v_t + x\,v_p$ $PV = mRT$

2-2-3

Izračunati kinet. energiju lopte mase 2,5 kg koja se kreće brzinom 20 km/h.

$$E_k = \frac{mv^2}{2} = \frac{2,5 \cdot 5,55^2}{2} = 38,50 \text{ J}$$

$$v = 20 \text{ km/h} = 20 \cdot \frac{1000}{3600} = 5,55 \text{ m/s}$$

2-2-4

Izračunati kin. energiju teniske lopte mase 150 gr koja se kreće brzinom 100 km/h

$$E_k = \frac{m \cdot v^2}{2} = \frac{0,15 \cdot 27,77^2}{2} = 57,838 \text{ J}$$

$$v = 100 \cdot 0,277 = 27,77 \text{ m/s}$$

$$m = 150 : 1000 = 0,15 \text{ kg}$$

2-2-5

Predmet mase 14,5 kg slobodno pada s visine 120 m i ima početnu brzinu 25 m/s. Ako je ubrzanje $9,8 \text{ m/s}^2$, odredi brzinu predmeta neposredno pred udarom o zemlju. Otpor zraka pri padu zanemariti.

$m = 14,5$ kg

$h = 120$ m

$v_0 = 25$ m/s

$g = 9,8 \text{ m/s}^2$

$E_p = mgh = 14,5 \cdot 9,8 \cdot 120 = 17052$ J

$v^2 = v_0^2 + 2gh$

$v^2 = 625 + 2 \cdot 9,8 \cdot 120$

$v^2 = 2977$

$v = \sqrt{2977} = 54,56$ m/s

$E_k = \frac{mv^2}{2}$

$17052 = \frac{mv^2}{2}$

$\frac{34104}{14,5} = v^2$

$v = 48,497$ m/s

$E_k = 0, E_p = \max$

$E_k = \max, E_p = 0$

$E = E_p + E_k$

2-2-6

Avion mase 80 t kreće se brzinom 900 km/h na maloj nadmorskoj visini 10 000 m. Ako se pretpostavi kvar na avionu, zbog čega on počne vertikalno padati odrediti brzinu aviona neposredno prije sudara sa Zemljom. Pretpostaviti $g = 9{,}5\ m/s^2$, $w_0 = 0{,}1 \cdot w$, zanemariti otpor zraka.

$m = 80\ t = 80000\ kg$

$w = 900\ km/h = 900 \cdot 0{,}277 = 249{,}3\ m/s$

$h = 10000\ m$

$g = 9{,}5\ m/s^2$

$w_0 = 0{,}1 \cdot w = 0{,}1 \cdot 249{,}3 = 24{,}93\ m/s$

Princip.

$E_p = mgh = 10000 \cdot 9{,}5 \cdot 80000 = 7600000000$

$E_k = \frac{mw^2}{2}$

$\frac{7600000000}{2 \cdot 80000} = w^2$

$w = 435{,}889\ m/s$

$w^2 = w_0^2 + 2gh$

$w^2 = 621{,}5 + 190000$

$w = 436{,}6$

2-2-7

Automobil mase 2 000 lb_m kreće se brzinom 105 ft/s i pri tom kretanju savlada visinsku razliku od 2 300 ft, oslobođeno kao kinetičke energije. Ako je gravitaciono ubrzanje 32 ft/s^2 i ako se njegova kinetička energija u krajnjem stanju povećala za 180 000 ft lb, izračunati krajnju brzinu automobila.

$m = 2000\ lb_m = 2000 \cdot \frac{1}{2{,}2046}\ kg = 907{,}19\ kg$

$w = 105\ ft/s = 105 \cdot \frac{1}{3{,}2808}\ m/s = 32\ m/s$

$h = 2300\ ft = 2300 \cdot \frac{1}{3{,}2808} = 701{,}048\ m$

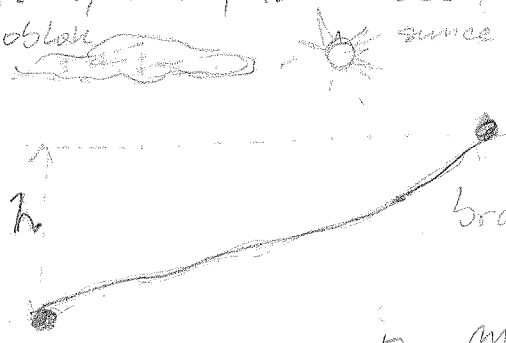
$g = 32\ ft/s^2 = 32 \cdot \frac{1}{3{,}2808} = 9{,}75\ m/s^2$

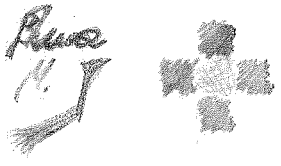
$E_{k_2} = E_{k_1} + 180\,000\ ftlb_f \Rightarrow$ $180\,000\ ftlb_f = 180\,000 \cdot \frac{1}{737,56}\ kJ = 244,04\ kJ$

$E_p = mgh = 907,19 \cdot 9,75 \cdot 701,048 = 6200841,417\ J = 6200,84\ kJ$

$E = E_k + E_p$

$E = const.$





$E_{k_1} = \frac{mv^2}{2} = \frac{907,19 \cdot 32^2}{2}$

$E_{k_1} = 464\,481,28\ J = 464,48\ kJ$

$\frac{mv^2}{2} = E_{k_1} + 244,04\ kJ$

$v = 39,52\ m/s$

2-2-8

Promjena prijelaza idealnog plina u zatvorenom sustavu, cilindar sa klipom kojeg se kreće bez trenja, vrši se prema zakonu $P = 9,6 \cdot V^{-1} + 3,5\ [bar]$ - od volumena $1,5\ m^3$ do volumena $3,5\ m^3$. Odrediti rad promjene volumena i u P-v dijagramu označiti površinu koja je proporc. radu. Također, odrediti količinu topline koju je potrebno odvesti plinu ili odvesti od plina da bi njegovo unutrašnja energija ostala ista nakon procesa.

$P = 9,6 \cdot V^{-1} + 3,5$

$V_1 = 1,5\ m^3$

$V_2 = 3,5\ m^3$

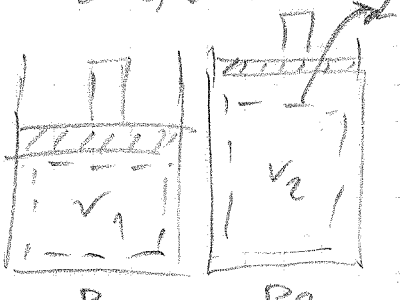
$L_{1,2} = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{9,6}{V}\,dV + \int_{V_1}^{V_2} 3,5\,dV$

$L_{1,2} = 9,6 \ln V \Big|_{V_1}^{V_2} + 3,5V \Big|_{V_1}^{V_2}$

$L = 9,6 \ln \frac{V_2}{V_1} + 3,5 (V_2 - V_1)$

$L = 9,6 \ln \frac{3,5}{1,5} + 3,5 (3,5 - 1,5)$

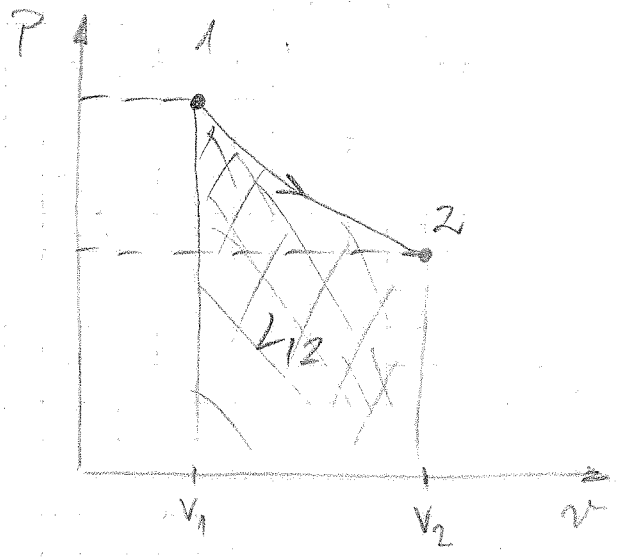
$L = 9,6 \cdot 0,84 + 3,5 \cdot 2 = 8,06 + 7 = 15,06 \cdot 10^5\ J$



$\Delta U = Q - L$

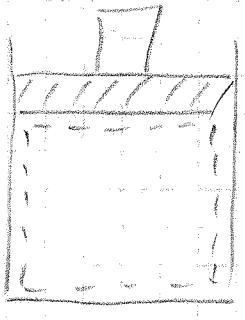
$\Delta U = 0$ jer je $U_1 = U_2$

$Q - L = 1506$ kJ



2-2-9

Zrak se nalazi u cilindru s pokretnim klipom, zatvorenu sistem, čije je stanje definirano početnim volumenom 0,14 m³, apsolutnim tlakom 9 bar-a i temperaturom 41°C. Klip se lagano dok zrak ekspandira u politropskom procesu do tlaka 2,6 bar-a. Eksponent politrope je 1,25. Potrebno je odrediti izvršni rad i razmijenjenu toplotu u opisanom procesu.



$V_1 = 0{,}14\ m^3$ $\quad V_2 = 0{,}38\ m^3$

$p_{apa1} = 9$ bar $\quad p_{apa2} = 2{,}6$ bar

$t_1 = 41°C \quad t_2$

$n = 1{,}25$

$L_{12} = -\frac{R}{n-1}(T_2 - T_1)$

rad promjene volumena

$pV^n = \text{const}$

$p_1 V_1^n = p_2 V_2^n$

$\frac{p_1}{p_2} V_1^n = V_2^n$

$V_2 = \frac{9}{2{,}6} \cdot 0{,}14^{\frac{1,25}{1,25}}$

$V_2 = \sqrt{}^3$

$V_2 = 0{,}38\ m^3$

$t_1 = 41^\circ C = 314{,}15\ K = T_1$

$\rightarrow pV = nRT$

$T_1 V_1^{n-1} = T_2 V_2^{n-1}$ ker je za politrop. proces $TV^{n-1} = const$

$T_2 = T_1 \frac{V_1^{n-1}}{V_2^{n-1}}$

$T_2 = 314{,}15 \cdot \left(\frac{0{,}14}{0{,}38}\right)^{0{,}25}$

$T_2 = 314{,}15 \cdot 0{,}779$

$T_2 = 244{,}75\ K = 27{,}6^\circ C$

$l_{12} = \frac{-R}{n-1}(T_2 - T_1)$ - rad prostjene volumna

$l_{12} = \frac{-287}{1{,}25-1}(244{,}75 - 314{,}15) = -1148 \cdot (-69{,}4) = 79671{,}2\ J/kg$

$R = 287\ J/kgK$ $\quad l = 79{,}67\ kJ/kg$

$\Delta U = q - l$

$q_{12} = c_M (T_2 - T_1)$

$q_{12} = -432 \cdot (-69{,}4)$

$q_{12} = 29980{,}8\ J/kg$

$q_{12} = 29{,}98\ kJ/kg$

$c_M = c_v \frac{n-\varkappa}{n-1}$ $\quad c_v = 720\ J/kgK$

$c_M = 720 \cdot \frac{1{,}25 - 1{,}4}{1{,}25-1}$

$c_M = -432\ J/kgK$

2-2-10

Lonac za kuhanje ima volumen 9 m^3. Voda u loncu se zagrijava blovolino do ključanja, a onda se ohlađuje do temperature 81°C, tako da u loncu ostane samo 0,35 kg vlažne pare, tj. mješavina vrele vode i zasićene pare. Ako se pretpostavi da vanjski ostaje zatvoren, onda je potrebno odrediti količinu dovedene topline vlažnoj pari do njezina tlaka 0,15 MPa

$V = 9\,m^3$

$t = 81°C$

$m = 0{,}35\,kg$

$p = 0{,}15\,MPa$

$\Delta U = mc_p \Delta t$

$\Delta U = Q - L$

2-2-11

Dotok expandira u cilindru sa pokretnim klipom bez trenja od volumena $0,1 m^3$ do $0,3 m^3$. Promjena pritiska u ovisnosti od volumena u toku procesa expanzije data je relacijom $P = 7,4 + 40 \cdot V + 60V^2$ gdje je $P[bar]$ i $V[m^3]$. Izračunati rad promjene volumena ili slobodni rad expanzije dotoka

$V_1 = 0,1 \, m^3$

$V_2 = 0,3 m^3$

$$L_{12} = \int_{V_1}^{V_2} P \, dV$$

$$L_{12} = \int_{V_1}^{V_2} (7,4 + 40V + 60V^2) \, dV$$

$$L_{12} = 7,4V \Big|_{V_1}^{V_2} + 40 \frac{V^2}{2} \Big|_{V_1}^{V_2} + 60 \frac{V^3}{3} \Big|_{V_1}^{V_2}$$

$$L_{12} = 7,4(0,3 - 0,1) + 20 (0,3^2 - 0,1^2) + 20 (0,3^3 - 0,1^3)$$

$$L_{12} = 1,48 + 20 \cdot 0,8 + 20 \cdot 0,026 = 1,48 + 1,6 + 0,52 = 3,6 \cdot 10^5 \, J$$

rad promjene volumena

2-2-12

Promjena stanja nekog sistema, odnosno promjena njegovog pritiska vrši se prema zakonu $P = \frac{9}{V} + 3{,}8$ [bar] od volumena $4{,}5\ m^3$ do $1{,}5\ m^3$. Za vrijeme tog procesa sistem odaje 200 kJ toplote. Odredi promjenu unutrašnje energije i entalpije sistema

$$P = \frac{9}{V} + 3{,}8$$

$$L_{12} = \int_{V_1}^{V_2} \left(\frac{9}{V} + 3{,}8\right) dV$$

$V_1 = 4{,}5\ m^3$

$V_2 = 1{,}5\ m^3$

$Q = 200\ kJ$

$$L_{12} = 9 \ln \frac{V_2}{V_1} + 3{,}8 (V_2 - V_1)$$

Q-odvedeno (−)

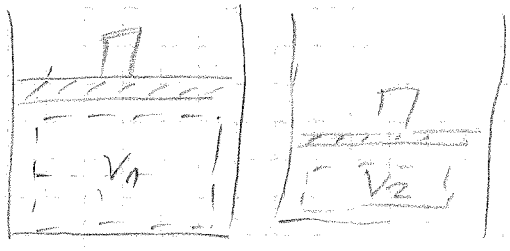
$$L_{12} = 9 \cdot \ln 0{,}333 + 3{,}8 (-3)$$

$$L_{12} = -9{,}97 - 11{,}4$$

$$L = -21{,}37 \cdot 10^5\ J = -2137{,}79\ kJ$$

$$\Delta U = Q - L$$

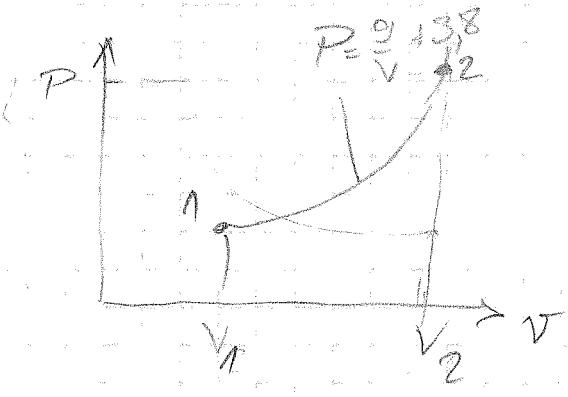
$$\Delta U = -200 + 2137{,}79 = 1937{,}79\ kJ$$



$$H = U + PV$$

$$dH = dU + PdV + V\cancel{dP}^{0}$$

$$H = 1937{,}79 - 2137{,}79 = -200\ kJ$$



2-2-13

Barometar se može iskoristiti za mjerenje visine nebodera. Ako je očitanje sa barometra na vrhu nebodera bilo 730 mmHg, a na dnu 765 mmHg potrebno je odrediti visinu nebodera. Pretpostaviti gustinu zraka 1,29 kg/m³

$P_1 = 730 \text{ mmHg} = 730 \cdot 0{,}133 = 97{,}09 \text{ kPa}$

$P_2 = 765 \text{ mmHg} = 765 \cdot 0{,}133 = 101{,}74 \text{ kPa}$

$\rho_{zr} = 1{,}29 \text{ kg/m}^3$

$1 \text{ kPa} = 7{,}501 \text{ mmHg}$

$1 \text{ mmHg} = \frac{1}{7{,}501} \text{ kPa} = 0{,}133 \text{ kPa}$

$P_2 - P_1 = \rho g h$

$101740 - 97090 = 1{,}29 \cdot 9{,}81 \cdot h$

$4650 = 12{,}65 h$

$\frac{4650}{12{,}65} = h$

$h = 367{,}59 \text{ m}$

2-2-14 *

U zatvorenom sistemu, cilindar sa pokretnim klipom, nalazi se 1,5 kg zraka na pritisku 7,5 bar-a. Tokom izobarnog procesa zraku se odvodi 49 kJ toplote, a njegov volumen se smanjuje od 0,15 m^3 do 0,09 m^3. Izračunati promjenu unutrašnje energije zraka u sistemu

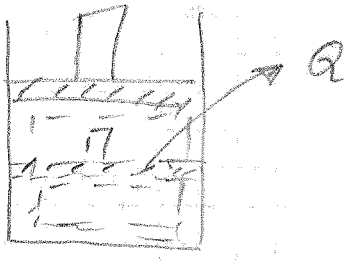
$m = 1,5$ kg

$p = 7,5$ bar $= 7,5 \cdot 10^5$ Pa

$Q = 49$ kJ

$V_1 = 0,15\ m^3$

$V_2 = 0,09\ m^3$



Q - odvedena (−)

2-2-15

U cilindru s pokretnim klipom nalazi se plin čije početno stanje definirano je tlakom 100 psi, temperaturom 355°F i volumenom 1,1 ft³. Plin je podvrgnut ravnotežnom procesu koji se odvija prema jednadžbi $PV^2 = konst.$ Tlak plina u krajnjem stanju je 25 psi. Ako se plinu tijekom procesa dovodi količina topline od 5,3 Btu, odredite promjenu unutarnje energije plina [kJ]

$p_1 = 100\ psi = 100 \cdot 6,89 = 685\ kPa$ | Q - dovedena (+)

$t_1 = 355°F = 179,44°C$

$V_1 = 1,1\ ft^3 = 0,03\ m^3$

$p_2 = 25\ psi = 172,25\ kPa$

$Q = 5,3\ Btu = 5,59\ kJ$

$P_1 V_1^2 = P_2 V_2^2$

$V_2 = \sqrt{\frac{P_1}{P_2} V_1^2}$

$V_2 = \sqrt{\frac{689000}{172250} \cdot 0,0009} = 0,06\ m^3$

$14,696\ psi = 101,325\ kPa$

$1\ psi = \frac{101,325}{14,696}\ kPa = 6,89\ kPa$

$1\ kJ = 0,9478\ Btu$

$1\ Btu = \frac{1}{0,9478}\ kJ = 1,055\ kJ$

$1\ m^3 = 35,315\ ft^3$

$1\ ft^3 = \frac{1}{35,315}\ m^3 = 0,028\ m^3$

$t[°C] = \frac{5}{9}\{t[°F] - 32\} = \frac{5}{9}(355 - 32) = \frac{5}{9} \cdot 323 =$

$= 179,44°C$

$$L_{12} = \int_{V_1}^{V_2} \frac{C}{V^2} dV = 620,1 \left(-\frac{1}{V_2} + \frac{1}{V_1}\right) = 620,1 \left(\frac{1}{0,03} - \frac{1}{0,06}\right)$$

$PV^2 = C$

$P = \frac{C}{V^2}$

$L_{12} = 620,1 (33,33 - 16,66)$

$L = 10332,93 \text{ J}$

$L = 10,33 \text{ kJ}$

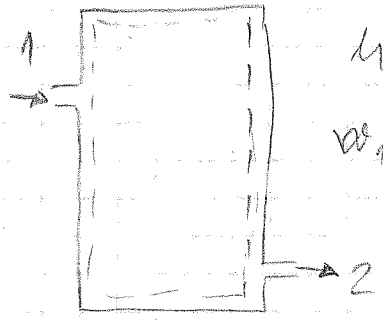
$\Delta U = Q - L$

$\Delta U = 5,59 - 10,33 = -4,74 \text{ kJ}$

3 KONZERVACIJA M. I E.

3-1-1

U stac. režimu vodena para na ulazu u kondenzator ima specifičnu entalpiju 2326 J/kg i brzinu 36,58 m/s. Na izlazu iz kondenzatora fazicima vode ima entalpiju 162,82 kJ/kg i brzinu 6,1 m/s. Ako se fizikalni promjena potenc. energije odredi razmjenjenom specif. toplotom u kondenzatoru.



$h_1 = 2326 \text{ J/kg}$

$w_1 = 36,58 \text{ m/s}$

$h_2 = 162,82 \text{ kJ/kg} = 162820 \text{ J/kg}$

$w_2 = 6,1 \text{ m/s}$

$q - \cancel{l}^{0} = (h_2 - h_1) + \left(\frac{w_2^2 - w_1^2}{2}\right) + g\cancel{(z_2 - z_1)}^{0}$

$q = (162820 - 2326) + \left(\frac{6,1^2 - 36,58^2}{2}\right)$

$q = 160494 + \frac{37,21 - 1338,09}{2}$

$q = 159843,55$

3-2-1

Voda na temp. 20°C, gustine 998 kg/m³ protječe kroz cijev popr. presjeka 5 cm². Ako je volumni protok vode 5,2 lit/s, onda je potrebno odrediti: brzinu vode i maseni protok vode kroz cijev

$t = 20°C$

$\rho = 998\ kg/m^3$

$A = 5\ cm^2 = 0{,}0005\ m^2$

$\dot{V} = 5{,}2\ l/s = 0{,}0052\ m^3/s$

1 m = 100 cm

1 m² = 10000 cm²

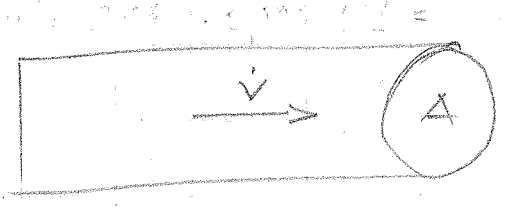
1 cm² = 0,0001 m²

1 l = 0,001 m³

1 m³ = 1000 l

$\dot{m} = \rho \dot{V} = \rho w A$

$\dot{m} = 998 \cdot 0{,}0052 = 5{,}19\ kg/s$



$\dot{m} = \rho w A$

$w = \frac{\dot{m}}{\rho A} = \frac{5{,}19}{998 \cdot 0{,}0005} = 10{,}4\ m/s$

3-2-2

Dušik, pri tlaku 200 kPa i temp. 25°C protječe kroz cijev unutr. promjera 45 mm s prosječnom brzinom 19 m/s. Ako se za proračun gustine dušika upotrijebi relacija $\rho = 3{,}37 \cdot 10^{-3} \cdot P \cdot T^{-1}\ [kg/m^3]$ pri čemu je $P[N/m^2]$ i $T[K]$ izračunati maseni protok kroz cijev.

$P = 200\ kPa$

$t = 25°C = 298{,}15\ K$

$d = 45\ mm = 0{,}045\ m$

$w = 19\ m/s$

$\rho = 3{,}37 \cdot 10^{-3} \cdot 200\,000 \cdot \frac{1}{298{,}15} = 2{,}26\ kg/m^3$

$A = \frac{d^2 \pi}{4} = 0{,}0016\ m^2$

$\dot{m} = \rho \dot{V} = \rho w A = 2{,}26 \cdot 19 \cdot 0{,}0016 = 0{,}068\ kg/s$

3-2-3

Zrak na prištisku 2 bar i temp 25°C protječe kroz cijev sa popr. presjekom $2{,}025 \cdot 10^{-3}\ m^2$ i prosječnom brzinom 19 m/s. Ako se za proračun gustine zraka može koristiti jednadžba stanja idealnog plina zrak kroz cijev.

$p = 2\ bar = 200000\ Pa$

$t = 25°C = 298{,}15\ K$

$A = 2{,}025 \cdot 10^{-3}\ m^2$

$w = 19\ m/s$

$\rho = 3{,}37 \cdot 10^{-3} \cdot p \cdot T^{-1}$

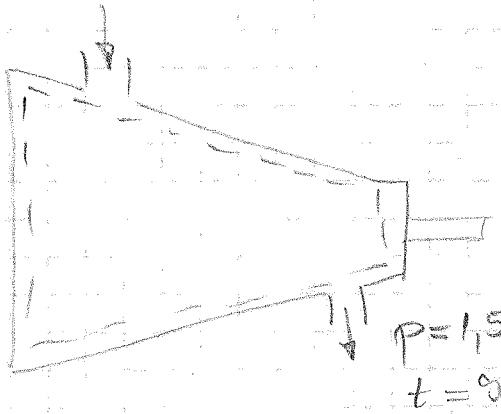
$\rho = 3{,}37 \cdot 10^{-3} \cdot 200000 \cdot \frac{1}{298{,}15}$

$\rho = 2{,}26\ kg/m^3$

$\dot{m} = \rho w A = 2{,}26 \cdot 19 \cdot 2{,}025 \cdot 10^{-3} = 0{,}087\ kg/s$

3-2-4

Na izlazu iz kompresora zrak ima prištisak 1,5 MPa, temp. 90°C i maseni protok 150 kg/min. Za proračun gustine zraka vrijedi $\rho = 3{,}4843 \cdot 10^{-3} \cdot p \cdot T^{-1}\ [kg/m^3]$ pri čemu je $p[N/m^2]$ i $T[K]$. Odredi unutarnji promjer cijevi na izlazu iz kompresora tako da vanjski presjek brzina ne prelazi 250 m/s.



$\rho = 3{,}4843 \cdot 10^{-3} \cdot 1500000 \cdot \frac{1}{363{,}15} = 14{,}39\ kg/m^3$

$\dot{m} = \rho \dot{V} = \rho w A$

$A = \frac{\dot{m}}{250 \cdot 14{,}39} = \frac{2{,}5}{3597{,}5} = 0{,}00069\ m^2$

$p = 1{,}5\ MPa = 1500000\ Pa$

$t = 90°C = 363{,}15\ K$

$\dot{m} = 150\ kg/min = 2{,}5\ kg/s$

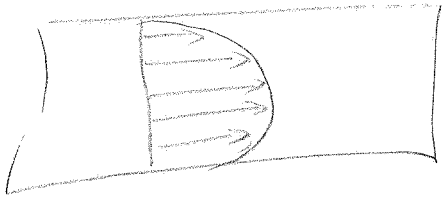
$w = 250\ m/s$

$A = \frac{d^2 \pi}{4}$

$\sqrt{\frac{4A}{\pi}} = d \Rightarrow d = 0{,}029\ m$

3-2-5

Ulje pri pritisku 700 kPa i temp. 250°C protječe kroz cijev promjera 150 mm. Brzina je parabolična i dana relacijom $w = 10 \cdot \left[1 - \left(\frac{r}{75}\right)^2\right]$ gdje je r[mm] - radijus poluprer. cijevi, a w[m/s] - brzina ulja. Ako se za proračun gustine ulja upotrijebi ista relacija kao u zadatku 3-2-2 odredi maksimalnu brzinu.



$p = 700\,kPa = 700\,000\,Pa$

$t = 250°C = 523{,}15\,K$

$d = 150\,mm = 0{,}15\,m \Rightarrow r = 0{,}075\,m$

$\rho = 3{,}37 \cdot 10^{-3} \cdot p \cdot T^{-1} = 3{,}37 \cdot 10^{-3} \cdot 700000 \cdot \frac{1}{523{,}15} = 4{,}5\ kg/m^3$

$w = 10 \cdot \left[1 - \left(\frac{r}{75}\right)^2\right] = 10 \cdot \left[1 - \left(\frac{0{,}075}{75}\right)^2\right] = 10 \cdot 0{,}99 = 9{,}99\ m/s$

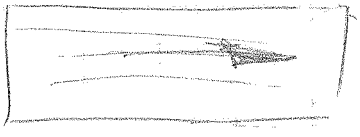
$\dot{m} = \rho w A = 4{,}5 \cdot 9{,}99 \cdot 0{,}035 = 1{,}588\ kg/s$

$A = \frac{d^2\pi}{4} = 0{,}035\,m^2$

3-2-6

Odredi maksimalnu protok zraka kroz dovodni cijevi promjera 70 mm ako su brzina i gustina zraka u poprečnom presjeku cijevi poznate i date kao funkcija polumjera relacijama $w = 25 \cdot \left[1 - \left(\frac{r}{35}\right)^2\right]$ i $\rho = 300 \cdot \left[4 - \left(\frac{r}{35}\right)^2\right]$ gdje je r[mm] - rad. poluprer. cijevi, w[m/s] - brzina zraka, ρ[kg/m³] - gustina.

$d = 70\,mm = 0{,}035\,m$



$w = 25 \cdot \left[1 - 0{,}000001\right] = 25\ m/s$

$\rho = 300\left[4 - 0{,}000001\right] = 1199{,}99\ kg/m^3$

$A = \frac{d^2\pi}{4} = 0{,}0019\,m^3$

$\dot{m} = \rho w A = 1200 \cdot 25 \cdot 0{,}0019$

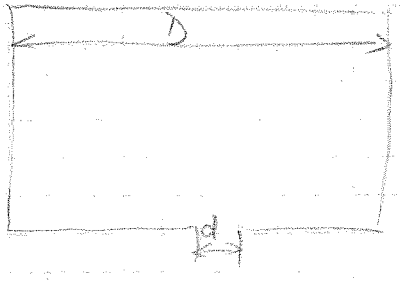
$\dot{m} = 57\ kg/s$

3-2-7

U otvorenoj cilindr. posudi promjera D[m] i visine H[m] nalazi se tečnost do max moguće visine u posudi. Na dnu posude kroz otvor promjera d[m] ističe voda u atmosferi brzinom $w = 4{,}43\sqrt{H}$ [m/s]. Odrediti u funkciji d, D i H zapreminski protok vode kroz otvor, brzinu vode na površini rezervoara i maseni protok vode kroz otvor ako je gustina vode 999 kg/m³

$\rho = 999$ kg/m³

$w = 4{,}43\sqrt{H}$ [m/s]



$\dot{V}, w$

$V = D^2 \pi H \qquad A = \frac{D^2\pi}{4}$

$\dot{V} = wA$

$\dot{V} = 4{,}43 \cdot \sqrt{H} \cdot \frac{d^2\pi}{4}$

$\dot{V} = 1{,}107\, d^2\pi\sqrt{H}$

$\dot{m} = \rho w A$

$\dot{m} = 999 \cdot 4{,}43\sqrt{H} \cdot \frac{d^2\pi}{4}$

$\dot{m} = 1105{,}89\sqrt{H}\, d^2\pi$

$\dot{m} = 3472{,}77\sqrt{H}\, d^2$

$\dot{V} = w_p A$

$1{,}107\, d^2\pi\sqrt{H} = w_p \cdot \frac{D^2\pi}{4}$

$4{,}43 \cdot \frac{d^2}{D^2}\sqrt{H} = w_p$

3-28

Vertikalni ličmo preklopni most imar masu 11 000 kg i max visinu dizanja 6,5 m. Odredi min snagu motora potrebnu da otvori odmosno podigne most do max visine za 3,5 min.

$m = 11\,000\,kg$

$h_{max} = 6,5\,m$

$t = 3,5\,min = 3,5 \cdot 60 = 210\,s$

$P = F \cdot v$

$F = m \cdot g$

$v = \frac{s}{t}$

$P = \frac{A}{t}$

$v \cdot t = s$

$v = \frac{s}{t} = \frac{6,5}{210} = 0,031\ m/s$

$E_{p_1} = 0$

$E_{p_2} = mgh = 11\,000 \cdot 9,81 \cdot 6,5 = 701\,415\ J$

$E_k = \frac{mv^2}{2} = \frac{11000 \cdot 0,031^2}{2} = 6,28\ J$

$A = E_{p_2} - E_{p_1}$ - rad mod tijelom povećava njegovu pot. energ.

$A_{uk} = E_{p_2} - E_{p_1} = E_{p_2} = 701,415\ J$

$P = \frac{A}{t} = \frac{701415}{210} = 3340,07\ W = 3,34\ kW$

3-2-9 ☆

U izoliranom kontejneru volumena 1,25 m³ nalazi se voda na temp. 90°C. U vodu se uranja kontejner AL volumena 0,11 m³ na temp. 20,5°C. Odredi temp. AL i vode u stanju mjerne toplinske ravnoteže.

$V_1 = 1{,}25\ m^3$

$t_1 = 90°C = 363{,}15\ K$ $\quad V = V_1 + V_2 = 1{,}25 + 0{,}11 = 1{,}36\ m^3$

$V_2 = 0{,}11\ m^3$

$t_2 = 20{,}5°C = 293{,}65\ K$

$\Delta U = Q - L$

$B_2 - B_1 = Q - L$

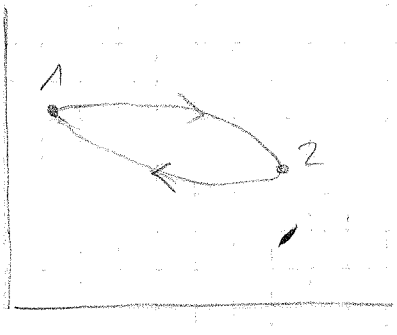
$B_2 = B_1$

3-2-10

Zatvoreni sistem je podvrgnut ciklusu sastavljenom od 2 kvazistat. procesa. Tokom procesa 1-2 energija sistema povećana je za 30 kJ. Tokom procesa 2-1 sistem u okolinu odaje 40 kJ topline. Ako je neto rad ciklusa (1-2-1) 10 kJ, odredi Q_{12}, L_{12}, L_{21}

$\oint dQ - \oint dL = \oint dB = 0$

$(Q_{12} + Q_{21}) - (L_{12} + L_{21}) = (B_2 - B_1) + (B_1 - B_2) = 0$



$L_{12} + L_{21} = 10$

$Q_{12} - 40 + 10 = 0$

$\boxed{Q_{12} = 30\ kJ}$

$Q_{12} - L_{12} = 35\,kJ$

$30 - L_{12} = 35$

$30 - 35 = L_{12}$

$\boxed{-5\,kJ = L_{12}}$

$L_{12} + L_{21} = 10$

$-5 + L_{21} = 10$

$\boxed{L_{21} = 10 + 5 = 15\,kJ}$

3-2-11 ✱

Kamnod železa mase 15,5 kg ma temp. 110,5 °C naložijo v izolirano kontejner. Ko se kontejner vsebi 10,5 L vode kaja ima temp. 15 °C določiti temp. vode in Fe v stanju najnižje termične ravnotežje.

$m_1 = 15{,}5\,kg \Rightarrow$

$t_1 = 110{,}5\,°C$

$m_2 = 10{,}5\,L = 10{,}5\,kg$

$t_2 = 15°$

t_{vode}

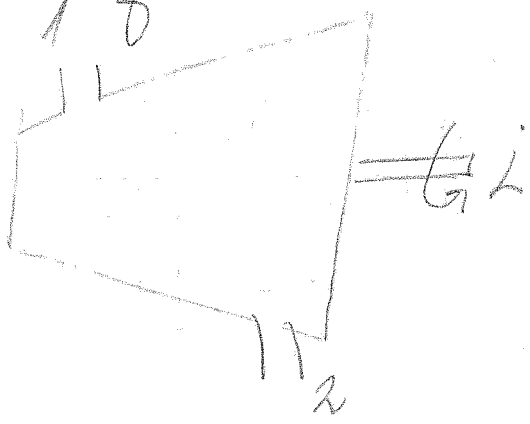
$t_{železa} =$

$Q = Q_1 + Q_2$

$m \cdot t \cdot c$

3-~~2~~-12

Na ulazu u turbinu vodena para pritiska 15 MPa i temp. 600°C, a na izlazu iz turbine para je mokrozasićena stanja na pritisku 100 kPa. Površina poprečnog presjeka toka pare na ulazu u turbinu je 0,051 m², a na izlazu 0,321 m². Ravnomjernom masenom protoku pare kroz turbinu je 35 kg/s. Kako se može zamisliti prijenos topline iz sistema u okolinu, izračunati osovinski rad turbine u jed. vremena.



15 000 000
150 bar
100 000 1 bar

$P_1 = 15\ MPa$ $\quad P_2 = 100\ kPa$

$t_1 = 600°C$ $\quad A_2 = 0{,}321\ m^2$

$A_1 = 0{,}051\ m^2$

$\dot{m} = 35\ kg/s$

$$\dot{Q}^{\,0} - \dot{L} = \dot{m}\left(h_1 + \frac{w_1^2}{2} + g\cancel{z_1}^{\,0}\right)_{1Z} + \dot{m}\left(h_2 + \frac{w_2^2}{2} + g\cancel{z_2}^{\,0}\right)_{IZ}$$

$$-\dot{L} = \dot{m}\left(h_2 - h_1 + \frac{w_2^2 + w_1^2}{2}\right)$$

$h_1 = 3581{,}2\ kJ/kg$ $\quad h_2 = h_p = 2675\ kJ/kg$

$v_1 = 0{,}02489\ m^3/kg$ $\quad v_2 = v_p = 1{,}694\ m^3/kg$

$\dot{m} = \rho w_1 A_1$

$\dot{m} = \frac{w_1 A_1}{v_1}$

$\frac{\dot{m} v_1}{A_1} = w_1 = 17{,}08\ m/s$

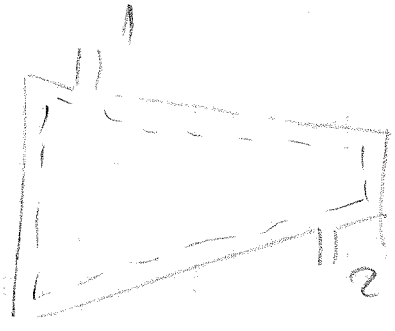
$\frac{\dot{m} v_2}{A_2} = w_2 = 184{,}7\ m/s$

$-\dot{L} = 35\left(2\,675\,000 - 3581200 + \frac{291,72 + 3414,09}{2}\right)$

$-\dot{L} = -906200 + 33822,37 \Rightarrow \quad \dot{L} = 872,37\ kW$

3-2-13

Na ulazu u kompresor protisak zraka je 100 kPa, a temp. 20°C, dok je na izlazu protisak 240 kPa, a temp 70°C. Ravnomjerni maseni protok zraka je 1,5 kg/s. Prosječna brzina strujanja zraka na ulazu u kompresor je 60 m/s, a na izlazu 120 m/s. Kroz kućište kompresora protječe rashladna voda tako da je razmjenjena količina topline između zraka i vode 19 kJ/kg zraka. Izračunati snagu kompresora ako je tok unutar i stacionaran.



$p_1 = 100\ kPa \qquad p_2 = 240\ kPa$

$t_1 = 20°C = 293,15K \qquad t_2 = 70°C = 343,15K$

$\dot{m} = 1,5\ kg/s$

$w_1 = 60\ m/s \qquad w_2 = 120\ m/s$

$q = 19\ kJ/kg$

$$q - l = \left[h_2 - h_1 + \frac{w_2^2 - w_1^2}{2} + g(z_2 - z_1)\right]$$

$$19000 - l = \left[c_p(t_2 - t_1) + \frac{w_2^2 - w_1^2}{2} + g(z_2 - z_1)\right]$$

$$19000 - l = \left[1010(343,15 - 293,15) + \frac{14400 - 3600}{2}\right]$$

$$19000 - l = (1010 \cdot 50 + 5400)$$

$$19000 - l = 55900$$

$$19000 - 55900 = l$$

$$l = -36900\ W = -36,9\ kW$$

3-2-14

Određivanje pumpe ako ima stalan maseni protok vode od 350 L/min, temp. vode 20°C i visinu dizanja 150 m. Pretpost. adijabatski i stacionarni proces pumpanja te zanemarivši promjenu temp. i unutr. energije vode prije i poslije pumpanja

$\dot{m} = 350\ L/min \Rightarrow \dot{V} = \frac{350}{60}\ L/s = 5{,}83\ L/s = 0{,}0058\ m^3/s$

$t = 20°C = 293{,}15\ K$

$\dot{m} = \rho \dot{V} = 1000 \cdot 0{,}0058\ m^3/s = 5{,}83\ kg/s$

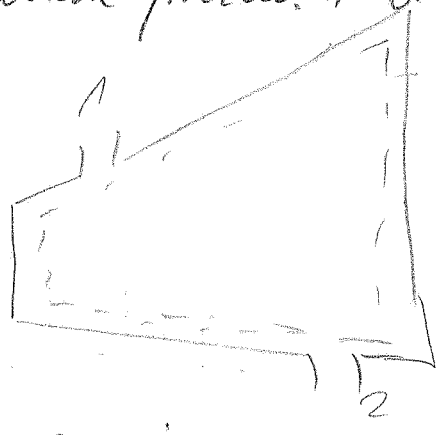
$z_2 = 150\ m$

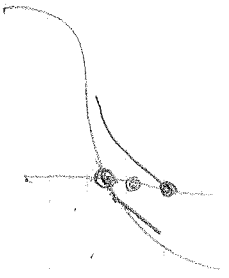
$$\dot{Q} - \dot{L} = \dot{m}\left(u_2 - u_1 + \frac{w_2^2 - w_1^2}{2} + g(z_2 - z_1)\right)$$

$$-\dot{L} = 5{,}83\,(9{,}81 \cdot 150) = 8578{,}84\ W = 8{,}58\ kW$$

3-2-15 ★

Vodena para pri pritisku 1000 psi, temp. 1000 °F ulazi u turbinu brzinom 210 ft/s. Na izlazu iz turbine para je u zasićenom stanju na pritisku 2,0 psi. Prečnik cijevi na ulazu u turbinu je 1,5 ft, a na izlazu 12 ft. Odredi maseni protok pare i njenu izlaznu brzinu. Rezultate prevedi u SI jedinice.





$p_1 = 1000$ psi
$t_1 = 1000$ °F
$w_1 = 210$ ft/s
$d_1 = 1,5$ ft

$p_2 = 2$ psi
$d_2 = 12$ ft

$\dot{m} = ?$
$w_2 = ?$

14,696 psi = 101,325 kPa

1 psi = $\frac{101,325}{14,696}$ kPa = 6,894 kPa

$p_1 = 1000 \cdot 6,894 = 6894$ kPa = 6894 000 Pa ≈ 69 bar

$p_2 = 2 \cdot 6,894 = 13,788$ kPa = 13 788 Pa ≈ 0,13 bar

$t[°C] = \frac{5}{9}\{t[°F] - 32\} = \frac{5}{9}\{1000 - 32\} = 537,77$ °C

$w_1 = \frac{1}{3,2808} \cdot 210$ m/s = 64 m/s

$d_1 = \frac{1,5}{3,2808}$ m = 0,45 m

$d_2 = \frac{12}{3,2808}$ m = 3,65 m

$A_1 = \frac{d_1^2 \pi}{4}$ $A_2 = \frac{d_2^2 \pi}{4}$

$A_1 = 0{,}31\ m^2$ $A_2 = 10{,}45\ m^2$

$\dot{V}_1 = w_1 A_1 = 64 \cdot 0{,}31 = 19{,}84\ m^3/s$

$\dot{V}_2 = w_2 A_2 = 1{,}898 \cdot 10{,}45 = 19{,}83\ m^3/s$

$\dot{m}_1 = \rho w_1 A_1$ $\dot{m} = \rho w_2 A_2$

$\dot{m} = \rho \dot{V}$

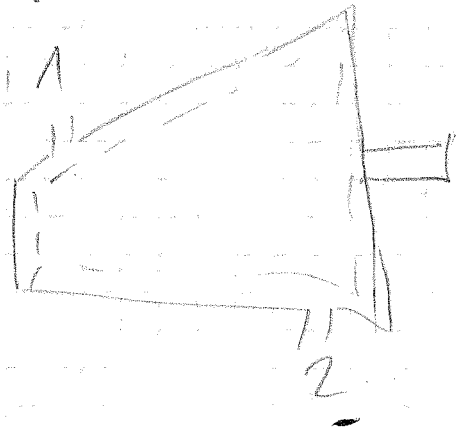
$\rho w_1 A_1 = \rho w_2 A_2$

$\frac{w_1 A_1}{A_2} = w_2 = \frac{64 \cdot 0{,}31}{10{,}45} = 1{,}898\ m/s$ $\Rightarrow w_2 = 1{,}898 \cdot 3{,}2808 = 6{,}226\ ft/s$

$\dot{Q} - \dot{L} = \dot{m}\left(h_2 - h_1 + \frac{w_2^2 - w_1^2}{2} + g(z_2 - z_1)\right)$ ili $q - l = \left(h_2 - h_1 + \frac{w_2^2 - w_1^2}{2} + g(z_2 - z_1)\right)$

3-2-16 ☆

Vodena para na ulazu u turbinu ima tlak 40 bar temp. 440°C i brzinu strujanja 100 m/s kroz poprečni presjek ujeva 0,05 m^2. Na izlazu iz turbine para je u vlažnom stanju, tlak 0,3 bar, a vlažnost 10%. Ako je brzina pare na izlazu 200 m/s, odredi maseni protok pare i presjek cijevi na izlazu



$p_1 = 40\ bar = 4\ MPa$

$w_1 = 100\ m/s$

$A_1 = 0{,}05\ m^2$

$p_2 = 0{,}3\ bar = 30\ kPa$

$w_2 = 200\ m/s$ $x = 0{,}9$

$\dot{m} = ?$

$A_2 = ?$

$\dot{m}_1 = \dot{m}_2$

$\rho w_1 A_1 = \rho w_2 A_2$

$\frac{w_1 A_1}{w_2} = A_2 = \frac{100 \cdot 0{,}05}{200} = 0{,}025\ m^2$

3-2-17 ✗

Voda protječe kroz glavnu cijev promjera 1 in, pri tlaku 20 psi i temp. 60°F. Na kraju glavne cijevi nalazi se mlaznica promjera 0,25 in. Brzina istjecanja vode iz mlaznice je 20 ft/s. Odredi maseni protok vode i njezinu brzinu u cijevi. Rezultate preračunati u jedinicama SI.

$d_1 = 1$ in $\Rightarrow d_1 = \frac{1}{39{,}370}\ m = 0{,}025\ m$

$p_1 = 20$ psi $\Rightarrow p_1 = 20 \cdot 6{,}894 = 137{,}88$ kPa

$t_1 = 60°F \Rightarrow t_1[°C] = \frac{5}{9}(60 - 32) = 15{,}55°C$

$d_2 = 0{,}25$ in $\Rightarrow d_2 = \frac{0{,}25}{39{,}370}\ m = 0{,}0063\ m$

$w_2 = 20$ ft/s $\Rightarrow w_2 = \frac{20}{3{,}2808} = 6{,}09\ m/s$

3-2-18 *

Voda na ulazu u pumpu ima pritisak 1 bar i temp. 20°C
Protok vode na ulazu je 0,2 m^3/min s unutarnjim promjerom cijevi 150 mm, na izlazu voda ima iste temp., a tok se dijeli na 2 struje kroz 2 cjevovoda promjera 50 mm i 70 mm.
Maseni protok vode kroz manju cijev je 2 kg/s. Odredi brzinu vode kroz oba izlazna cijevi.

$p_1 = 1$ bar
$t_1 = 20°C$
$d_1 = 150$ mm
$\dot{V}_1 = 0,2\ m^3/min$

$t_2 = 20°C$
$d_2 = 50$ mm
$\dot{m}_2 = 2$ kg/s

$t_3 = 20°C$
$d_3 = 70$ mm

3-2-19 ✱

Zrak expandira u mlaznici od pritiska 25 psi, temp 200°F početnom brzinom 100 ft/s do pritiska na izlazu iz mlaznice 14,5 psi i temp 80°F. Toplotni gubitak mlaznice prema okolini je 1,5 Btu/lb$_m$. Odredi brzinu zraka na izlazu iz mlaznice, odnos presjeka na ulazu i izlazu. Rezultate prez i u SI jedinicama..

$p_1 = 25\ psi = 25 \cdot 6,894 = 172,35\ kPa$ $p_2 = 14,5\ psi = 99,96\ kPa$

$t_1 = 200°F = 93,33°C$ $t_2 = 80°F = 26,66°C$

$w_1 = 100\ ft/s = 30,48\ m/s$ $q = 1,5\ Btu/lb_m = 1,5 \cdot 2,326 = 3,489\ kJ/kg$

3-2-20 ✱

Argon struji kroz adijabatsku mlaznicu i dana maseni protok 2,55 kg/s. Stanje na ulazu je $p = 5,3$ bar, $T = 500$ K a izlazno stanje na izlazu $p = 0,95$ bar i $T = 400$ K. Ako je ulazni presjek mlaznice 2x veći od izlaznog, odredite brzinu argona. Također, odredite volumen i gustoću argona na ulazu i izlazu iz mlaznice.

$\dot{m} = 2,55$ kg/s

$p_1 = 5,3$ bar

$T_1 = 500$ K

$\lambda_1 = \lambda_1$

$p_2 = 0,95$ bar

$T_2 = 400$ K

$A_2 = 2A_1$

$\dot{m} = \rho w_1 A_1$ $\quad \dot{m} = \rho w_2 A_2$

$\frac{\dot{m}}{w_1 A_1} = \frac{\dot{m}}{w_2 A_2} \Rightarrow \frac{1}{w_1 A_1} = \frac{1}{w_2 2A_1} \Rightarrow \frac{1}{w_1} = \frac{1}{2w_2} \Rightarrow w_1 = 2w_2$

3-2-21 ✱

Na ulazu u mlaznicu pregrijane vodene pare je 30 bar, a temp. 320 °C. Na izlazu pregrijane pare je 14 bar, a njena brzina 530 m/s. Maseni protok pare kroz mlaznicu je 8 t/h. Ako se predpostavi adijabatsko strujanje pare kroz mlaznicu i da je njena početna brzina ≈0 odrediti temp. i entalpiju pare na izlazu i popr. presjek mlaznice na izlazu.

$p_1 = 30 \text{ bar} = 3 \text{ MPa}$ $\quad p_2 = 14 \text{ bar} = 1{,}4 \text{ MPa}$

$t_1 = 320 °C$ $\quad w_2 = 530 \text{ m/s}$

$w_1 \approx 0$ $\quad \dot{m} = 8 \text{ t/h}$

$Q - L + \dot{m}\left(h_2 - h_1 + \frac{w_2^2 - w_1^2}{2} + g(z_2 - z_1)\right)$

P-v-T promjene čiste supstance

4-2-1

Linearnom interpolacijom ili ekstrapolacijom, koristeći odgov. tablice odredi spec. entalpiju, spec. volumen i spec. entropiju zasićene vode i zasićene vodene pare za temp. 122°C.

$t = 122°C$ iz tablice P-3-1

$v_{t120} = 1{,}0603 \ dm^3/kg$

$v_{t125} = 1{,}065 \ dm^3/kg$

$$v_t = v_{t120} + \frac{v_{t125} - v_{t120}}{t_2 - t_1}(t - t_1)$$

$$v_t = 1{,}0603 + \frac{0{,}0047}{5} \cdot 2$$

$1 \ m = 10 \ dm$

$1 \ m^2 = 100 \ dm^2$

$1 \ m^3 = 1000 \ dm^3$

$1 \ dm^3 = 0{,}001 \ m^3$

$$v_t = 1{,}06218 \ dm^3/kg = 0{,}0010618 \ m^3/kg$$

$v_{t120} = 0{,}0010603 \ m^3/kg$

$v_{t125} = 0{,}001065 \ m^3/kg$

$v_{p120} = 0{,}8917 \ m^3/kg$

$v_{p125} = 0{,}7704 \ m^3/kg$

$$v_p = v_{p120} + \frac{v_{p125} - v_{p120}}{t_2 - t_1}(t - t_1)$$

$$v_p = 0{,}8917 - \left(\frac{0{,}1213}{5} \cdot 2\right)$$

$$v_p = 0{,}84318 \ m^3/kg$$

$h_{t120} = 503{,}7 \ kJ/kg$

$h_{t125} = 525 \ kJ/kg$

$$h_t = h_{t120} + \frac{h_{t125} - h_{t120}}{t_2 - t_1}(t - t_1)$$

$$h_t = 503{,}7 + \frac{525 - 503{,}7}{5} \cdot 2$$

$$h_t = 512{,}22 \ kJ/kg$$

$h_{p120} = 2706 \ kJ/kg$

$h_{p125} = 2713 \ kJ/kg$

$$h_p = h_{p120} + \frac{h_{p125} - h_{p120}}{t_2 - t_1}(t - t_1)$$

$$h_p = 2706 + \frac{2713 - 2706}{5} \cdot 2$$

$$\boxed{h_p = 2708{,}8 \ kJ/kg}$$

$s_{t120} = 1{,}5277 \ kJ/kgK$

$s_{t125} = 1{,}58 \ kJ/kgK$

$$s_t = s_{t120} + \frac{s_{t125} - s_{t120}}{5} \cdot 2$$

$$s_t = 1{,}5277 + \frac{1{,}58 - 1{,}5277}{5} \cdot 2$$

$$\boxed{s_t = 1{,}54862 \ kJ/kgK}$$

$s_{p120} = 7{,}129 \ kJ/kgK$

$s_{p125} = 7{,}0777 \ kJ/kgK$

$$s_p = s_{p120} + \frac{s_{p125} - s_{p120}}{t_2 - t_1}(t - t_1)$$

$$s_p = 7{,}129 + \frac{7{,}0777 - 7{,}129}{5} \cdot 2$$

$$\boxed{s_p = 7{,}10848 \ kJ/kgK}$$

4-2-2

Linearnom interpol. iz dat. očitanjem odredi spec. entalpiju, volumen, entropiju zasićene vode i zasićene pare za pritisak 5,1 bar.

$p = 5{,}1$ bar ove iz tablice P-3-2

$v_{t1} = 1{,}0927 \ dm^3/kg$

$v_{t2} = 1{,}1007 \ dm^3/kg$

index 1 za $p = 5$ bar

index 2 za $p = 6$ bar

$p_2 - p_1 = 1$, $p - p_1 = 0{,}1$

$$v_t = 1{,}0927 + \frac{1{,}1007 - 1{,}0927}{p_2 - p_1}(p - p_1)$$

$$v_t = 1{,}0935 \ dm^3/kg$$

$v_{p1} = 0,3747 \ m^3/kg$

$v_{p2} = 0,3156 \ m^3/kg$

$$v_p = v_{p1} + \frac{v_{p2} - v_{p1}}{p_2 - p_1}(p - p_1)$$

$$v_p = 0,3747 + \frac{0,3156 - 0,3747}{1} \cdot 0,1$$

$$v_p = 0,36879 \ m^3/kg$$

$h_{t_1} = 640,1 \ kJ/kg$

$h_{t_2} = 670,5 \ kJ/kg$

$$h_t = 640,1 + (670,5 - 640,1) \cdot 0,1$$

$$h_t = 643,14 \ kJ/kg$$

$h_{p1} = 2749 \ kJ/kg$

$h_{p2} = 2757 \ kJ/kg$

$$h_p = 2749 + (2757 - 2749) \cdot 0,1$$

$$h_p = 2749,8 \ kJ/kg$$

$s_{t_1} = 1,86 \ kJ/kgK$

$s_{t_2} = 1,931 \ kJ/kgK$

$$s_t = 1,86 + (1,931 - 1,86) \cdot 0,1$$

$$s_t = 1,8671 \ kJ/kgK$$

$s_{p1} = 6,822 \ kJ/kgK$

$s_{p2} = 6,76 \ kJ/kgK$

$$s_p = 6,822 + (6,76 - 6,822) \cdot 0,1$$

$$s_p = 6,8158 \ kJ/kgK$$

4-2-3

Lin. interpol. ili dir. očit. konstoći tablice odredi spec. volumen, entalp., entrop. zasić. vode i vodene pare za temp. 370°C

P-3-1

$t = 370°C$

$v_t = 2,22\ dm^3/kg$ $\quad h_t = 1893\ kJ/kg$ $\quad s_t = 4,1137\ kJ/kgK$

$v_p = 0,00493\ m^3/kg$ $\quad h_p = 2331\ kJ/kg$ $\quad s_p = 4,7951\ kJ/kgK$

4-2-4

Lin. interpol. ili dir. očitavanjem odredi spec. volumen, entalpiju i entropiju pregrijane vodene pare za $p = 250\ bar$, $T = 220°C$

P-3-3 $\left.\begin{matrix} t = 220°C \\ p = 250\ bar \end{matrix}\right\}$

$v = 1,128\ m^3/kg$

$h = 2910,6\ kJ/kg$

$s = 7,5905\ kJ/kgK$

4-2-5

Odredi spec. volumen, entalpiju, entropiju za

a) zasićenu vodu na temp 50°C

b) komprimiranu vodu na temp 50°C i pri 50MPa

c) vodu na temp. 50°C i pri. 50MPa

d) vodu na temp 500°C i pri. 50MPa

$50\ MPa = 500\ bar$

a) P-3-1

$v_t = 1,0121\ dm^3/kg$

$h_t = 209,3\ kJ/kg$

$s_t = 0,7038\ kJ/kgK$

5)

c) $t = 50°C$, $p = 50\,MPa = 500\,bar$ P-3-3

$$v = v_1 + \frac{v_2 - v_1}{t_2 - t_1}(t - t_1) = 0{,}0009987 + \frac{0{,}0009936 - 0{,}0009987}{60 - 40}(50 - 40) = 0{,}0009915\ m^3/kg$$

$$h = h_1 + \frac{h_2 - h_1}{t_2 - t_1}(t - t_1) = 211{,}23 + \frac{292{,}88 - 211{,}23}{20} \cdot 10 = 252{,}055\ kJ/kg$$

$$s = s_1 + \frac{s_2 - s_1}{t_2 - t_1}(t - t_1) = 0{,}553 + \frac{0{,}805 - 0{,}553}{20} \cdot 10 = 0{,}679\ kJ/kgK$$

d) $t = 500°C$, $p = 500\,bar$ P-3-3

$v = 0{,}003892\ m^3/kg$

$h = 2724{,}2\ kJ/kg$

$s = 5{,}173\ kJ/kgK$

4-2-6

Interpol. ili direktno, ucitanje odgov. tablice odredi spec. entalp., volumen i entrop. vode pri pritisku 2 bar, temp 72°C

$p = 2$ bar, $t = 72°C$ P-3-3

$$v = v_1 + \frac{v_2 - v_1}{t_2 - t_1}(t - t_1) = 0{,}0010228 + \frac{0{,}0010292 - 0{,}0010228}{80 - 70}(72 - 70)$$

$$v = 0{,}00102408\ m^3/kg$$

$$h = h_1 + \frac{h_2 - h_1}{t_2 - t_1}(t - t_1) = 293{,}0 + \frac{335{,}0 - 293{,}0}{80 - 70}(72 - 70)$$

$$h = 301{,}4\ kJ/kg$$

$$s = s_1 + \frac{s_2 - s_1}{t_2 - t_1}(t - t_1) = 0{,}9548 + \frac{1{,}0752 - 0{,}9548}{80 - 70}(72 - 70)$$

$$s = 0{,}97888\ kJ/kgK$$

4-2-7

Odredit' vlažnost pare (x), tj. sadržaj' pare u mješavini, spec. volumen i spec. entropiju vlažne pare ako je poznata njena spec. entalpija $h = 2{,}450\ MJ/kg$ i $t = 50°C$

P-3-1

$v_t = 1{,}0121\ dm^3/kg$ | $h_t = 209{,}3\ kJ/kg$ $s_t = 0{,}7038\ kJ/kgK$

$v_p = 12{,}04\ m^3/kg$ | $h_p = 2592\ kJ/kg$ $s_p = 8{,}0753\ kJ/kgK$

$p = 0{,}1233$ bar

$h = 2{,}450\ MJ/kg = 2450\ kJ/kg$

$v_1 = 0{,}0010121\ m^3/kg$

$h_x = (1 - x) \cdot h_t + x \cdot h_p$

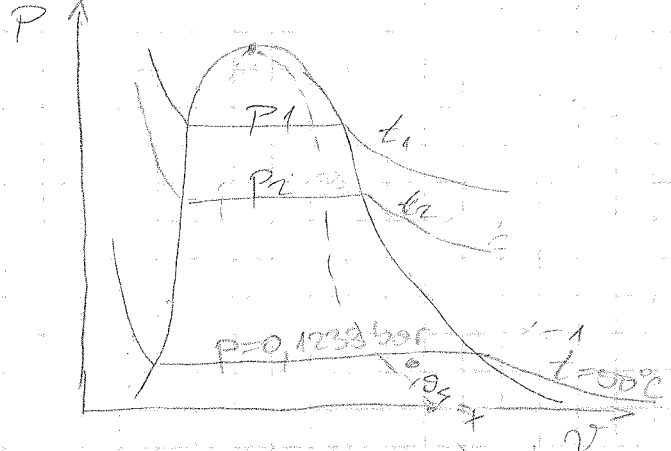
$2450 = (1 - x) \cdot 209{,}3 + x \cdot 2592$

$2450 = 209{,}3 - 209{,}3 \cdot x + 2592x$

$2450 - 209{,}3 = 2383{,}7x$

$2240{,}7 = 2383{,}7x$

$\frac{2240{,}7}{2383{,}7} = x \Rightarrow x = 0{,}94$



$v_x = (1-x)v_t + xv_p$

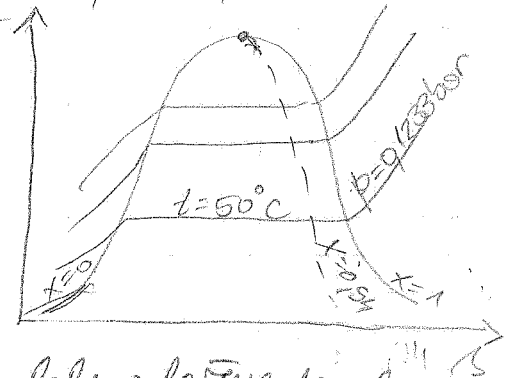
$v_x = (1-0{,}94)0{,}0010121 + 0{,}94 \cdot 12{,}04 = 0{,}000060726 + 11{,}3176$

$\underline{v_x = 11{,}3176\ m^3/kg}$

$s_x = (1-x)s_t + x s_p = (1-0{,}94)\,97038 + 0{,}94 \cdot 8{,}0758$

$s_x = 0{,}042228 + 7{,}591252$

$\underline{s_x = 7{,}63348\ kJ/kgK}$



4-2-8

Odrediti spec. volumen, spec. entrop. i entalp. vlažne pare ako je sadržaj pare $x = 95\%$ i temp. $95°C$

P-3-1

$t = 95°C \quad x = 0{,}95 \Rightarrow p = 0{,}8451\ bar$

$v_t = 1{,}0396\ dm^3/kg \quad h_L = 398\ kJ/kg \quad s_t = 1{,}2502\ kJ/kgK$

$v_p = 1{,}982\ m^3/kg \quad h_p = 2668\ kJ/kg \quad s_p = 7{,}4155\ kJ/kgK$

$v_t = 0{,}0010396\ m^3/kg$

$v_x = (1-0{,}95) \cdot 0{,}0010396 + 0{,}95 \cdot 1{,}982$

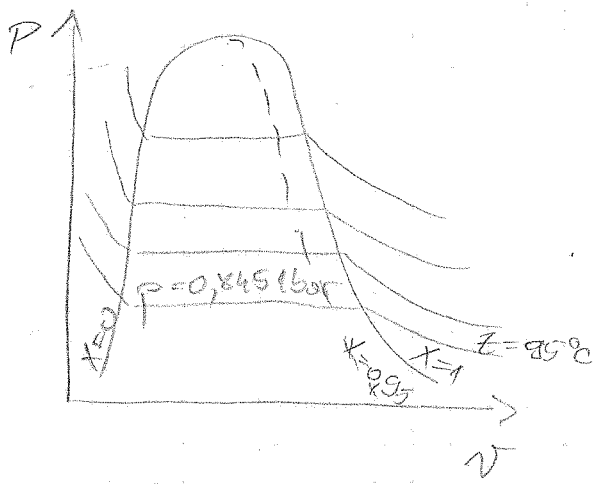
$v_x = 0{,}00005198 + 1{,}8829$

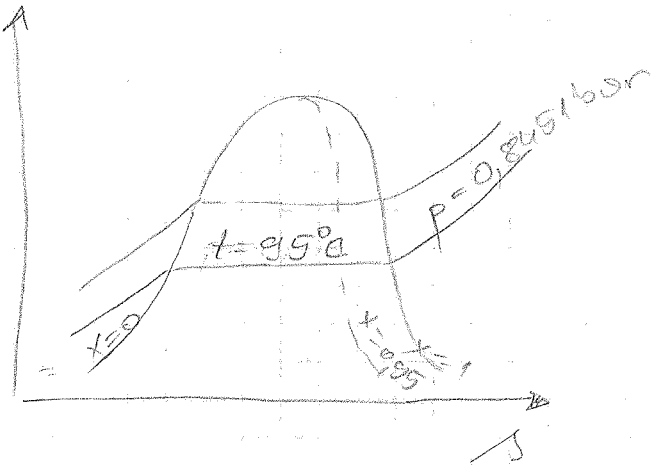
$\underline{v_x = 1{,}883\ m^3/kg}$

$h_x = 0{,}05 \cdot 398 + 0{,}95 \cdot 2{,}668$

$h_x = 19{,}9 + 2{,}5346 = \underline{22{,}4346\ kJ/kg}$

$s_x = 0{,}05 \cdot 1{,}2502 + 0{,}95 \cdot 7{,}4155 = 0{,}062501 + 7{,}0447 = \underline{7{,}107\ kJ/kgK}$





4-2=9

Opisati stanje vode, tj. da li je tečnost, mješavina ili para za uvjete

a) $p = 13\ MPa$, $t = 360°C$

b) $p = 6\ MPa$, $t = 279,6°C$

c) $p = 50\ MPa$, $t = 250°C$

d) $p = 20\ bar$, $t = 100°C$

e) $t = 240°C$, $x = 0,5$

f) $t = 260°C$, $v = 0,44\ m^3/kg$

a)

$p = 130\ bar$, $t = 360°C$

P-3-3

$p_1 = 100\ bar$

$p_2 = 150\ bar$

$t_{z1} = 311,03°C$

$t_{z2} = 342,12°C$

$$t_z = t_{z1} + \frac{t_{z2} - t_{z1}}{p_2 - p_1}(p - p_1)$$

$$t_z = 311,03 + \frac{342,12 - 311,03}{150 - 100}(130 - 100)$$

$t_z = 329,726°C$

$t > t_z \Rightarrow$ pregrijana para

$360 > 329,726$

$t < t_z \Rightarrow$ pothl. tečnost

$t = t_z \Rightarrow$ zasićena mješ.

$t > t_z \Rightarrow$ pregrijana para

?!?!

b) P-3-3

$p = 6\ MPa = 60\ bar$, $t = 275,6\ °C$

$p_1 = 50\ bar$ $\quad t_{z1} = 263,977\ °C$

$p_2 = 70\ bar$ $\quad t_{z2} = 285,86\ °C$

$$t_z = t_{z1} + \frac{t_{z2} - t_{z1}}{p_2 - p_1}(p - p_1)$$

$$t_z = 263,977 + \frac{285,86 - 263,977}{70 - 50}(60 - 50)$$

$t_z = 274,92\ °C$

$t > t_z \Rightarrow$ pregr. para

c) P-3-3

$p = 50\ MPa = 500\ bar$, $t = 250\ °C$

- podhlajena voda

d) P-3-3

$p = 20\ bar$, $t = 100\ °C$

- podhlajena tekočost

e) P-3-1

$t = 240\ °C$, $x = 0,5$

$h_t = 1037,5\ kJ/kg$

$h_p = 2803\ kJ/kg$

$h_t < h < h_p$

$1037,5 < 1920,25 < 2803$

$\Downarrow$

Zavičena mokrosta

$h_x = (1 - x) \cdot h_t + x \cdot h_p$

$h_x = (1 - 0,5) \cdot 1037,5 + 0,5 \cdot 2803$

$h_x = 518,75 + 1401,5 = 1920,25\ kJ/kg$

P-3-3

b) $t = 260°C$, $v = 0{,}44\ m^3/kg = 440\ dm^3/kg$

4-2-10

Posuda pod pístkom mala objem $0{,}2\ m^3$ a obsahuje $1{,}43\ kg$ vodnej pary. Ak je $p = 2\ MPa$, určte teplotu.

$V = 0{,}2\ m^3$

$m = 1{,}43\ kg$

$P = 2\ MPa = 20\ bar$

$$v = \frac{V}{m} = \frac{0{,}2}{1{,}43} = 0{,}13986\ m^3/kg$$

P-3-3

$$v = v_1 + \frac{v_2 - v_1}{t_2 - t_1}(t - t_1)$$

$$0{,}13986 = 0{,}1360 + \frac{0{,}1411 - 0{,}1360}{360 - 340}(t - 340)$$

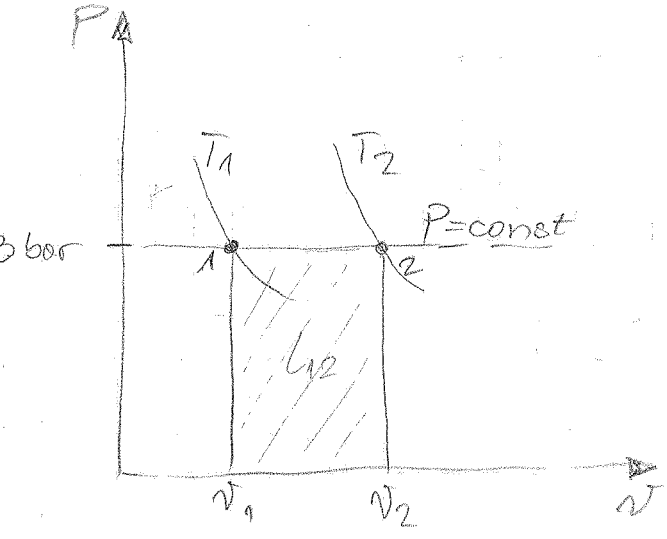
$$0{,}13986 - 0{,}1360 = 0{,}000255t - 0{,}0867$$

$$\frac{0{,}09056}{0{,}000255} = t$$

$$t = 355{,}137\ °C$$

4-2-11

U cilindru sa pokretnim klipom nalazi se 3,2 kg vode na temp 200°C i pritisku 300 kPa. Zagrijavanjem, pri const. pritisku, temp. vode se povećala na 430°C. Potrebno je izračunati proces u P-v dijagr., a zatim odrediti promjenu volumena, entalpije, unutr. energije za navedeni proces.



$m = 3{,}2\ kg$

$t_1 = 200°C = 473{,}15\ K = T_1$

$p = 300\ kPa = 3\ bar$

$t_2 = 430°C = 703{,}15\ K = T_2$

P-3-3

$u_{200°} = 2865{,}6\ kJ/kg = u_1$

$u_{430°} = 3337{,}6\ kJ/kg = u_2$

$q - l = \Delta u$

$q := u_2 - u_1 = 3337{,}6 - 2865{,}6 = 472\ kJ/kg$

$$u_{430°} = u_{420} + \frac{u_{440} - u_{420}}{t_{440} - t_{420}} (t_{430} - t_{420})$$

$$u_{430} = 3316{,}6 + \frac{3358{,}6 - 3316{,}6}{440 - 420} (430 - 420)$$

$$u_{430} = 3337{,}6$$

$v_1 = 0{,}7164\ m^3/kg$

$v_2 = v_{430} = 1{,}0783\ m^3/kg$

$$v_{430} = v_{420} + \frac{v_{440} - v_{420}}{t_{440} - t_{420}} (t_{430} - t_{420})$$

$$v_{430} = 1{,}0626 + \frac{1{,}094 - 1{,}0626}{440 - 420} (430 - 420)$$

$$v_{430} = 1{,}0783\ m^3/kg$$

$h = u + Pv$

$u_1 = h_1 - Pv_1$

$u_1 = 2865600 - 300000 \cdot 0,7164 = 2650,68 \ kJ/kg$

$u_2 = 3337600 - 300000 \cdot 1,0783 = 3014,11 \ kJ/kg$

$q - l = \Delta u$

$\Delta u = u_2 - u_1 = 363,43 \ kJ/kg$

$q - \Delta u = l$

$472 - 363,43 = l$

$l = 108,57 \ kJ/kg$

$\Delta H = m \cdot \Delta h = m(h_2 - h_1) = 3,2 \cdot (3337,6 - 2865,6)$

$\Delta H = 1510,4 \ kJ$

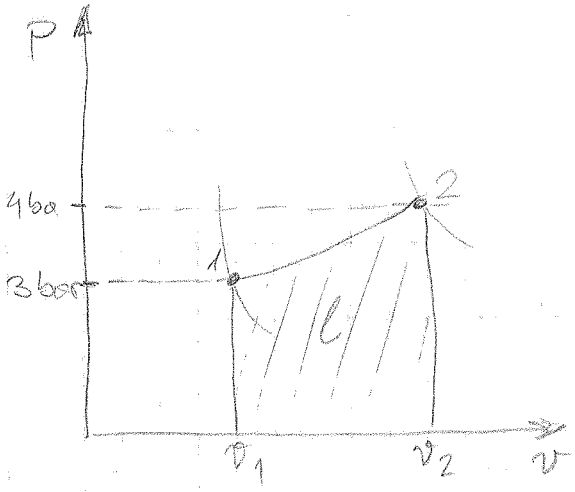
$\Delta V = m \cdot (v_2 - v_1) = 3,2 (1,0783 - 0,7164)$

$\Delta V = 1,15808 \ m^3$

$\Delta U = \Delta u \cdot m = 3,2 \cdot 363,43 = 1162,976 \ kJ$

4-2-12

U zatvorenoj posudi se nalazi 1,5 kg vode i 1,3 kg vodene pare pri pritisku 3 bar. Zagrijavanjem se pritisak u posudi poveća za 400 kPa. Potrebno je tematski prikazati proces u P-v dijagramu, odrediti promjenu volumena, promjenu entalpije i unutr. energije za navedeni proces.



P-3-2

$m_v = 1{,}5\ kg$

$m_p = 1{,}3\ kg$

$p_1 = 3\ bar = 300\ kPa$

$p_2 = 400\ kPa = 4\ bar$

$v_{t1} = 1{,}0733\ dm^3/kg$ $\quad u_{t1} = 461{,}4\ kJ/kg$

$v_{p1} = 0{,}6057\ m^3/kg$ $\quad u_{p1} = 2725\ kJ/kg$

$v_{t2} = 1{,}0836\ dm^3/kg$ $\quad u_{t2} = 604{,}7\ kJ/kg$

$v_{p2} = 0{,}4624\ m^3/kg$ $\quad u_{p2} = 2738\ kJ/kg$

masa vlažne pare $m = m_v + m_p = 1{,}5 + 1{,}3 = 2{,}8\ kg$

sadržaj pare $x = \frac{m_p}{m} = \frac{1{,}3}{2{,}8} = 0{,}46$

$v_1 = (1-x)\,v_{t1} + x \cdot v_{p1} = (1-0{,}46)\cdot 0{,}0010733 + 0{,}46 \cdot 0{,}6057$

$v_1 = 0{,}000579582 + 0{,}278622$

$v_1 = 0{,}279201582\ m^3/kg$

$v_2 = (1-x)v_{f2} + x \cdot v_{p2} = 0,54 \cdot 0,0010836 + 0,46 \cdot 0,4624$

$v_2 = 0,0005854344 + 0,212704$

$v_2 = 0,2132894344 \ m^3/kg$

$h_1 = 0,54 \cdot 561,4 + 0,46 \cdot 2725 = 303,156 + 1253,5$

$h_1 = 1556,656 \ kJ/kg$

$h_2 = 0,54 \cdot 604,7 + 0,46 \cdot 2738 = 326,538 + 1259,48$

$h_2 = 1586,018 \ kJ/kg$

$u_1 = h_1 + p_1 v_1 = 1556656 + 300000 \cdot 0,27920$

$u_1 = 1640,416 \ kJ/kg$

$u_2 = h_2 + p_2 v_2 = 1586018 + 400000 \cdot 0,21329$

$u_2 = 1671,334 \ kJ/kg$

$\Delta u = u_2 - u_1 = 1671,334 - 1640,416 = 30,918 \ kJ/kg$

$\Delta U = m \cdot \Delta u = 2,8 \cdot 30,918 = \boxed{86,57 \ kJ}$

$\Delta v = v_2 - v_1 = 0,21329 - 0,27920 = -0,06591 \ m^3/kg$

$\Delta V = m \cdot \Delta v = 2,8 \cdot (-0,06591) = \boxed{-0,1845 \ m^3}$

$\Delta h = h_2 - h_1 = 1586,018 - 1556,656 = 29,362 \ kJ/kg$

$\Delta H = m \cdot \Delta h = 2,8 \cdot 29,362 = \boxed{82,2136 \ kJ}$

4-2-13

Odredi masu vode koja se nalazi u posudi volumena $3\,m^3$ pod sljedećim uvjetima:

a) $t = 600\,^\circ C$, $p = 2\,MPa$

b) Zasićena para na temp. $160\,^\circ C$

c) Zasićena voda na temp. $160\,^\circ C$

d) $p = 500\,kPa$, $x = 0{,}95$

a)

$t = 600\,^\circ C$, $p = 2\,MPa = 20\,bar$

P-3-3

$v = 0{,}1995\ m^3/kg$

$u = 3689{,}5\ kJ/kg$

$$v = \frac{V}{m} \Rightarrow m = \frac{V}{v} = \frac{3\,m^3}{0{,}1995\ \frac{m^3}{kg}} = 15{,}037\,kg$$

b) $t = 160\,^\circ C$

P-3-1

$v_p = 0{,}3068\ m^3/kg$

$$m = \frac{V}{v} = \frac{3}{0{,}3068} = 9{,}778\,kg$$

c) $t = 160\,^\circ C$

P-3-1

$v_t = 1{,}1021\ dm^3/kg = 0{,}0011021\ m^3/kg$

$$m = \frac{V}{v} = \frac{3}{0{,}0011021} = 2722{,}076\,kg$$

d) $p = 500\,kPa = 5\,bar$, $x = 0{,}55$

P-3-2

$v_t = 1{,}0927\ dm^3/kg = 0{,}0010927\ m^3/kg$

$v_p = 0{,}3747\ m^3/kg$

$v = (1-x)v_t + x \cdot v_p = (1-0{,}55) \cdot 0{,}0010927 + 0{,}55 \cdot 0{,}3747$

$v = 0{,}000491715 + 0{,}206085 = 0{,}206576715\ m^3/kg$

$$m = \frac{V}{v} = \frac{3}{0{,}20658} = 14{,}522\ kg$$

4-2-14

U zatvorenoj posudi volumena $4\ m^3$ nalazi se vodena para pri pritisku 0,3 MPa, temp. 500°C. Odrediti masu pare.

$V = 4\ m^3$

$p = 0{,}3\ MPa = 3\ bar$

$t = 500\ °C$

P-3-3

$v = 1{,}187\ m^3/kg$

$$m = \frac{V}{v} = \frac{4}{1{,}187} = 3{,}3698\ kg$$

4-2-15

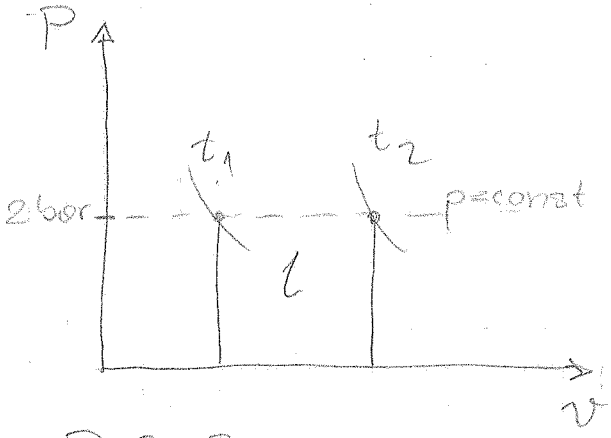
Izračunati promjenu spec. unutr. energije vodene pare u izobarnom procesu na tlaku 200 kPa kada se temperatura promijeni sa 800 °C na 1000 °C.

$p = 200\ kPa = 2\ bar$

$t_1 = 800\,°C$

$t_2 = 1000\,°C$

$\Delta u = u_2 - u_1$



P-3-3

$v_1 = 2{,}475\ m^3/kg$ $\quad v_2 = ?$

$h_1 = 4158\ kJ/kg$ $\quad h_2 = ?$

$s_1 = 9{,}2453$

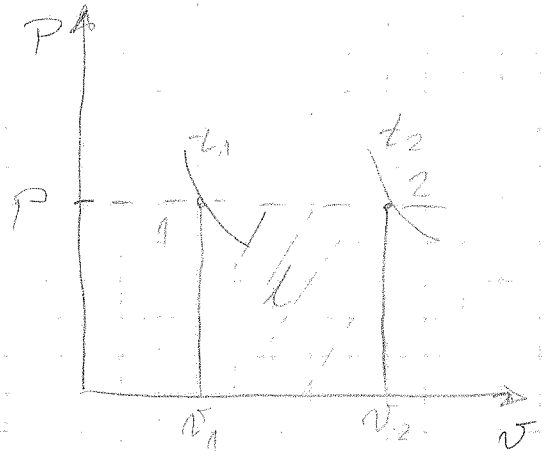
4-2-16

Suhozasićena vodena para temp. 200°C zagrijava se u izobarnom procesu do temp. 500°C. Odredi spec. rad promj. volumena ili slob. rad koji pregr. para daje okolici tijekom navedenog procesa

$t_1 = 200°C$

$t_2 = 500°C$

$x = 1$



P-3-1

$v_{p1} = 0,1272\ m^3/kg$

$u_{p1} = 2793\ kJ/kg$ $\Rightarrow p = 15,551\ bar = 1555100\ Pa$

P-3-3

Interpolacija za $p_1 = 15\ bar$ i $p_2 = 20\ bar$, za $t = 500°C$

$$v_{p2} = v_x + \frac{v_y - v_x}{p_2 - p_1}(p - p_1) = 0,2351 + \frac{0,1756 - 0,2351}{20 - 15}(15,551 - 15)$$

$v_{p2} = 0,2285\ m^3/kg$

$$u_{p2} = u_x + \frac{u_y - u_x}{p_2 - p_1}(p - p_1)$$

$$u_{p2} = 3472{,}9 + \frac{3467{,}4 - 3472{,}9}{5} \cdot 0{,}551$$

$$u_{p2} = 3472{,}29 \ kJ/kg$$

$$l = \int_1^2 p\,dv = p\cdot(v_2 - v_1)$$

$$l = 1555100 \cdot (0{,}2285 - 0{,}1272)$$

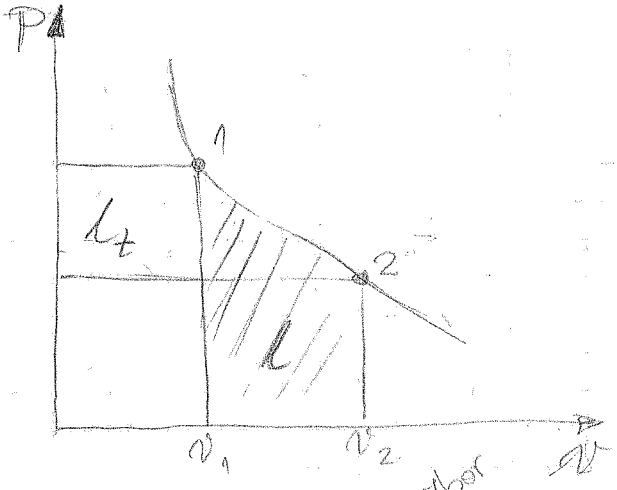
$$l = 154531{,}63 J = 157{,}93 \ kJ$$

4-2-17

U cilindru s pokretnim klipom nalazi se 10 kg zasićene vode na temp 180°C. Odredi slobodni rad sistema u izotermnom procesu bez trenja do je krajnje stanje zasićeno vodeno para.

$m_v = 10 \ kg$

$t = 180°C$



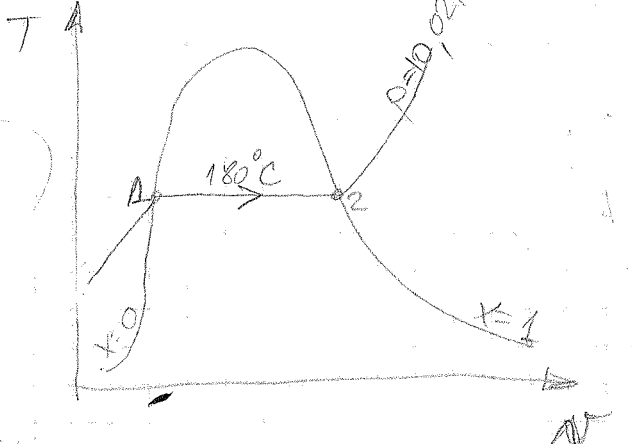
P-3-1

$v_t = 1{,}1275 \ dm^3/kg$

$v_p = 0{,}1939 \ m^3/kg$

$x_1 = 0$

$x_2 = 1$



$v_1 = (1 - x_1)v_t + x_1 v_p$

$v_1 = 0{,}0011275 \ m^3/kg$

$v_2 = (1 - x_2)v_t + x \cdot v_p$

$v_2 = 0 \cdot v_t + 0{,}1939 = 0{,}1939 \ m^3/kg$

$p_1 = 10,024\ bar = 1002400\ Pa$ = const

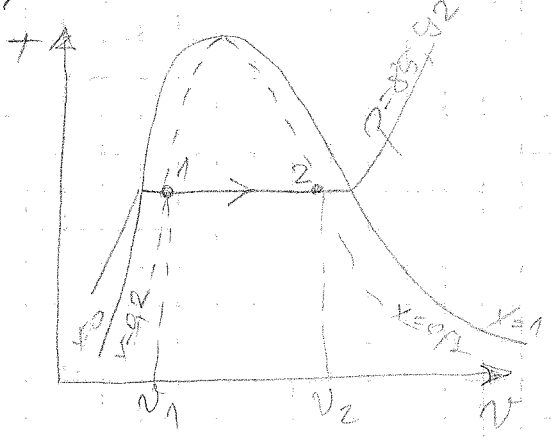
$$l = \int_1^2 p\,dv = p(v_2 - v_1) = 1002400 \cdot (0,1939 - 0,001275)$$

$$l = 193292,98\ J/kg = 193,29\ kJ/kg$$

$$L = m\,l = 1932,93\ kJ$$

4-2-18

Odredi rad koji se dobije ekspanzijom 9 kg vlažne pare u zatvorenom sistemu bez trenja i izotermno ako je početno stanje vlažne pare definisano sa $t = 300°C$ i $x = 0,2$ a krajnje sa $x = 0,9$.



$m = 9\ kg$

$t_1 = 300°C$

$x_1 = 0,2$

$x_2 = 0,9$

$v_t = 1,4036\ dm^3/kg$

$v_p = 0,02164\ m^3/kg$

$p = 85,92\ bar$

$p = 8592000\ Pa$

$$v_1 = (1 - x_1)\,v_t + x_1 v_p = 0,8 \cdot 0,0014036 + 0,2 \cdot 0,02164 = 0,0011228 + 0,004328$$

$$v_1 = 0,005451\ m^3/kg$$

$$v_2 = (1 - x_2)\,v_t + x_2 \cdot v_p = 0,1 \cdot 0,0014036 + 0,9 \cdot 0,02164 = 0,0001403 + 0,019476$$

$$v_2 = 0,019617\ m^3/kg$$

$$l = \int_1^2 P\,dv = P(v_2 - v_1)$$

$$l' = 8592000(0{,}01961 - 0{,}00545) = 121662{,}72\ J/kg = 121{,}66\ kJ/kg$$

$$L = m\,l = 9 \cdot 121{,}66\ kJ/kg$$

$$L = 1094{,}964\ kJ$$

4-2-19

Stanje vlažne vodene pare je definirano pritiskom zasićenja 760 mmHg i stepenom vlažnosti $x = 0{,}7$, odredi:

a) spec. volumen vlažne pare

b) promjenu entropije za proces potpune kondenzacije

c) promjenu entalpije za proces od zasić. tečnosti do zasić. pare

$p_2 = 760\ mmHg = 101{,}08\ kPa$

$x = 0{,}7$

$$1\ mmHg = \frac{1}{1{,}501}\ kPa = 0{,}133\ kPa$$

4-2-20

Stanje vlažne pare u kondenzatoru parne turbine je definirano pritiskom 0,1 bar i stepenom vlažnosti $x=0,9$. Potrebno je odrediti:

a) spec. volumen vlažne pare
b) promjenu entropije za proces nastanka potpune kondenzacije
c) promjenu entalpije za proces od zasić. tečnosti do zasić. pare
d) skematski prikazati stanje pare i procese pod b) i c) u P-v i T-s dijagramu

a)

$p = 0,1 \text{ bar} = 10000 \text{ Pa} = 10 \text{ kPa}$

$x = 0,9$

P-3-2

$v_t = 1,0001 \text{ dm}^3/\text{kg}$ $\quad s_t = 0,1054 \text{ kJ/kgK}$

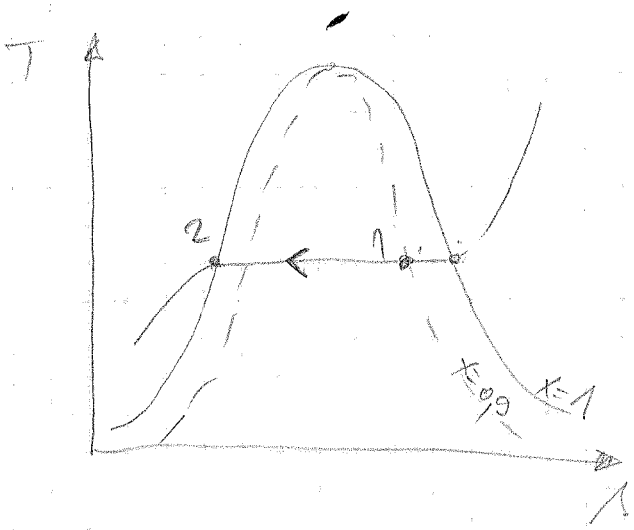
$v_p = 129,9 \text{ m}^3/\text{kg}$ $\quad s_p = 8,975 \text{ kJ/kgK}$

$v_x = (1-x)v_t + x \cdot v_p = 0,1 \cdot 0,0010001 + 0,9 \cdot 129,9$

$v_x = 0,00010001 + 116,91$

$v_x = 116,9101 \text{ m}^3/\text{kg}$

b)



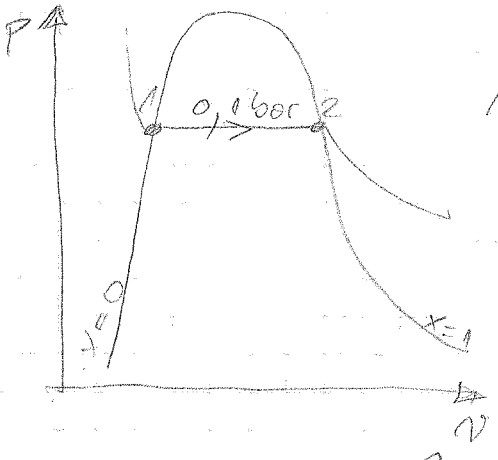
$s_x = (1-x)s_l + x \cdot s_p = 0{,}1 \cdot 0{,}1054 + 0{,}9 \cdot 8{,}975$

$s_x = 0{,}01054 + 8{,}0775$

$s_x = 8{,}08804 \ kJ/kgK$

$\Delta s = s_l - s_x = 0{,}1054 - 8{,}08804 = -7{,}98264 \ kJ/kgK$

c)



$u_l = 29{,}32 \ kJ/kg$

$u_p = 2513 \ kJ/kg$

$x_1 = 0$

$x_2 = 1$

$u_1 = (1-x_1)v_l + x_1 v_p = 29{,}32 \ kJ/kg = v_l$

$u_2 = (1-x_2)v_l + x_2 v_p = 2513 \ kJ/kg = v_p$

$\Delta u = u_2 - u_1 = 2513 - 29{,}32 = 2483{,}68 \ kJ/kg$