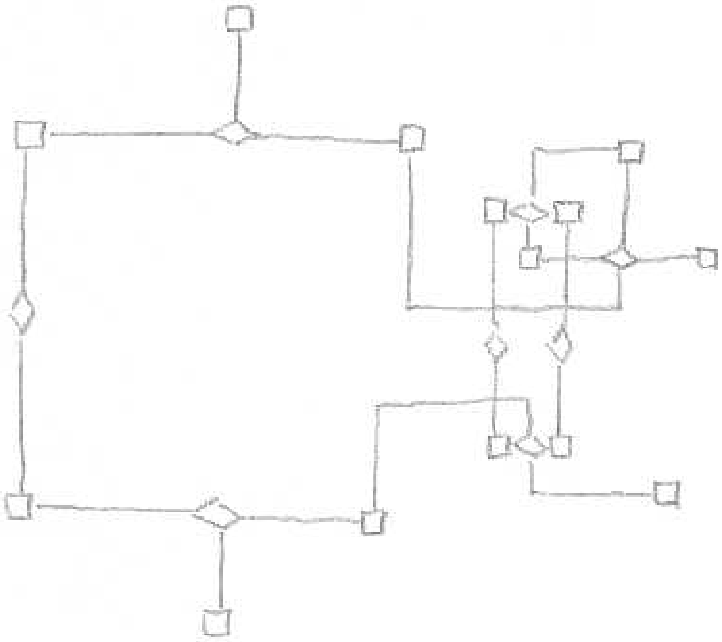
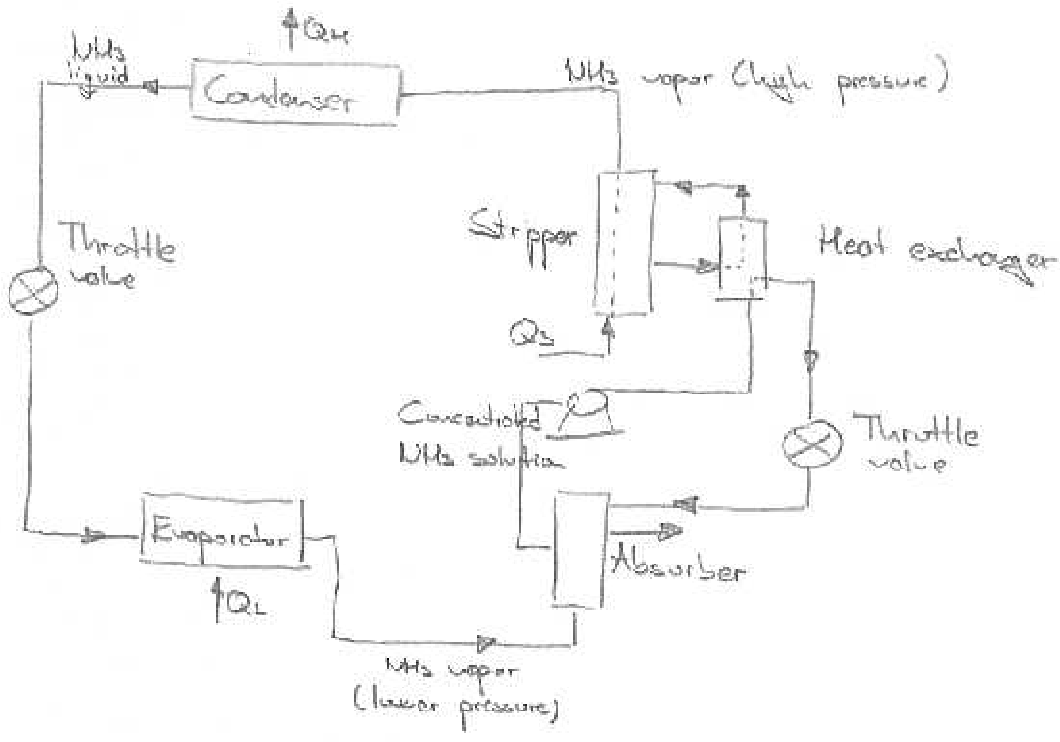
1

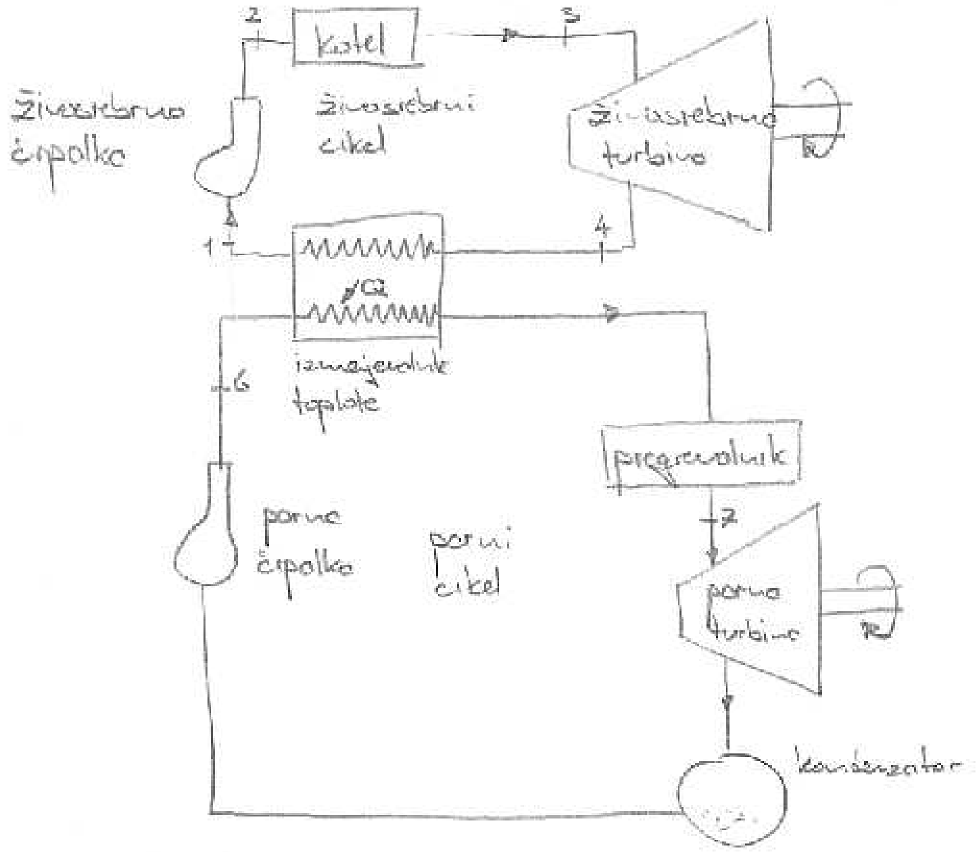
Absorbtion refrigoration system

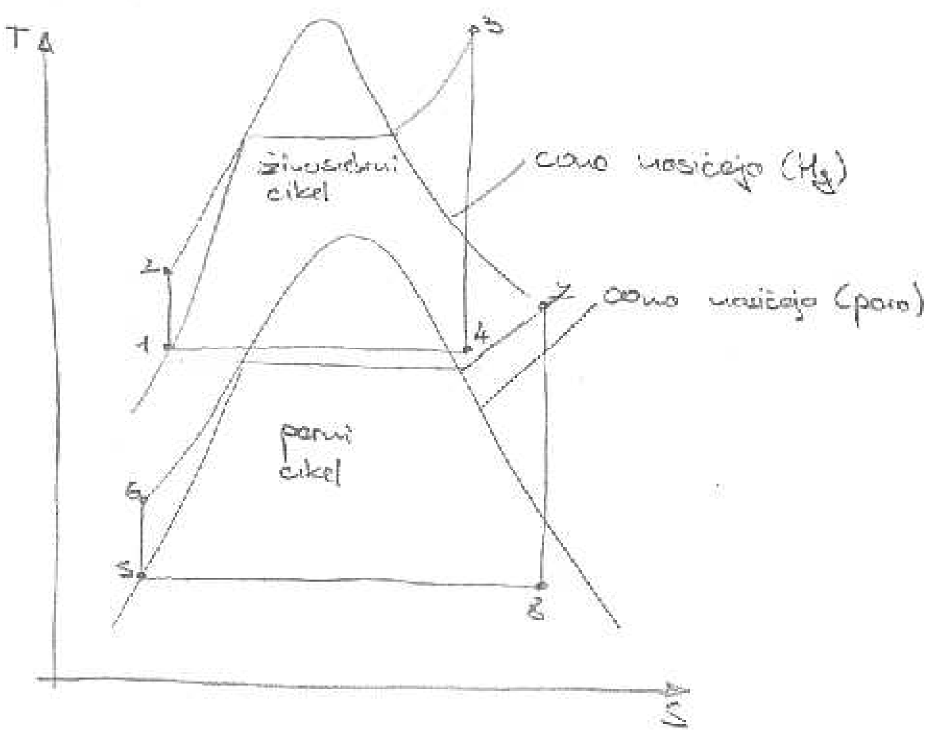




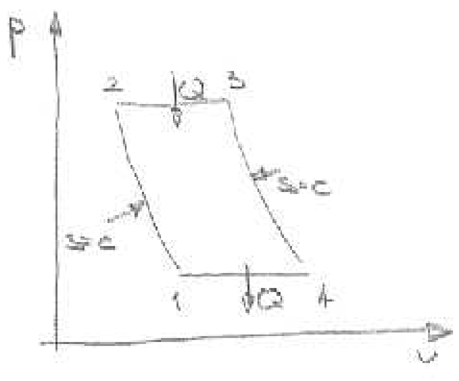
2

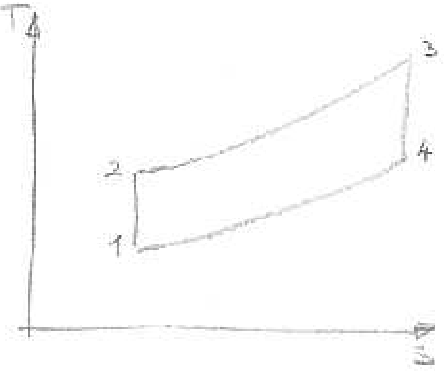
Binarni cikel – živo srebro – voda



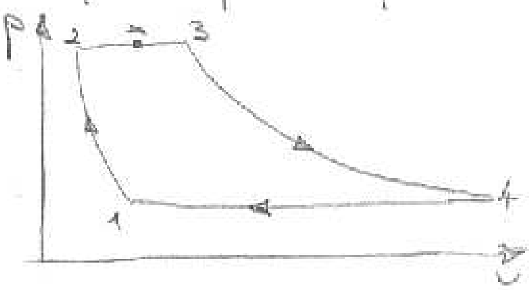


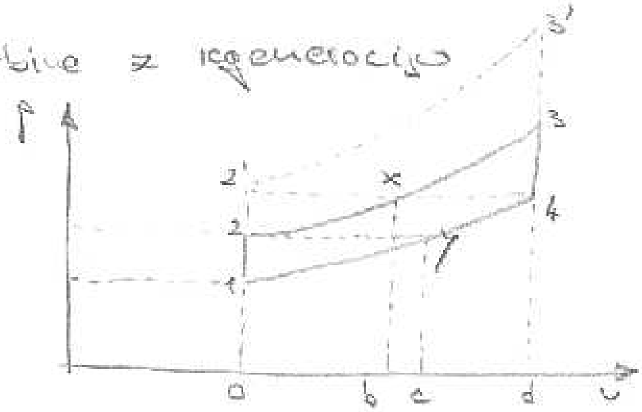
Braytonov proces je preprosta plinska turbina





Preprost proces plinske turbine z regeneracijo



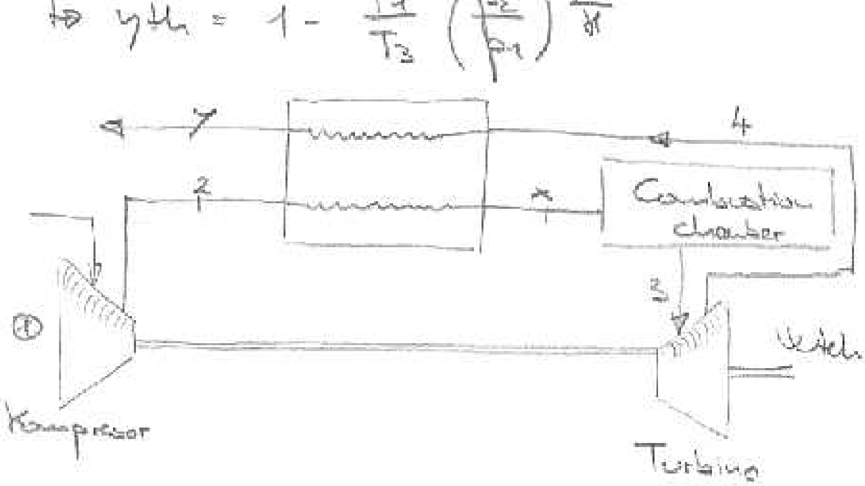


Izkoristek pri konstantni specifični toploti

za idealni regenerator $T_4 = T_x$ ($q_H = w_t$)

$$\Rightarrow \eta_{th} = 1 - \frac{c_p \, (T_2 - T_1)}{c_p \, (T_3 - T_4)}$$

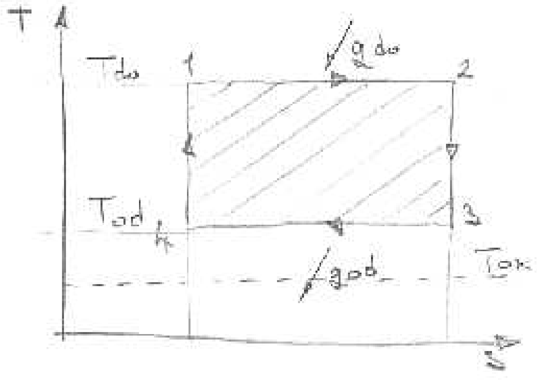
$$\Rightarrow \eta_{th} = 1 - \frac{T_1}{T_3} \left(\frac{p_2}{p_1} \right)^{\frac{\kappa - 1}{\kappa}}$$



1 gl. zakon termodinamike pravi, da se energije ne da niti uničiti, niti le ta ne more nastati iz sistema. Energije lahko le prehajajo iz ene oblike v drugo.

2 gl zakon termodinamike popisuje smer v kateri potekajo termodinamski procesi in omejuje pretvorljivost energij

- Carnotov proces



$$(q_{do})_{pov} = (q_{12})_{pov} = T_{do}(s_2 - s_1)$$

$$(q_{od})_{pov} = (q_{34})_{pov} = T_{od}(s_4 - s_3)$$

$$= -T_{od}(s_3 - s_4)$$

$$= -T_{od}(s_2 - s_1)$$

ker $w = q_{do} - |q_{od}| = T_{do}(s_2 - s_1) - T_{od}(s_2 - s_1)$

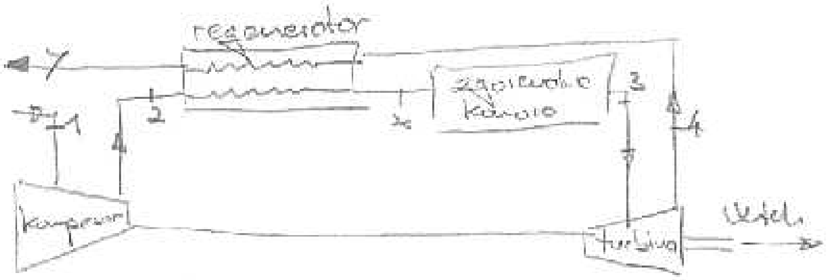
$$= (T_{do} - T_{od})(s_2 - s_1)$$

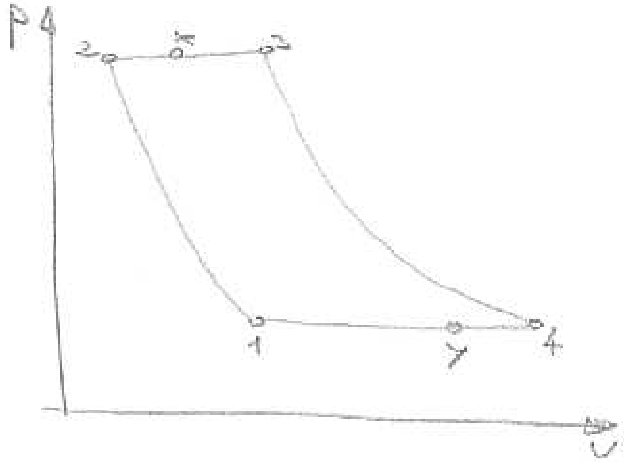
ker $\eta_{thc} = \frac{w_{pov}}{(q_{do})_{pov}} = \frac{(T_{do} - T_{od})(s_2 - s_1)}{T_{do}(s_2 - s_1)}$

$$\eta_{thc} = 1 - \frac{T_{od}}{T_{do}}$$

Nekemu krožnemu procesu je nemogoče dovedeno toploto v celoti spremeniti v delo.

Cikel plinske turbine z regeneratorjem





$c_p \approx konst$

$$\eta_{th} = \frac{c_p(T_3-T_4) - c_p(T_2-T_1)}{c_p(T_3-T_x)}$$

$T_4 = T_x \quad q_h = w_t$

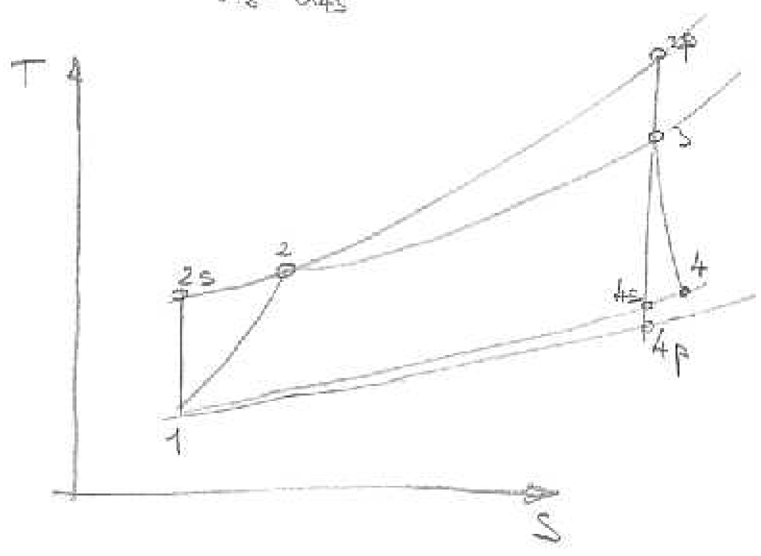
$$\eta_{th} = 1 - \frac{c_p(T_2-T_1)}{c_p(T_3-T_4)}$$

$$\Rightarrow \eta_{th} = 1 - \frac{T_1}{T_3}\left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}}$$

- Izgube:

$$\eta_{kompresija} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$\eta_{turbine} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$



Clapeyron - Clausiusova enačba:

$$\left(\frac{dP}{dT}\right)_{sat} = \frac{P h_{fg}}{R T^2}$$

h_{fg} .. uparjalna toplota

$$\left(\frac{dP}{P}\right)_{sat} = \frac{h_{fg}}{R}\left(\frac{dT}{T^2}\right)_{sat}$$

$$\ln\left(\frac{P_2}{P_1}\right)_{sat} \cong \frac{h_{fg}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)_{sat}$$

$v_g \gg v_f$

$v_{fg} \cong v_g$

$v_g = \frac{RT}{P}$

Clapeyronova enačba

$\left(\frac{dp}{dT}\right)_v = \left(\frac{ds}{dv}\right)_T$ → prepisana 3. Maxwellova enačba

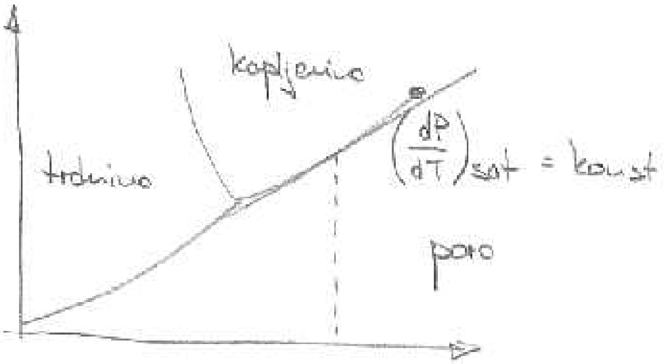
$s_g - s_f = \left(\frac{dp}{dT}\right)_{sat} (v_g - v_f)$

$\left(\frac{dp}{dT}\right)_{sat} = \frac{s_{fg}}{v_{fg}}$

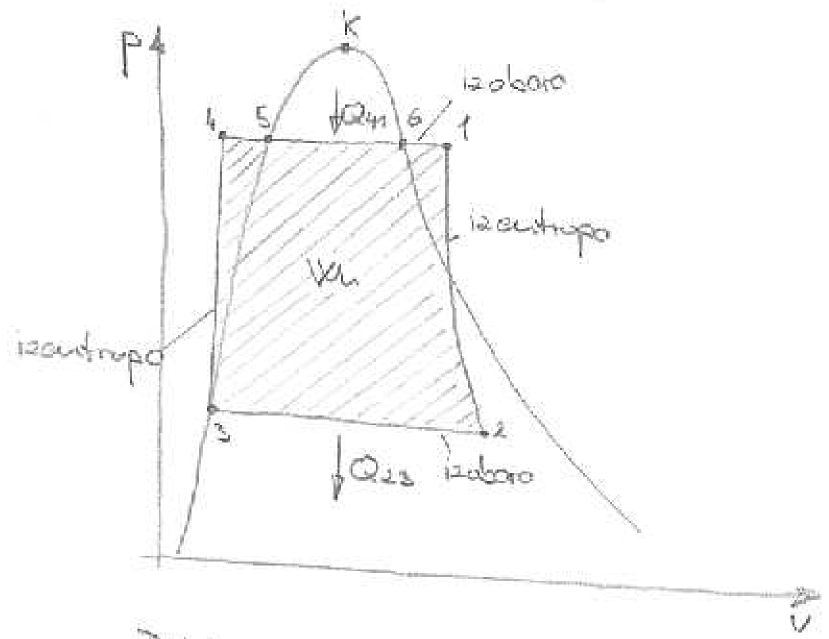
$dh = Tds + vdp$ → $\int_f^g dh = \int_f^g Tds$ → $h_{fg} = Ts_{fg}$

$$\left(\frac{dp}{dT}\right)_{sat} = \frac{h_{fg}}{Tv_{fg}}$$

- Uparjalna toplota $h_{fg} = r$
- zavisi od snovi



Clausius - Rankinov proces



- krožni parni proces
- proces sestavljata po dve izentropi in dve izobari
- tu gre za spremembo agregatnega stanja iz kapljevine v paro
- zaprt proces

Potek:

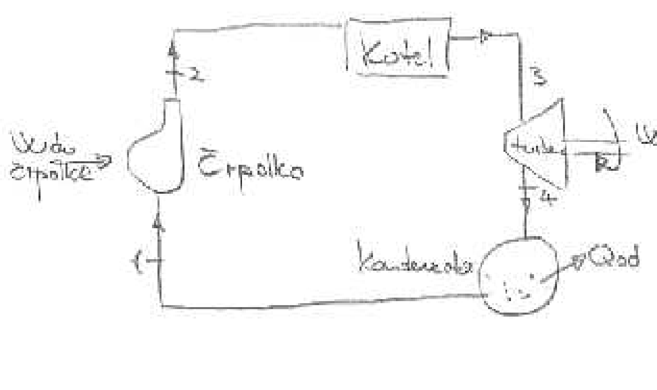
1 → 2 ekspanzija ali izentropno širjenje

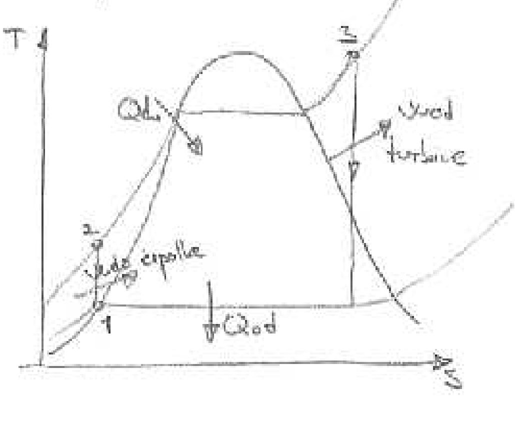
2 → 3 izobarno odvajanje toplote pri likvidni kondenzaciji pare

3 → 4 izentropno naraščanje tlaka tekoče vode

4 → 5 → 6 → 1 izobarno dovajanje toplote in nastajanje suhe nasičene pare oziroma pregrete pare

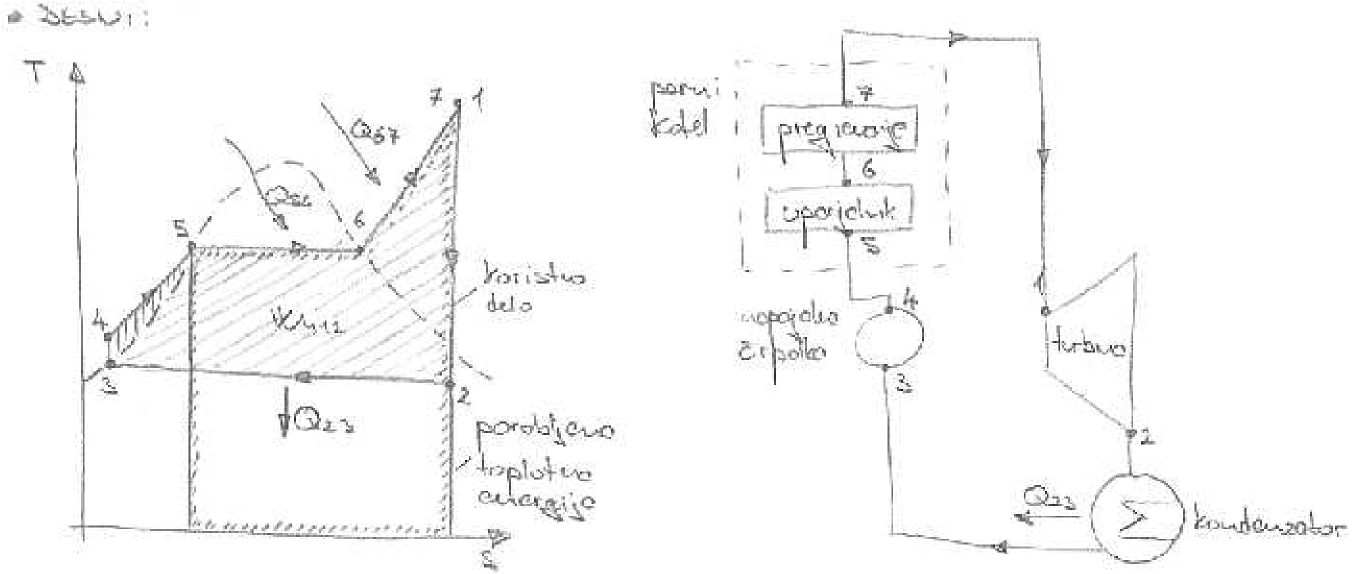
- Zgornja slika prikazuje proces v povezavi z diagramom p,v za vodno paro. Lahko rišemo tudi v T,s diagram.
- Ločimo levi in desni Clausius - Rankinov proces
- Zapišemo lahko še preprost Rankinov cikel





Desni in levi Clausius - Rankinov proces

• DESNI:



• LEVI:

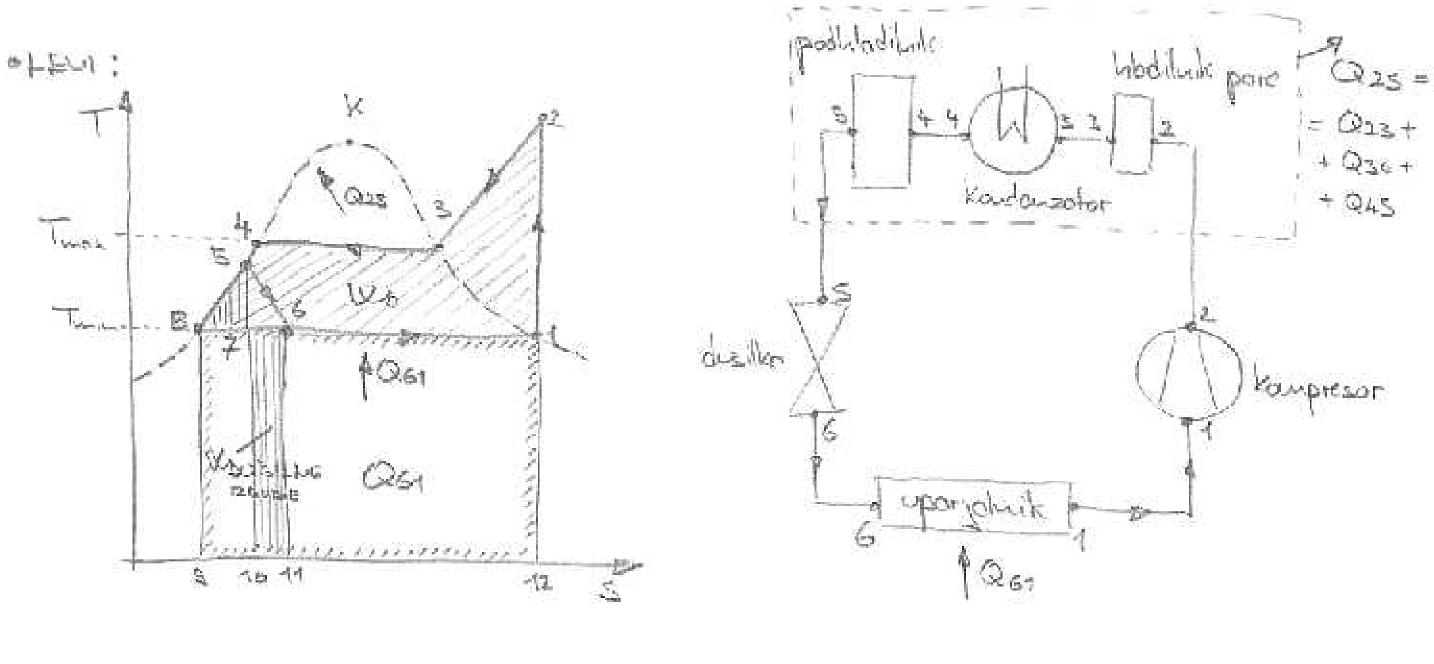
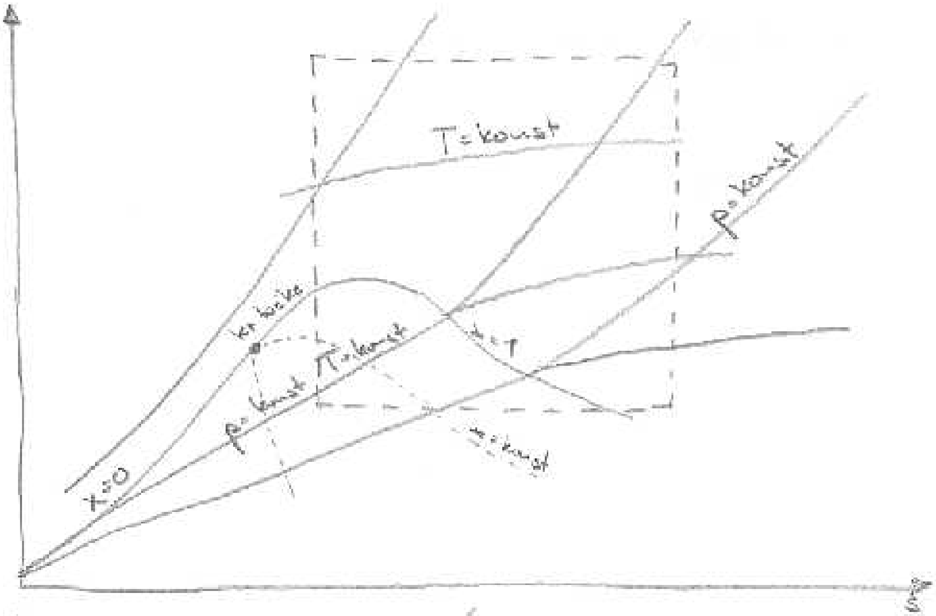
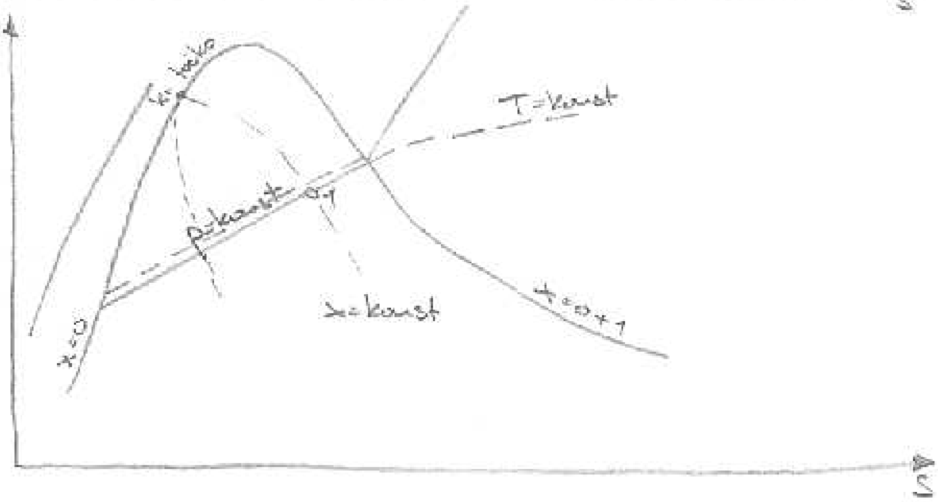
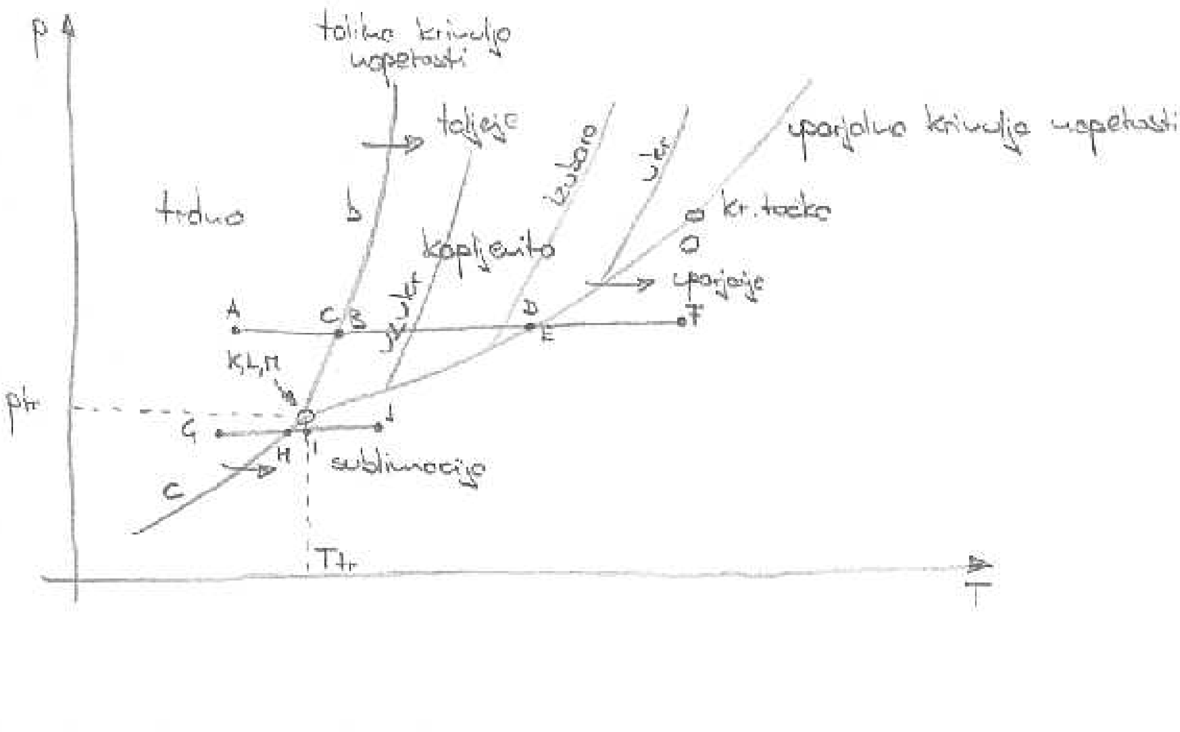


Diagram stanja

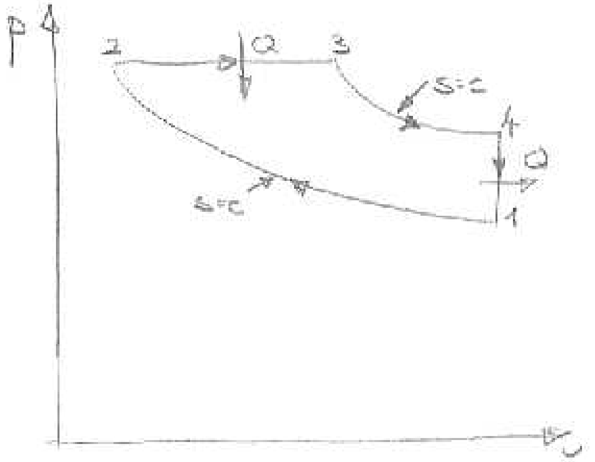


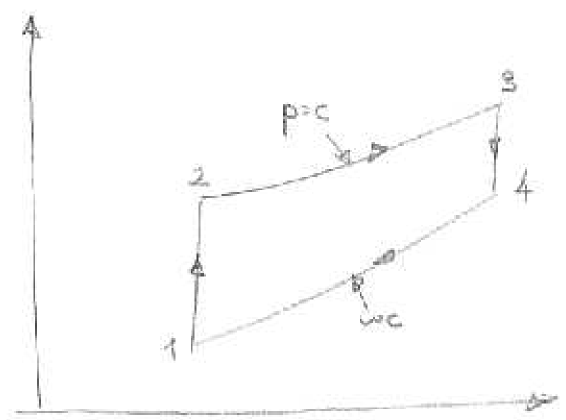




11

Dizel proces





- Definicija izkoristka porabe idealnega plina, pri konstantni specifični toploti.

$$\eta = \frac{W}{Q_{dov}} = 1 - \frac{Q_{odv}}{Q_{dov}} = 1 - \frac{m c_v (T_4 - T_1)}{m c_p (T_3 - T_2)} = 1 - \frac{T_1 (T_4/T_1 - 1)}{\kappa T_2 (T_3/T_2 - 1)}$$

$\kappa = \frac{c_p}{c_v}$; $r_v = \frac{v}{v_2}$ ... izentropsko kompresijsko razmerje

$$\eta = 1 - \frac{T_4/T_1 - 1}{\kappa (T_3/T_2 - 1) r_v^{\kappa - 1}}$$

- Termični izkoristek

$$\eta = 1 - \frac{c_p (T_4 - T_1)}{c_p (T_3 - T_2)} = 1 - \frac{T_1 (T_4/T_1 - 1)}{T_2 (T_3/T_2 - 1)}$$

$p_3/p_4 = p_2/p_1$

$$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{\kappa}{\kappa-1}} = \frac{p_3}{p_4} = \left(\frac{T_3}{T_4}\right)^{\frac{\kappa}{\kappa-1}}$$

$$\eta = 1 - \left(\frac{p_2}{p_1}\right)^{\frac{1-\kappa}{\kappa}}$$

- Delo

$W_{teh} = m c_p (T_3 - T_4) - m c_p (T_2 - T_1)$

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

$W_{teh} = m c_p (T_3 - T_3 T_1/T_2 - T_2 + T_1)$

Enačbe:

- Eksergija hlad toplote, ki jo je treba dov. v hladilnico

$$\dot{E}_R = \left(1 - \frac{T_{ok}}{T_R}\right) \dot{Q}_R$$

- Anergija, ki jo je treba iz hladilnice odvesti

$$\dot{B}_R = \frac{T_{ok}}{T_R} Q_R > \dot{Q}_R$$

- Potrebna moč pri povračljivem procesu

$$|P_{pov}| = |\dot{E}_R| = \left(\frac{T_{ok}}{T_R} - 1\right) \dot{Q}_R$$

- Pot. moč pri nepov. proc.

$$|P| = |\dot{E}_R| + \dot{E}_{izg}$$

- V okolico odvedena toplota pri nepov. proc

$$|\dot{Q}_{ok}| = \dot{B}_R + \dot{E}_{izg} = (\dot{Q}_{ok})_{pov} + \dot{E}_{izg}$$

- Eksergijski izkoristek

$$\zeta_R = \frac{|\dot{E}_R|}{|P|} = \frac{|\dot{E}_R|}{|\dot{E}_R| + \dot{E}_{izg}}$$

- Hladilno število

$$\varepsilon_R = \frac{\dot{Q}_R}{|P|}$$

- Eksergija je energija, ki se lahko pri dani okolici pretvori v vsako drugo obliko energije
- Anergija je energija, ki se ne da pretvorit v eksergijo

Vsaka energija je sestavljena iz eksergije in anergije

ENERGIJA = EKSERGIJA + ANERGIJA

Glede na 2. zakon termodinamike velja tudi

I Pri vseh nepovračljivih procesih se eksergija spreminja v anergijo

II Samo pri povračljivih procesih ostaja energija konstantna

III Nemogoče je anergijo pretvoriti v eksergijo

Izguba eksergije: Tisti del eksergije, ki se pri nepovračljivem procesu pretvori v anergijo.

- Eksergija toplote

$$E_{Q12} = \int_1^2 \left(1 - \frac{T_{ok}}{T}\right) \delta Q$$

če $T = konst$

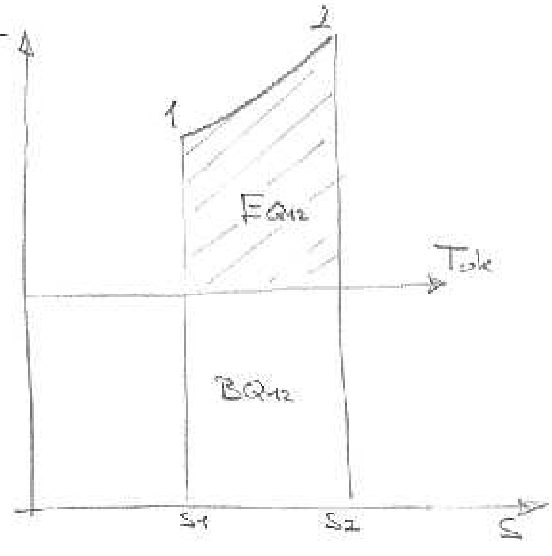
$$E_{Q12} = \frac{T - T_{ok}}{T} Q_{12} \rightarrow \mu_c Q_{12}; \quad \mu_c = \frac{T - T_{ok}}{T}$$ ... karnotski faktor

- Anergija toplote

$$B_{Q12} = T_{ok} \int_1^2 \frac{\delta Q}{T}$$

če $T = konst$

$$B_{Q12} = \frac{T_{ok}}{T} Q_{12}$$



- Eksergija entalpije

$e = h - h_{ok} (s - s_{ok})$

$b = h_{ok} + T_{ok} (s - s_{ok})$

Na splošno ocenjujemo procese z eksergijskim izkoristkom. To je razmerje med energijo, ki jo iz procesa dobimo (W_2) in energijo, ki jo v proces vložimo (W_1)

$$\eta = \frac{W_2}{W_1}$$

oziroma

$$\xi = \frac{E_2}{E_1}$$

E_2... dobljeno
E_1... vloženo

- $\xi_{pov} = 1$ pri povračljivih procesih
- $\xi_{nep} < 1$ pri nepovračljivih procesih

Za analize procesov poznamo:

- SANKEYEV DIAGRAM (diagram pretoka energij)

$$\sum_i W_{i,do} = \sum |W_{i,od}|$$

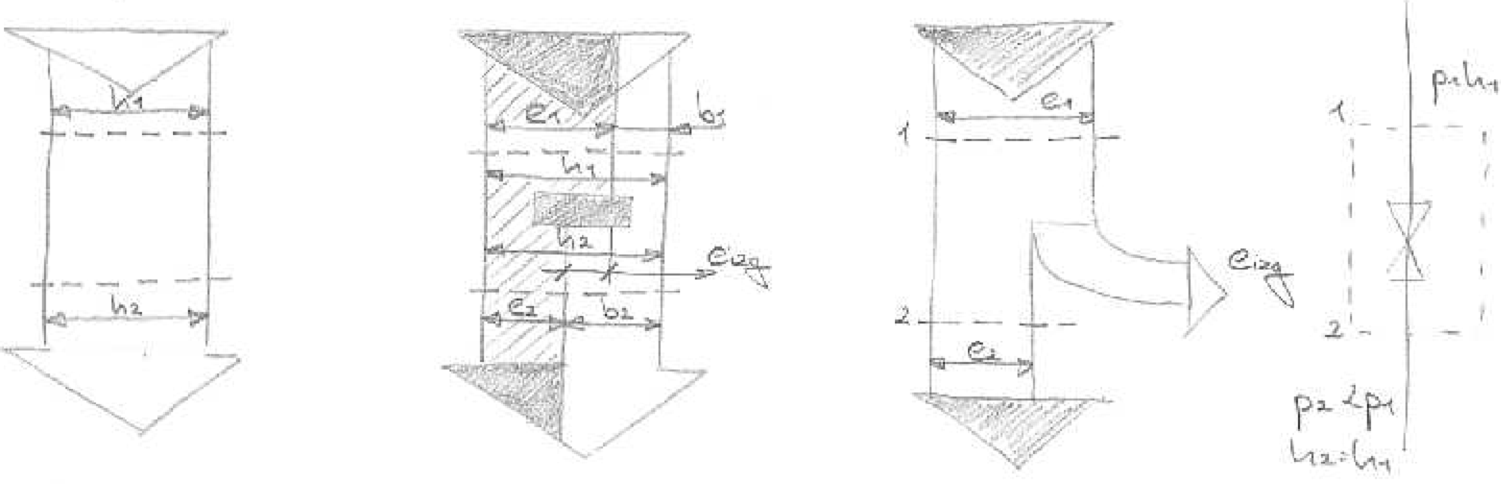
- GRASSMANNOV DIAGRAM (diagram pretoka eksergij)

$$\sum_i E_{i,do} \geq \sum_i |E_{i,od}|$$

- RANTOV DIAGRAM (kvalitativni diagram pretoka energij)

$$\sum_i (E+B)_{i,do} = \sum |E+B|$$

Sankeyev Rantov Grassmannov Shema



Za dušenje

Gibbsove relacije

$du = Tds - Pdv$

$dh = Tds - vdP$

Helmholzova funkcija - definicija proste energije

$a = u - Ts$

Gibbsova funkcija - definicija proste entalpije

$g = h - Ts$

$da = du - Tds - sdT$

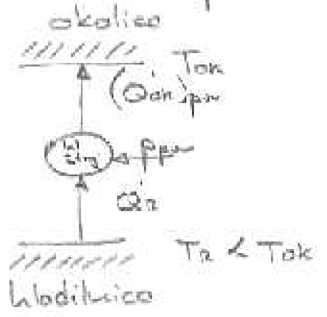
$dg = dh - Tds - sdT$

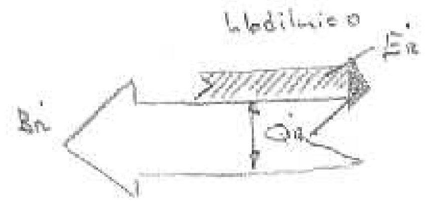
$da = -sdT - Pdv$

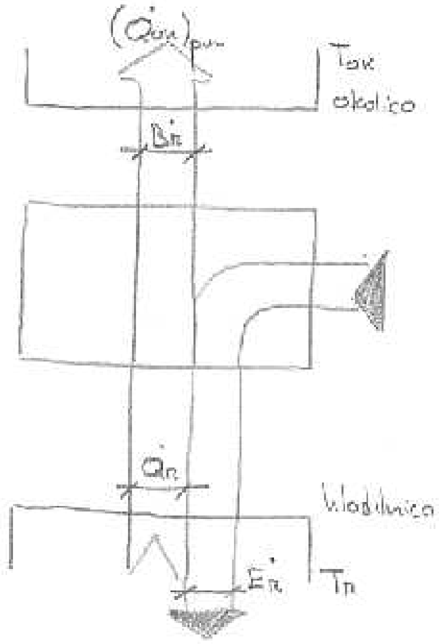
$dg = -sdT + vdP$ $\longrightarrow \left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$

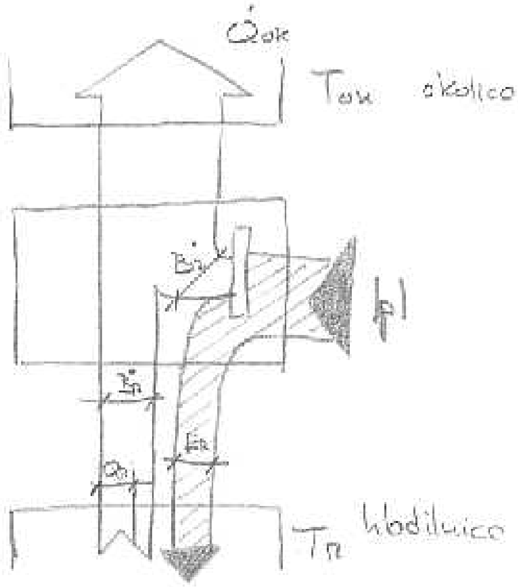
$dz = Mdx + Ndy$

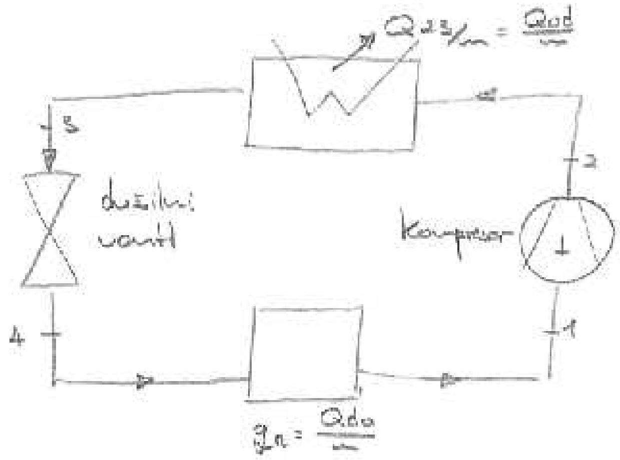
Hlodilni proces

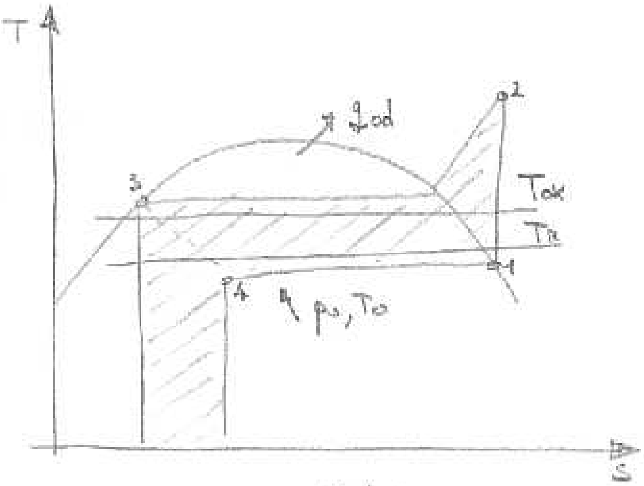


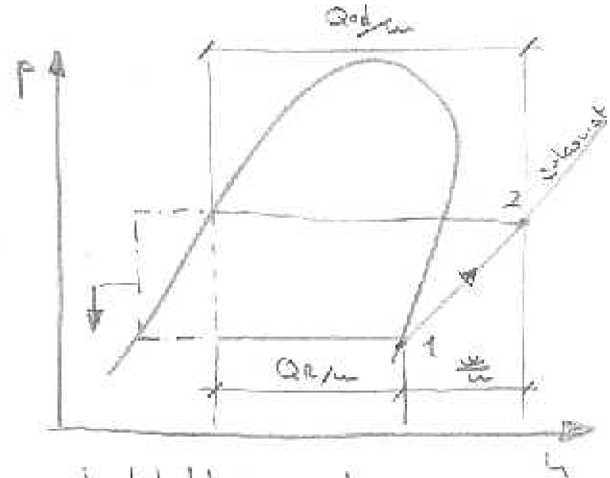


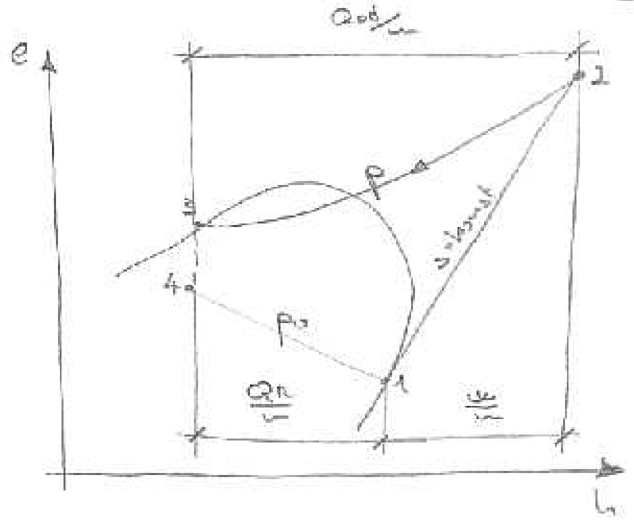










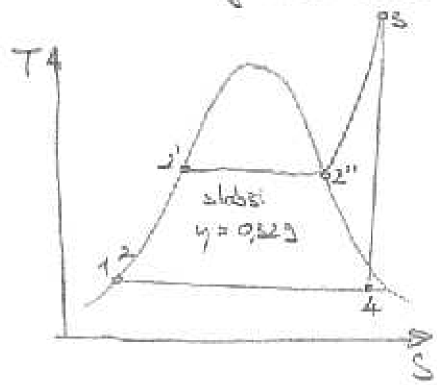


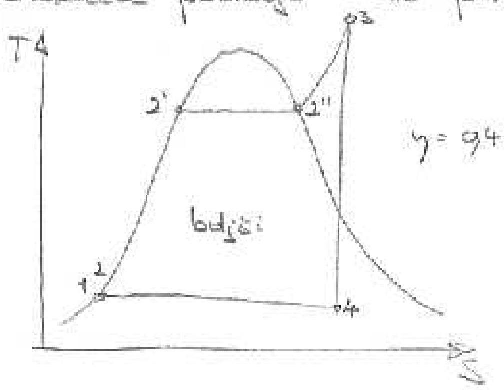
→ hladilni sistem s podhladitvijo

Z levim krožnim procesom odvajamo hladilno toploto

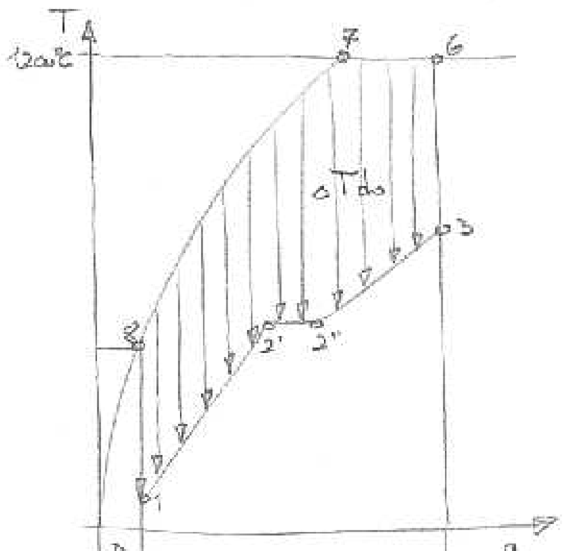
Izboljšanje izkoristka procesa

- čim manj časa smo v dvofaznem področju - voda - para

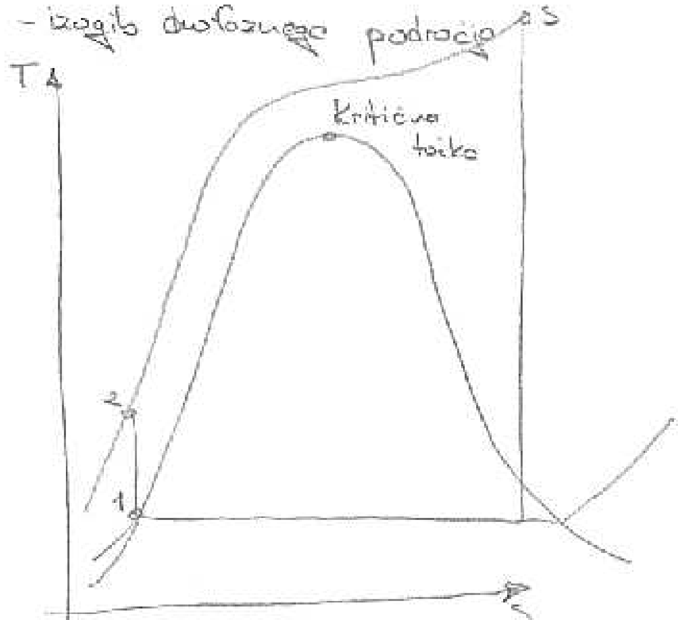




η = 0,447



- izogib dvofaznega področja



- uporaba za elektrarne
- potrebni so visoki tlaki

Izentropa je povračljiva adiabatna preobrazba

$Q_{12} = 0$

Iz 1. gl. zakona sledi

- $du = dq - pdv$

$du + pdv = 0$

$du = c_v(T)\,dT$

- $pv = RT$

$pdv + vdp = RdT$

$dT = \dfrac{pdv + vdp}{R}$

- $\kappa = \dfrac{c_p}{c_v} = \dfrac{c_v(T) + R}{c_v(T)}$

$c_v = \dfrac{R}{\kappa - 1}$

$c_v(T)\,dT + pdv = 0$

$$\frac{R}{\kappa-1}\,\frac{pdv + vdp}{R} + pdv = 0 \quad ; \quad \kappa\, pdv + vdp = 0$$

oziroma

$$\kappa \frac{dv}{v} + \frac{dp}{p} = 0 \quad / \int$$

$$\kappa \ln v + \ln p = \text{konst} \quad / \text{anti log.}$$

$p v^{\kappa} = \text{konst}$ → enačba izentrope idealnega plina

Zapišemo lahko še relacije:

$$\left(\frac{p_1}{p_2}\right) = \left(\frac{v_2}{v_1}\right)^{\kappa} \quad ; \quad \left(\frac{T_1}{T_2}\right) = \left(\frac{v_2}{v_1}\right)^{\kappa-1} \quad ; \quad \frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\kappa-1}{\kappa}}$$

Izguba eksergije – "izgubljeno delo"

$E_{izg} = T_{ok} \Delta s_{nep}$

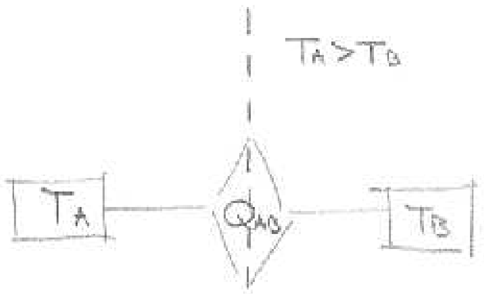
$\Delta s_{nep} = \sum \Delta s_i \geq 0$

I Izguba eksergije zaradi trenja

$$E_{izg,12} = T_{ok} \int_1^2 \frac{|dw_{tr}|}{T}$$

Torno delo je termodinamično toliko bolj škodljivo, kolikor nižja je temperatura, pri kateri ta nepovračljiv proces poteka

II Izguba eksergije pri prenosu toplote



$E_{izg} = T_{ok} \Delta s_{nep}$

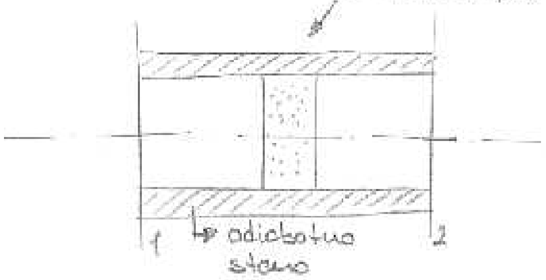
Za izboljšanje izkoristka:
- $T_A - T_B$ čim manjši
- proces naj poteka pri čim višjih temperaturah, da toliko $T_A - T_B$ ne pride toliko do izraza

ΔS_I ΔS_{II}

$\Delta S_I = -\frac{Q_{AB}}{T_A}$ $\Delta S_{II} = \frac{Q_{AB}}{T_B}$

$$\Delta s_{nep} = \sum_{i=1}^{n} \Delta s_i = Q_{AB} \frac{T_A - T_B}{T_A T_B}$$

III Dušitev, kar je ubistvu ekspanzija brez opravljanja dela



$h_2 - h_1 = q_{12} - w_{t12}$ ($q_{12} = 0$, $w_{t12} = 0$)

$h_2 = h_1$ → entalpija se ne spremeni

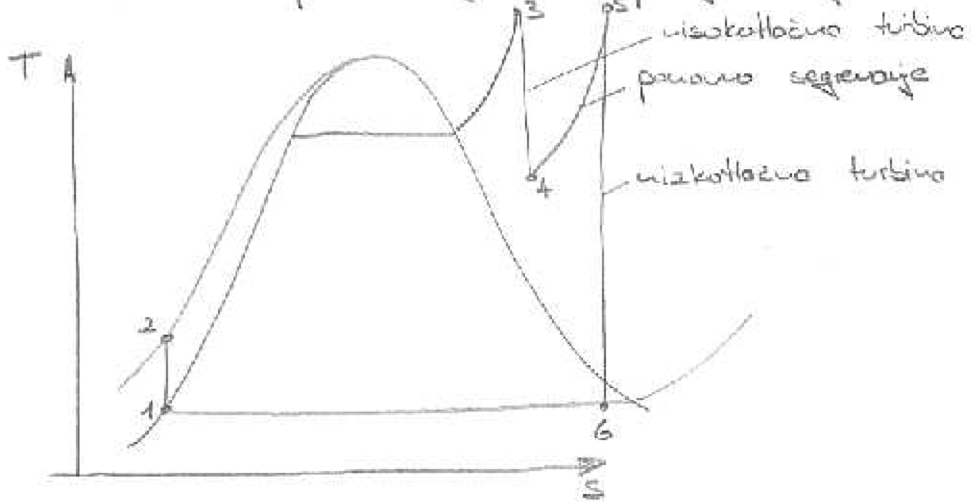
$$\Delta s_{nep} = \sum_{i=1}^{n} \Delta s_i = s_2 - s_1$$

$$e_{izg} = T_{ok} \Delta s_{nep} = T_{ok}(s_2 - s_1)$$

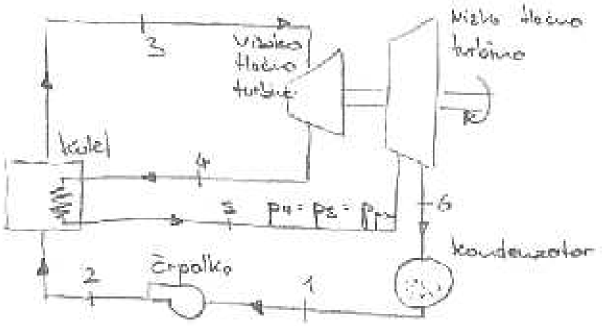
Če prenesemo to ugotovitev na idealni plin:

$$s_2 - s_1 = c_{p0} \ln\frac{T_2}{T_1} - R \ln\frac{p_2}{p_1}$$

Izkoristek pri dvojnem pregrevanju vodne pare

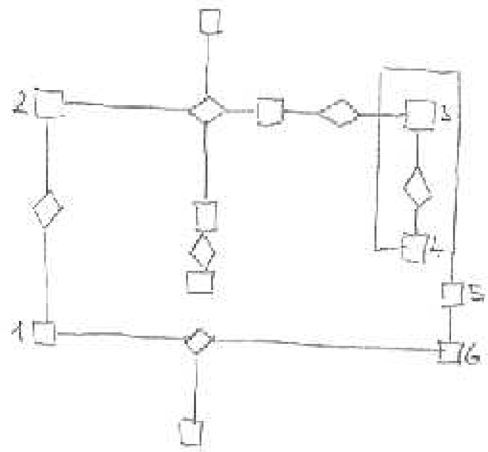


Shema

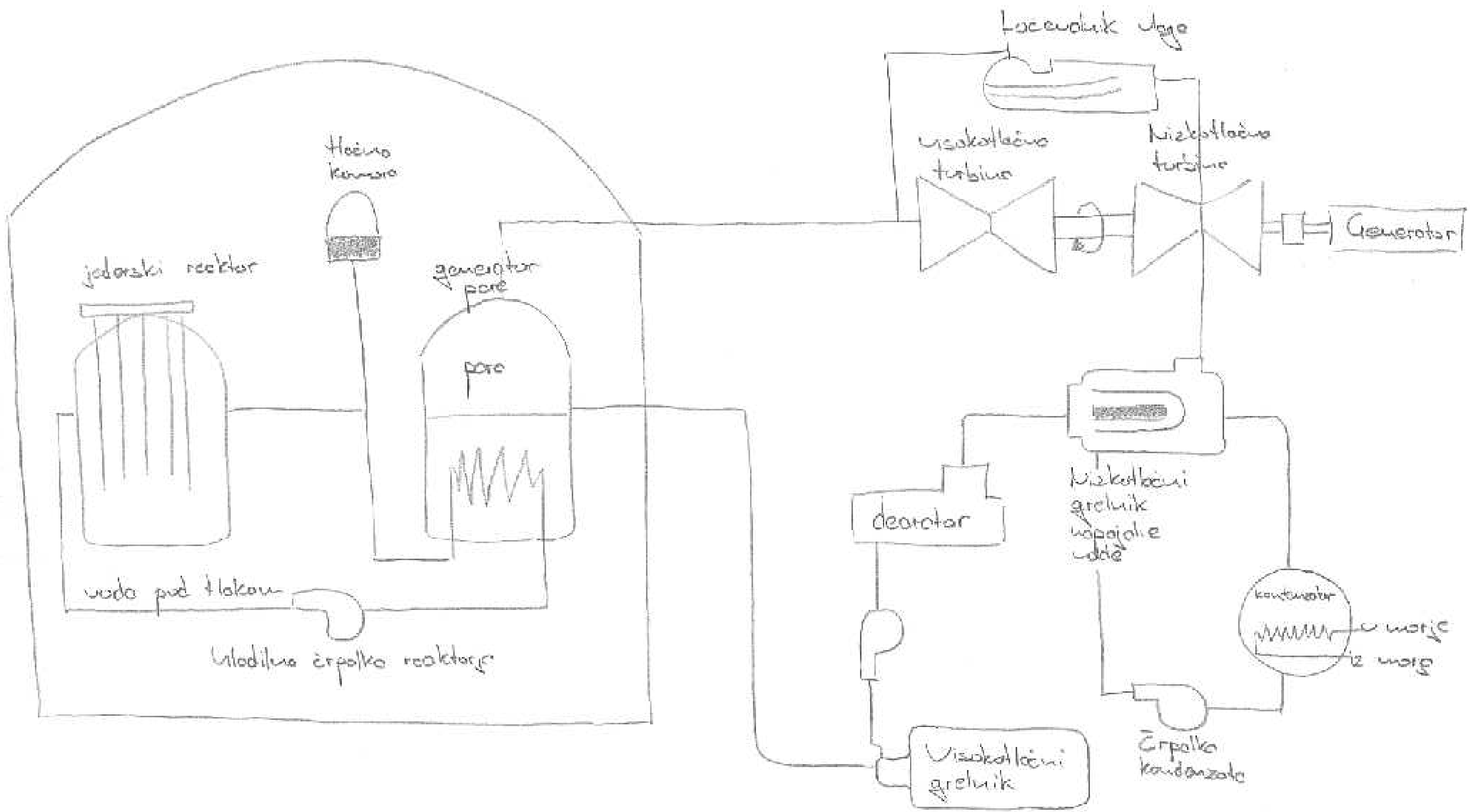


p_{ps} ... tlak ponovnega segrevanja

Strukturna slika



Tlačnovodna jedrska elektrarna

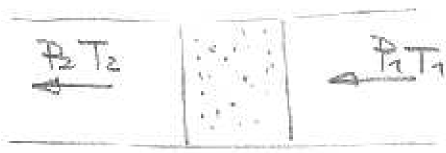


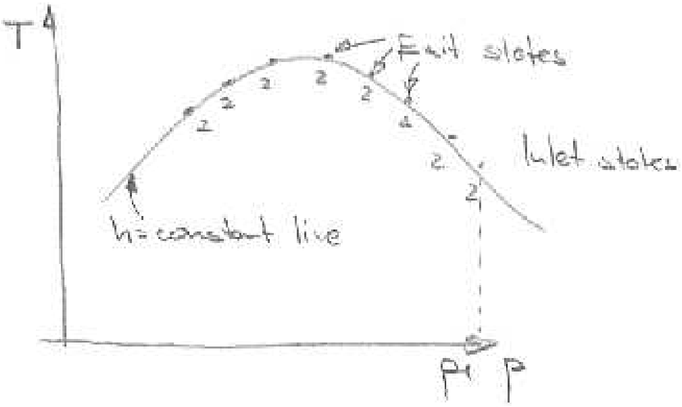
23

Joule Thompsonov koeficient

$$\mu = \left(\frac{\partial T}{\partial p}\right)_h$$

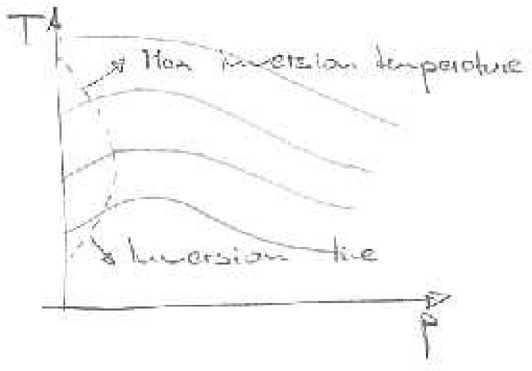
$$\mu \begin{cases} < 0 & \text{temperatura raste} \\ = 0 & \text{konstantna temperatura} \\ > 0 & \text{temperatura pada} \end{cases}$$

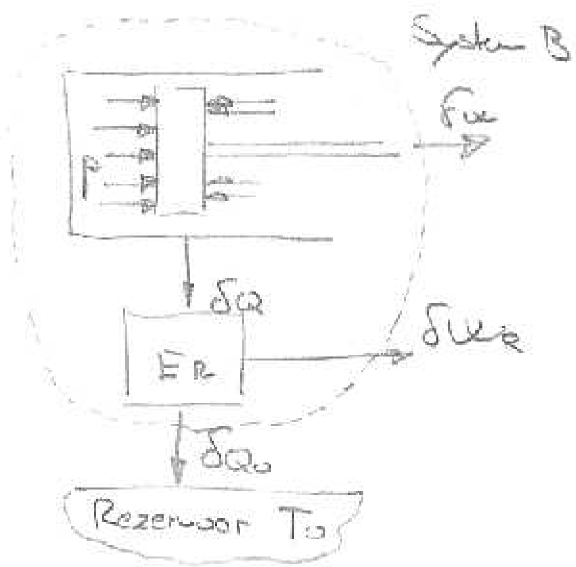




$$dh = c_p dT + \left[v - T\left(\frac{\partial v}{\partial T}\right)_p \right] dp$$

$$\frac{1}{c_p}\left[v - T\left(\frac{\partial v}{\partial T}\right)_p \right] = \left(\frac{\partial T}{\partial p}\right)_h = \mu$$





Kalorična enačba stanja za entalpijo $h = h(T,p)$

$$dh = \left(\frac{\partial h}{\partial T}\right)_p dT + \left(\frac{\partial h}{\partial p}\right)_T dp$$

$$dh = c_p dT + \left(\frac{\partial h}{\partial p}\right)_T dp$$

$$ds = \left(\frac{\partial s}{\partial T}\right)_p dT + \left(\frac{\partial s}{\partial p}\right)_T dp \qquad s = s(T,p)$$

$$dh = T\left(\frac{\partial s}{\partial T}\right)_p dT + \left[T\left(\frac{\partial s}{\partial p}\right)_T + v\right] dp$$

$$\left(\frac{\partial s}{\partial T}\right)_p = \frac{c_p}{T}$$

$$\left(\frac{\partial h}{\partial p}\right)_T = T\left(\frac{\partial s}{\partial p}\right)_T + v$$

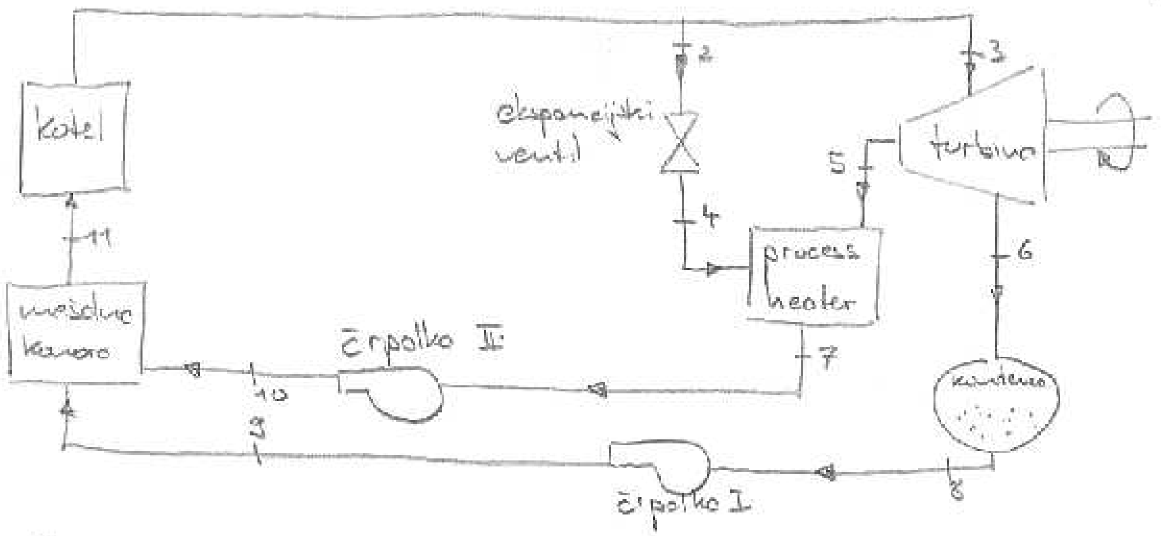
$$\left(\frac{\partial h}{\partial p}\right)_T = v - T\left(\frac{\partial v}{\partial T}\right)_p$$ ... 4. Maxwellova enačba

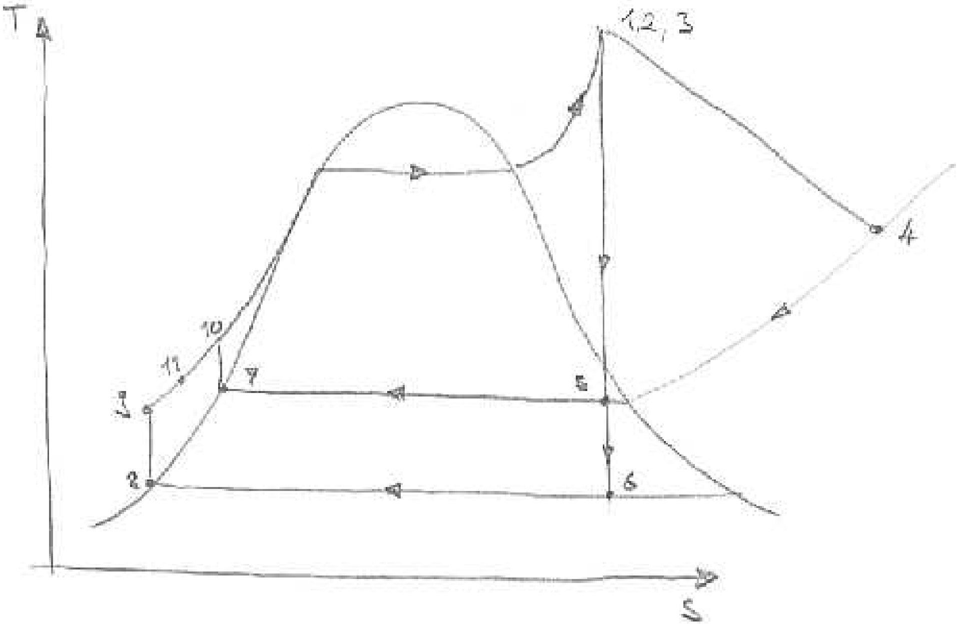
$$dh = c_p dT + \left[v - T\left(\frac{\partial v}{\partial T}\right)_p\right] dp$$

$$h_2 - h_1 = \int_{T_1}^{T_2} c_p dT + \int_{p_1}^{p_2} \left[v - T\left(\frac{\partial v}{\partial T}\right)_p\right] dp$$

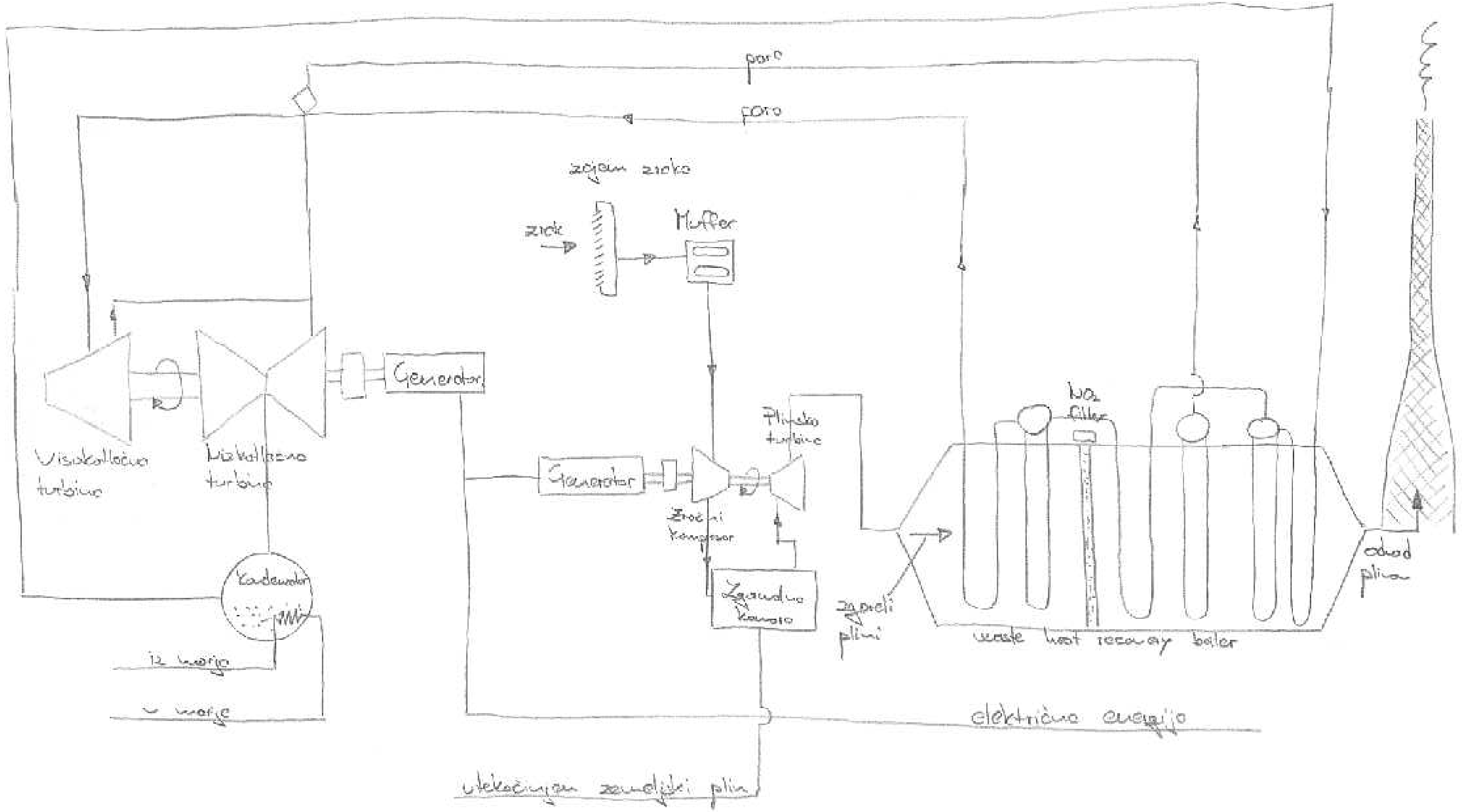
$$h_2 - h_1 = u_2 - u_1 + (p_2 v_2 - p_1 v_1)$$

Sočasno proizvodnja dveh ali več vrst energije ali kogeneracija

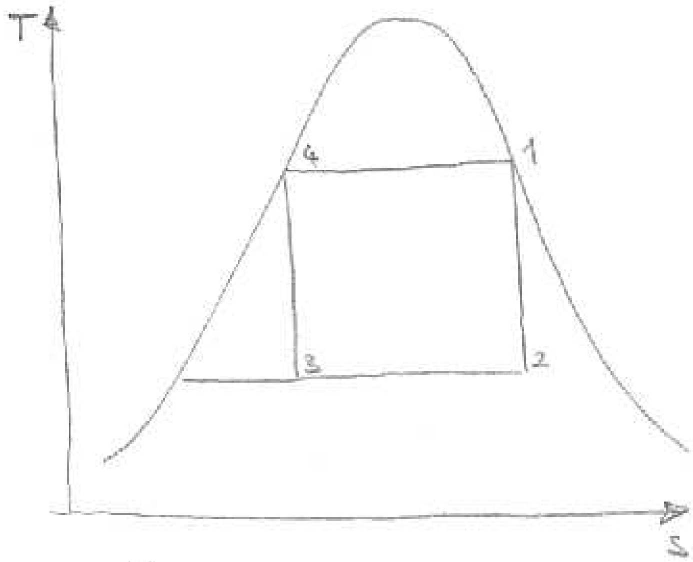


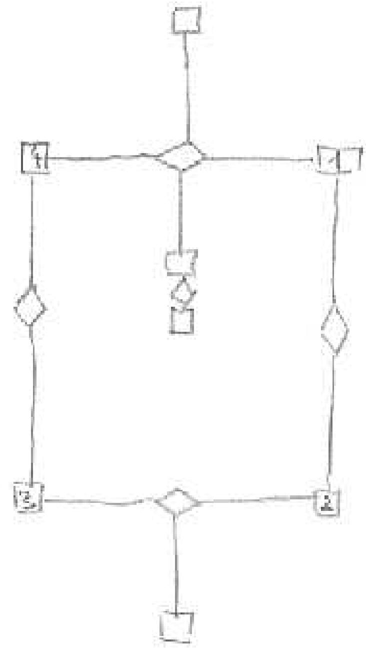


Kombinirana elektrarna



Krožni proces v T,s diagramu:





- nezaključen, odprt proces vpliva na del krožnega procesa in predstavlja tako izgube
- izkoristek krožnega procesa lahko povečamo, če dodamo novo zanko

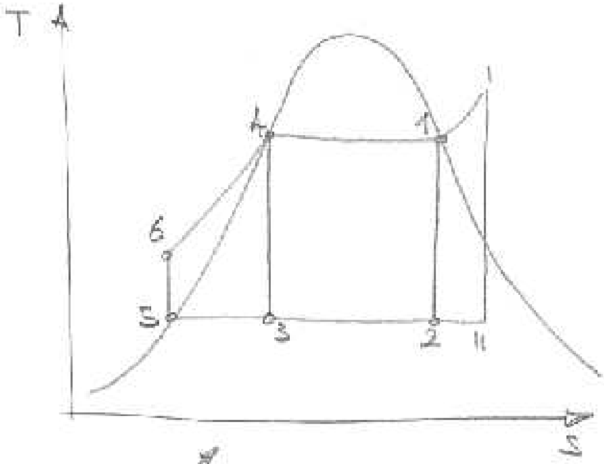
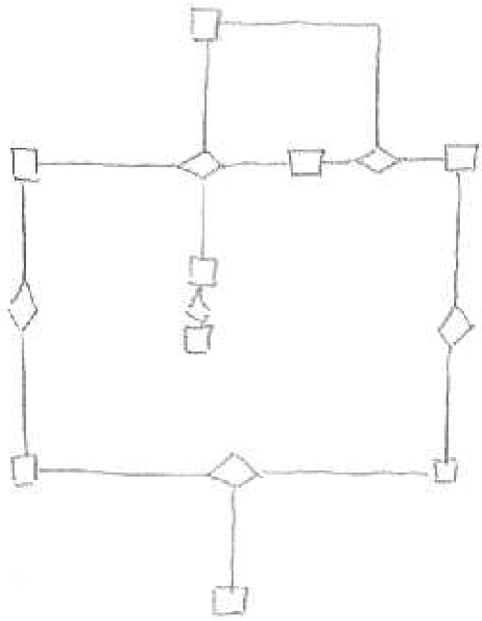
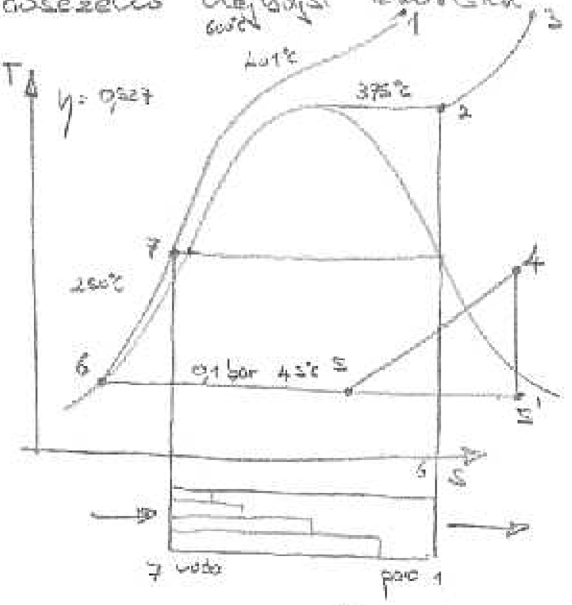


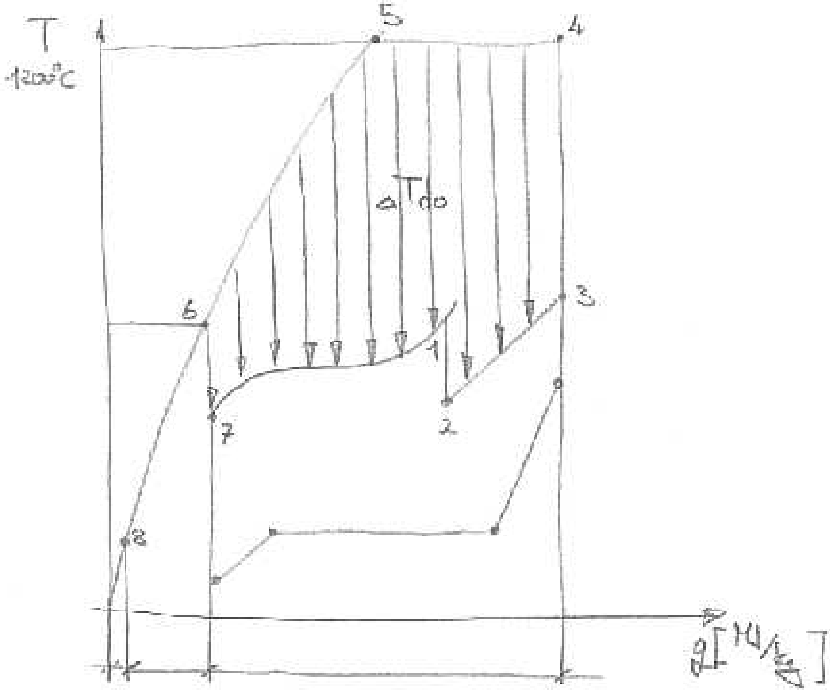
diagram izboljšanega krožnega procesa



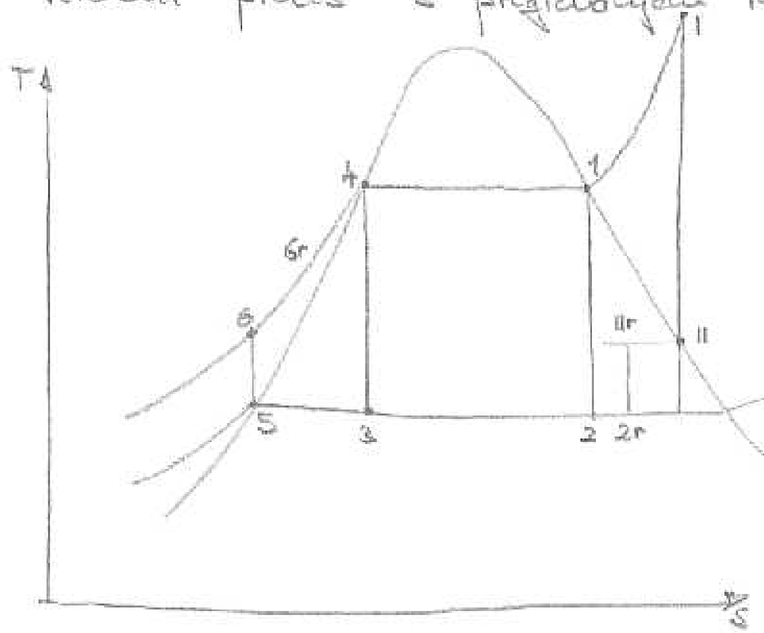
Krožni proces z dvojnim pregrevanjem in regeneracijo

- dosežemo najboljši izkoristek

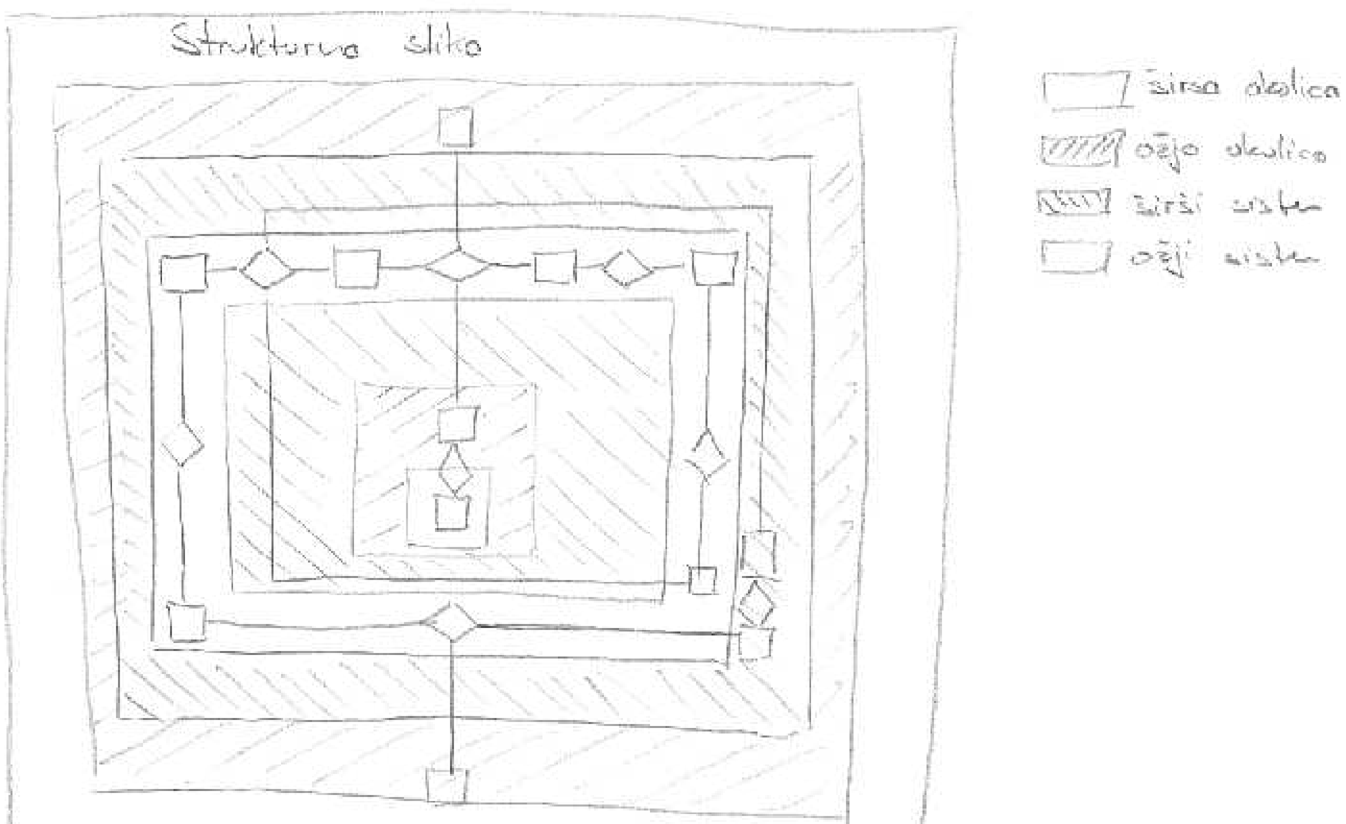




Krožni proces s pregrevanjem in regeneracijo



Strukturna slika



Maxwellove relacije so:

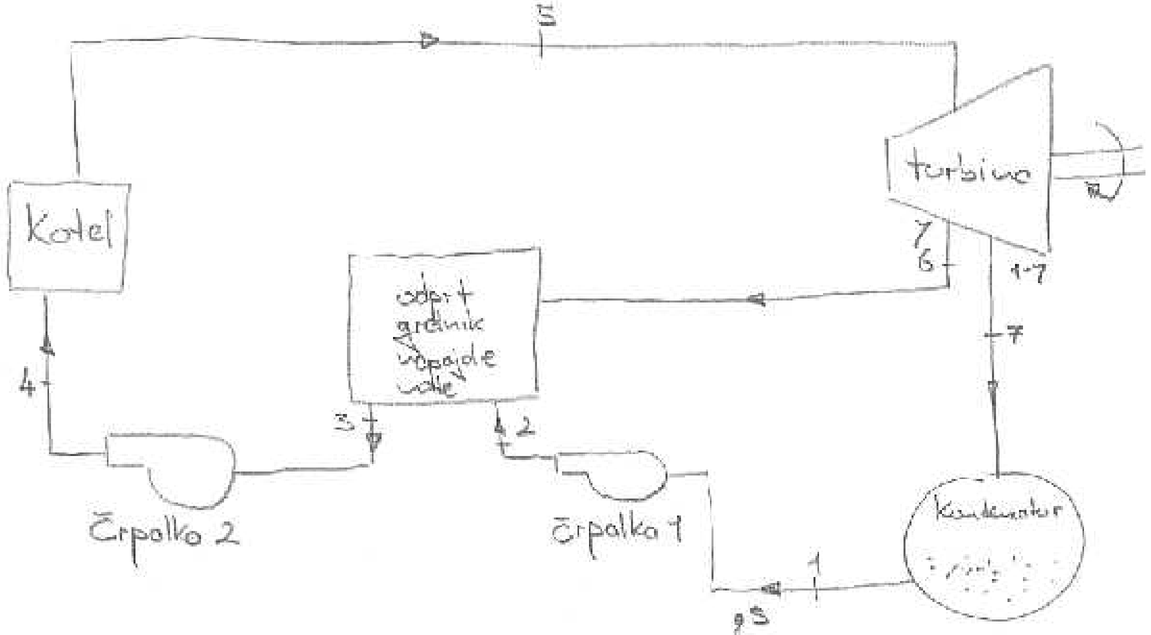
$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial p}{\partial S}\right)_V$$

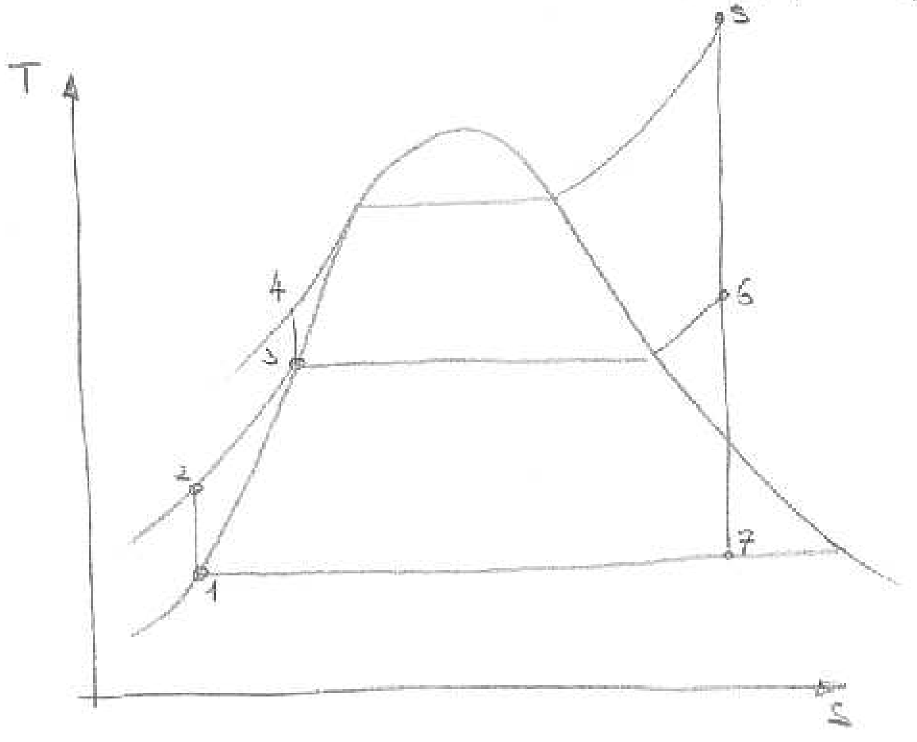
$$\left(\frac{\partial T}{\partial p}\right)_S = \left(\frac{\partial V}{\partial S}\right)_p$$

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial p}{\partial T}\right)_V$$

$$\left(\frac{\partial S}{\partial p}\right)_T = \left(\frac{\partial V}{\partial T}\right)_p$$

Odprt sistem gretja napajalne vode

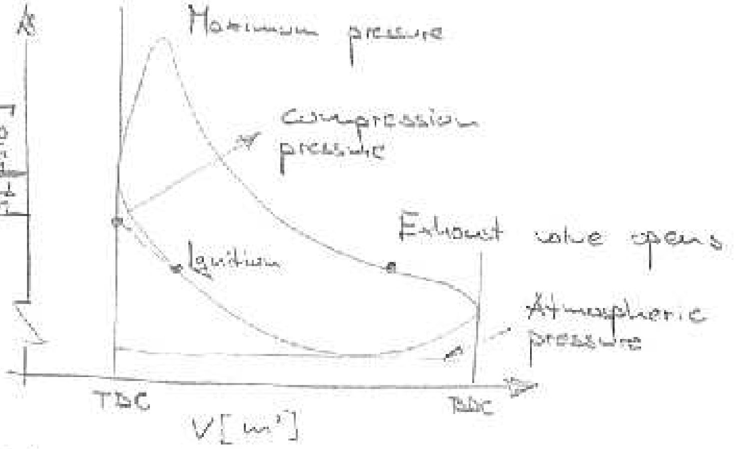


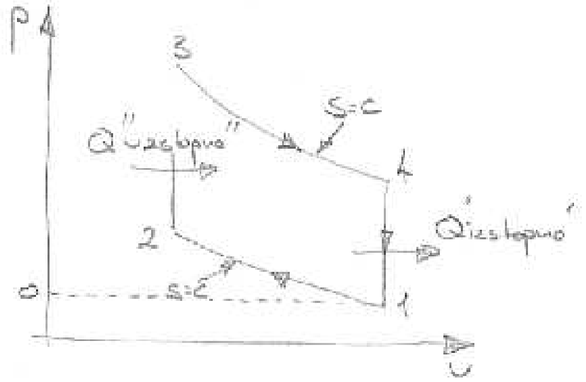


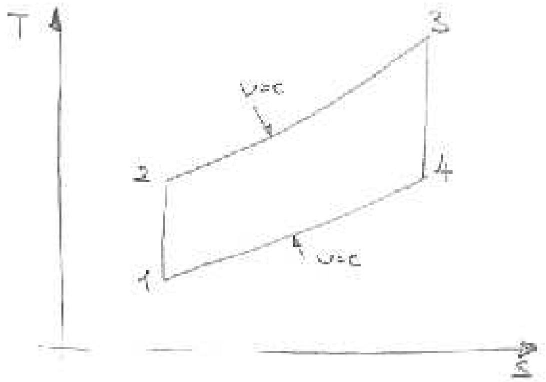
- večji izkoristek zaradi regenerativnega gretja napajalne vode

Ottov proces

Delamo karakteristiko procesa







IZKORISTEK

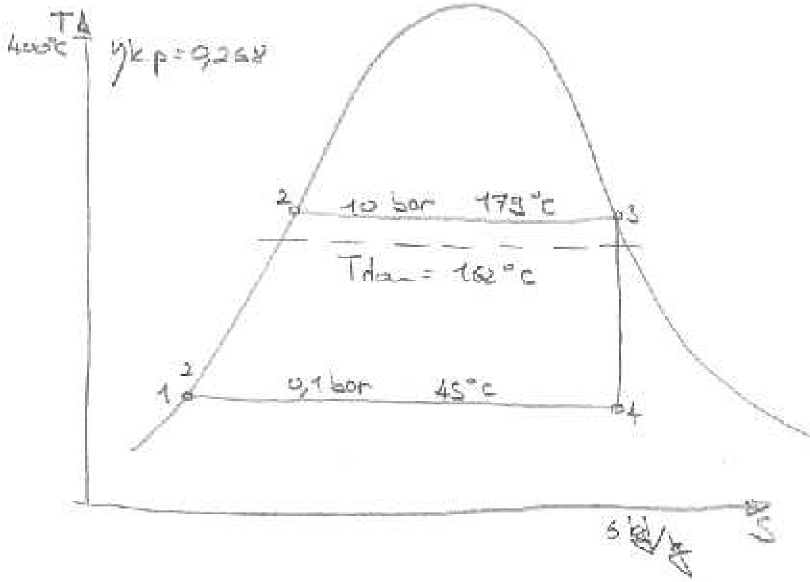
$$\eta = \frac{W_k}{Q_{dov}} = 1 - \frac{Q_{odv}}{Q_{dov}} = 1 - \frac{m c_v (T_4 - T_1)}{m c_v (T_3 - T_2)} = 1 - \frac{T_1 (T_4/T_1 - 1)}{T_2 (T_3/T_2 - 1)}$$

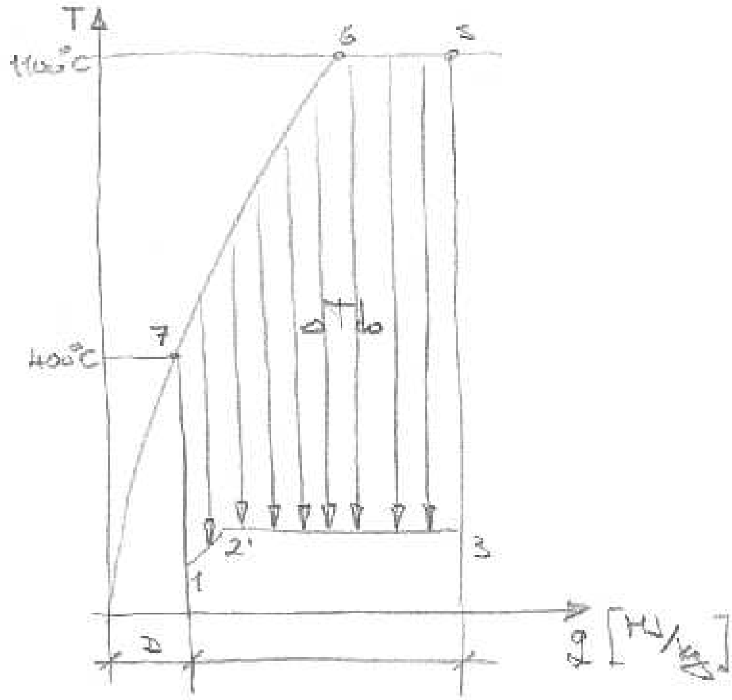
$V_1 = V_4$, $V_2 = V_3$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\kappa-1} = \frac{T_3}{T_4} = \left(\frac{V_1}{V_3}\right)^{\kappa-1} \rightarrow \frac{T_3}{T_2} = \frac{T_4}{T_1}$$

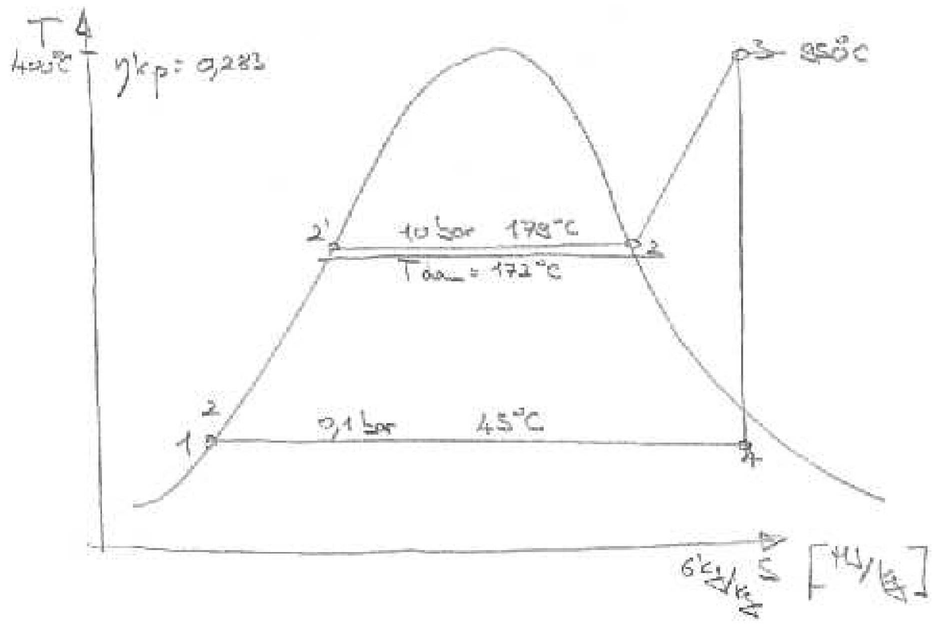
$$\rightarrow \eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{V_1}{V_2}\right)^{1-\kappa}$$ izkoristek

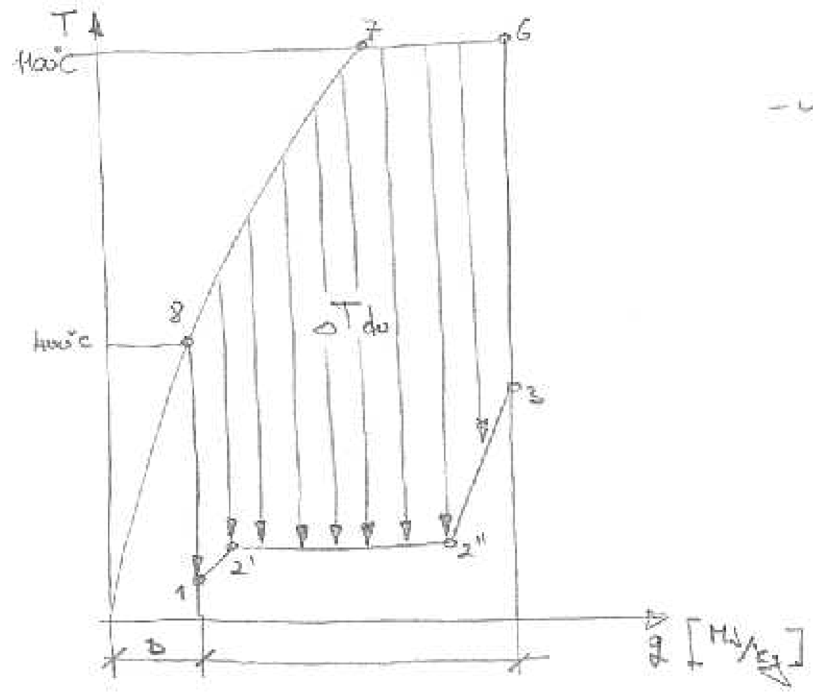
Parni proces z vodno paro





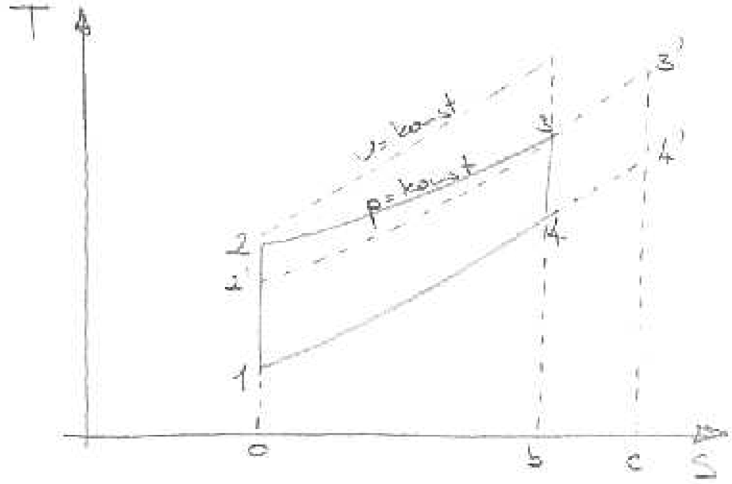
Parni proces z enojnim pregrevanjem vodne pare





- ni krožni proces

Primerjava med Ottovim in Dizel procesom

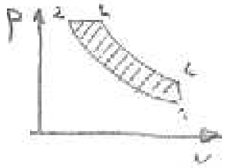


Če vzamemo Otto proces (1-2-3'-4-1) in Dizlov proces (1-2-3-4-1) z istim začetnim kompresijskim stanjem, volumnom in kompresijskim razmerjem ugotovimo, da ima boljši - višji izkoristek Otto proces.

V primeru, ko pa imamo Otto in Dizel proces z enako T in p pa ugotovimo, da ima Dizel boljši izkoristek. Tu je rešen problem, ki se mi zdi vredno omeniti - preveliko kompresijsko razmerje oz expanzije.

Primerjava toplotnih izkoristkov pri motorjih z notranjim izgorevanjem:

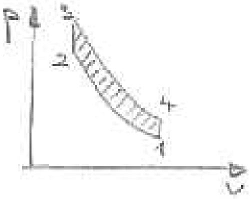
- Diesel:



$$\eta_{topl} = 1 - \frac{T_4 - T_1}{\kappa (T_3 - T_2)}$$

$$\eta_{topl} = 1 - \frac{1}{\varepsilon^{\kappa-1}} \cdot \frac{\varphi^{\kappa} - 1}{\kappa(\varphi - 1)}$$

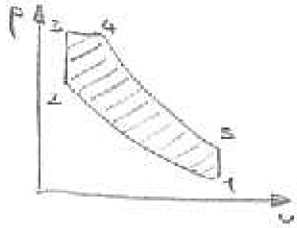
- Otto



$$\eta_{topl} = 1 - \frac{T_1}{T_2}$$

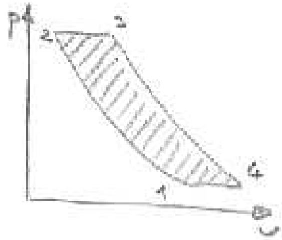
$$\eta_{topl} = 1 - \frac{1}{\varepsilon^{\kappa-1}}$$

- Seiliger



$$\eta_{topl} = 1 - \frac{T_5 - T_1}{T_3 - T_2 + \kappa (T_4 - T_3)}$$

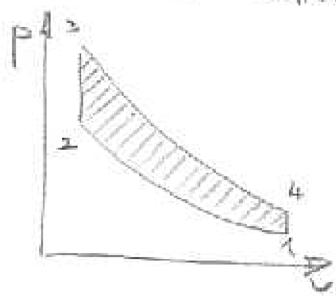
- Joule



$$\eta_{topl} = 1 - \frac{T_1}{T_2}$$

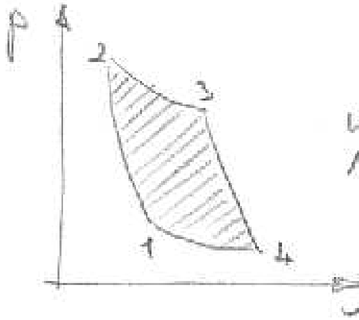
$$\eta_{topl} = 1 - \left(\frac{p_1}{p_2}\right)^{\frac{\kappa-1}{\kappa}}$$

- Ackeret Keller - Ericsson



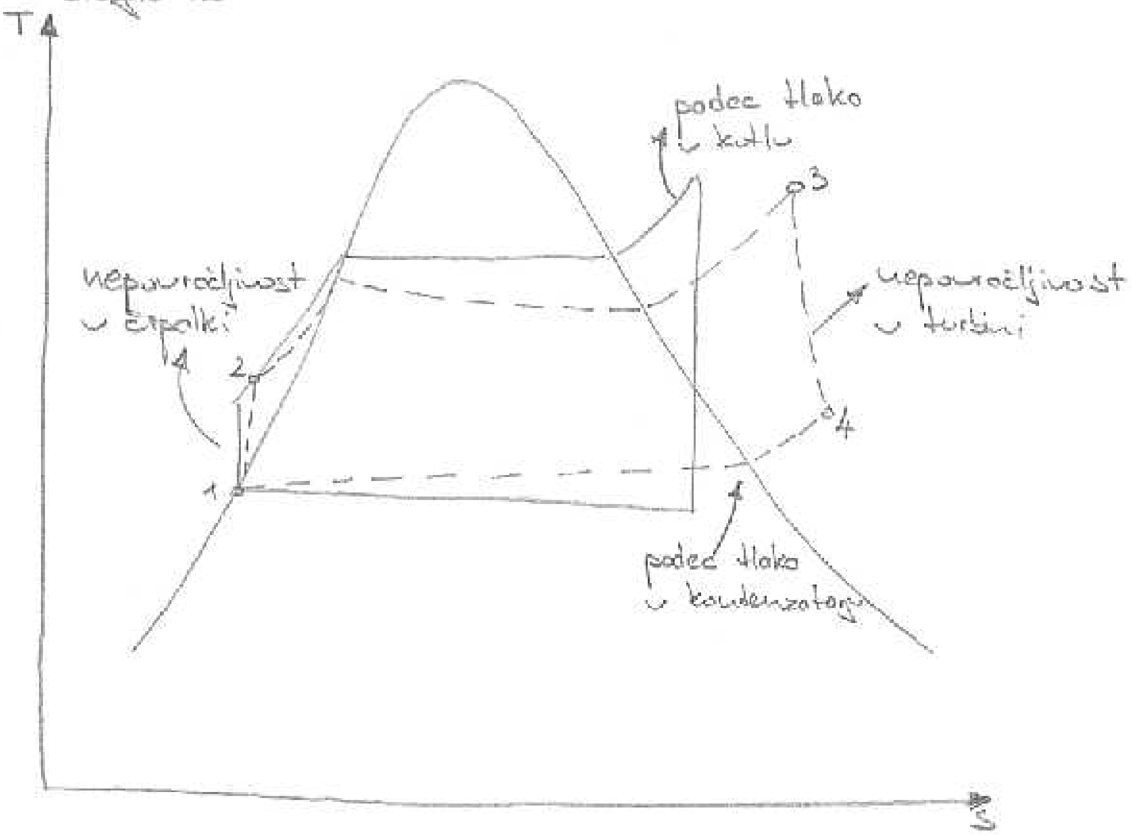
$$\eta_{topl} = 1 - \frac{T_1}{T_3}$$

- Carnot



$$\eta_{topl} = 1 - \frac{T_4}{T_2}$$

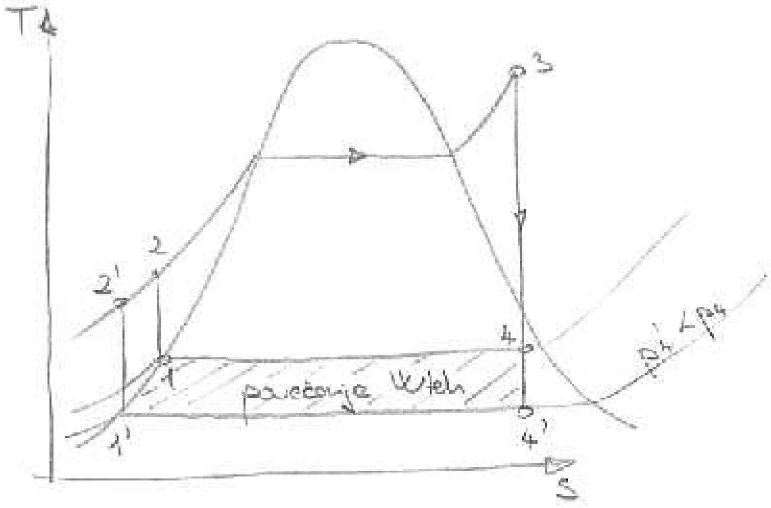
Primerjava realnega in idealnega procesa (Rankin) v T,s diagramu

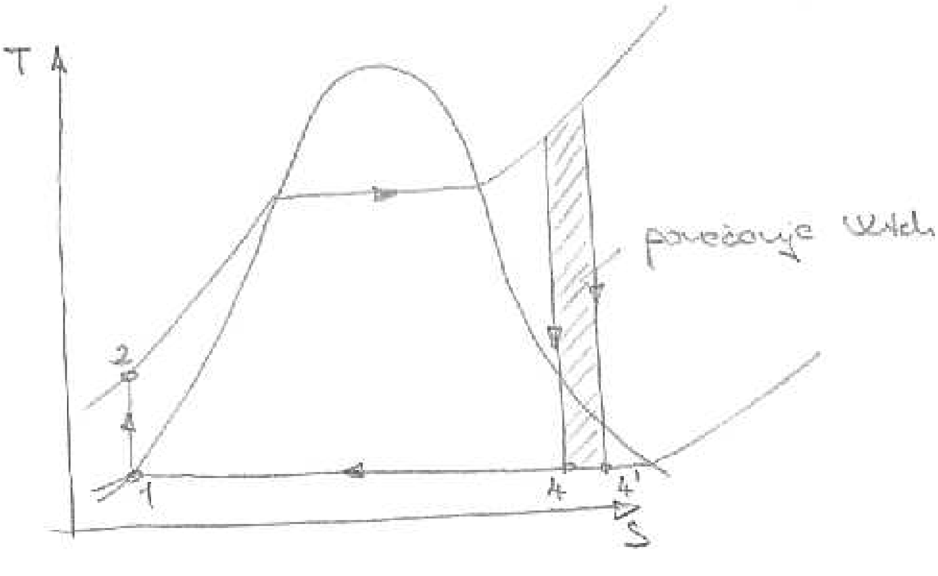


— realni cikel

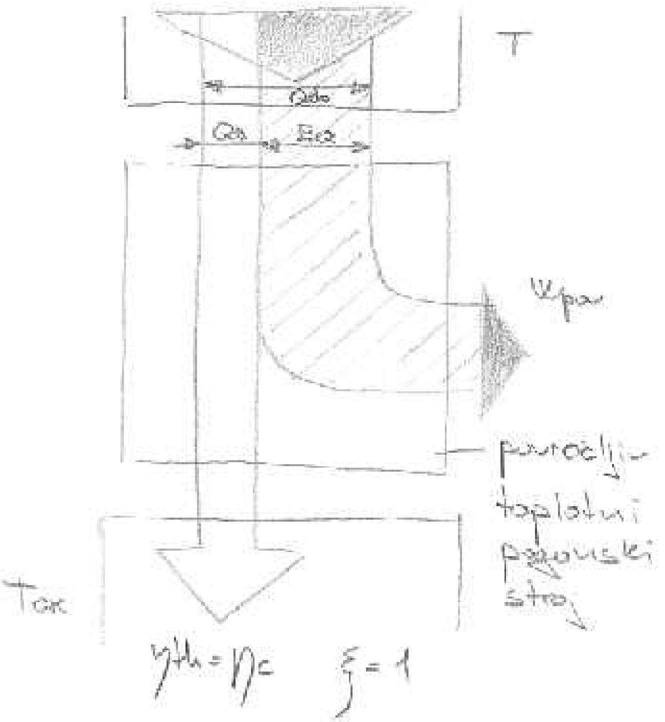
- - - idealni cikel

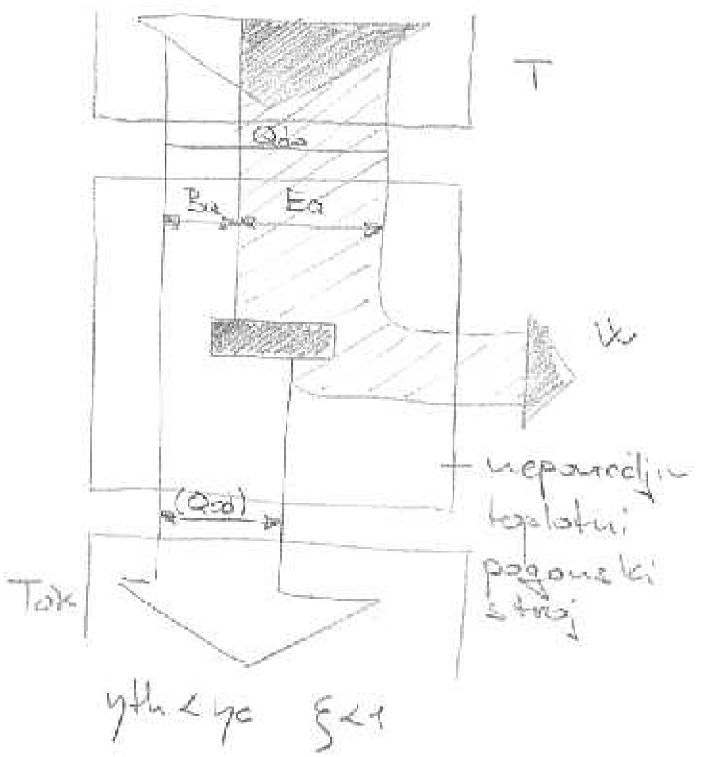
Primera povečave izkoristka Rankinovega procesa



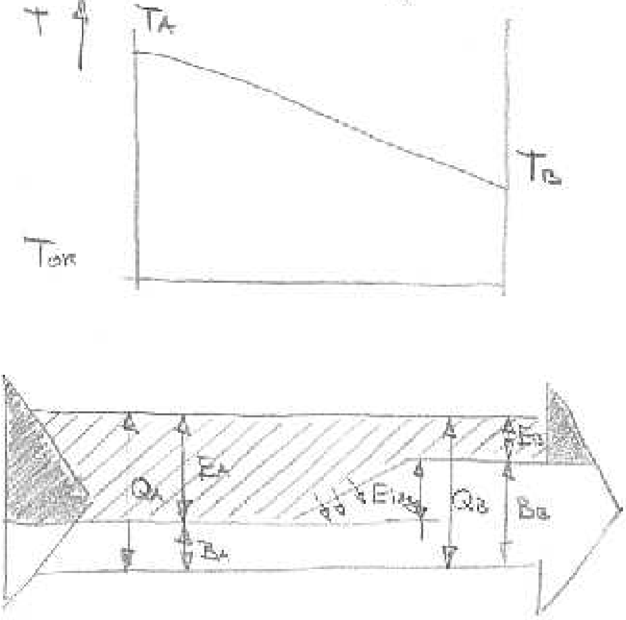


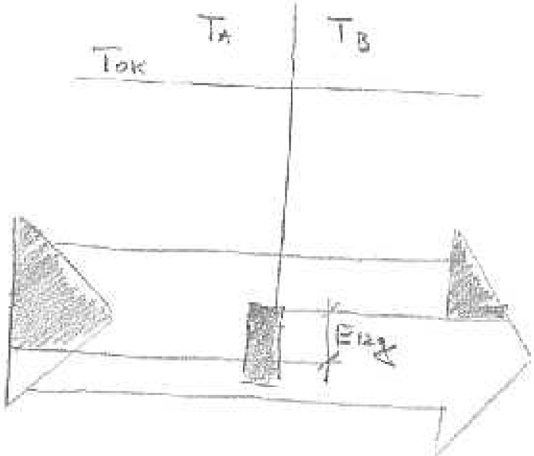
Ranta diagram za toplotni pogonski stroj





Rantov diagram za prenos toplote





Recipročnost - Cikličnost

- Recipročnost

$$\left(\frac{dx}{dz}\right)_y \left(\frac{dz}{dy}\right)_y = 1 \rightarrow \left(\frac{dx}{dz}\right)_y = \frac{1}{(dz/dx)_y}$$

- Cikličnost

$$\left(\frac{dz}{dx}\right)_y \left(\frac{dx}{dy}\right)_z = -\left(\frac{dz}{dy}\right)_x \rightarrow \left(\frac{dx}{dy}\right)_z \left(\frac{dy}{dz}\right)_x \left(\frac{dz}{dx}\right)_y = -1$$

- Recipročnost

$$\left(\frac{dv}{dT}\right)_p = \frac{1}{(dT/dv)_p} \qquad \left(\frac{dp}{dv}\right)_T = \frac{dp_T}{dv_T}$$

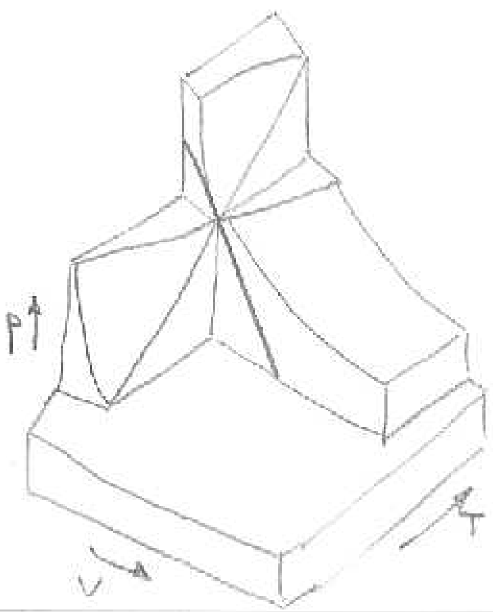
$$\frac{R}{p} = \frac{1}{p/R}$$

- Cikličnost

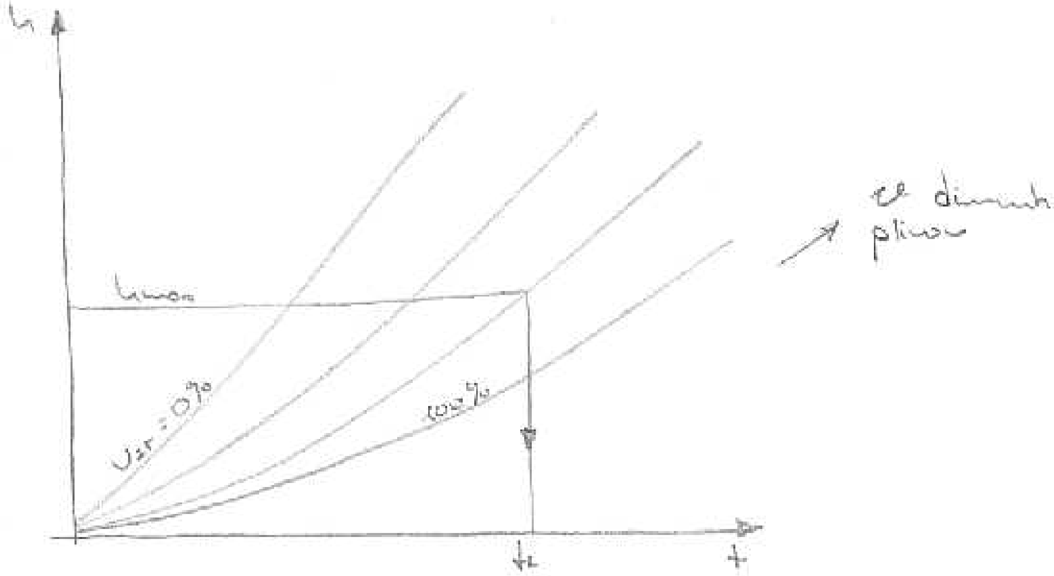
$$\left(\frac{dp}{dv}\right)_T \left(\frac{dv}{dT}\right)_p \left(\frac{dT}{dp}\right)_v = -1 \left(\frac{RT}{v^2}\right)\left(\frac{R}{p}\right)\left(\frac{v}{R}\right) = -\left(\frac{RT}{pv}\right) = -1$$

$$dp = \left(\frac{dp}{dT}\right)_v dT + \left(\frac{dp}{dv}\right)_T dv$$

$$dp = \frac{R\,dT}{v} - \frac{RT\,dv}{v^2}$$



Rosin - Fehlingov dijagram



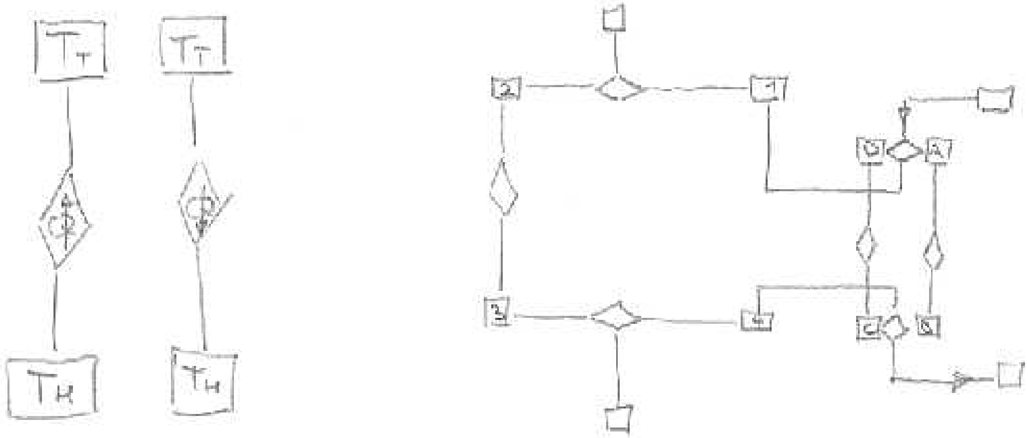
- volumski % zraka

$$v_{zr} = 100 \frac{(\lambda - 1) z_{min}}{D}$$

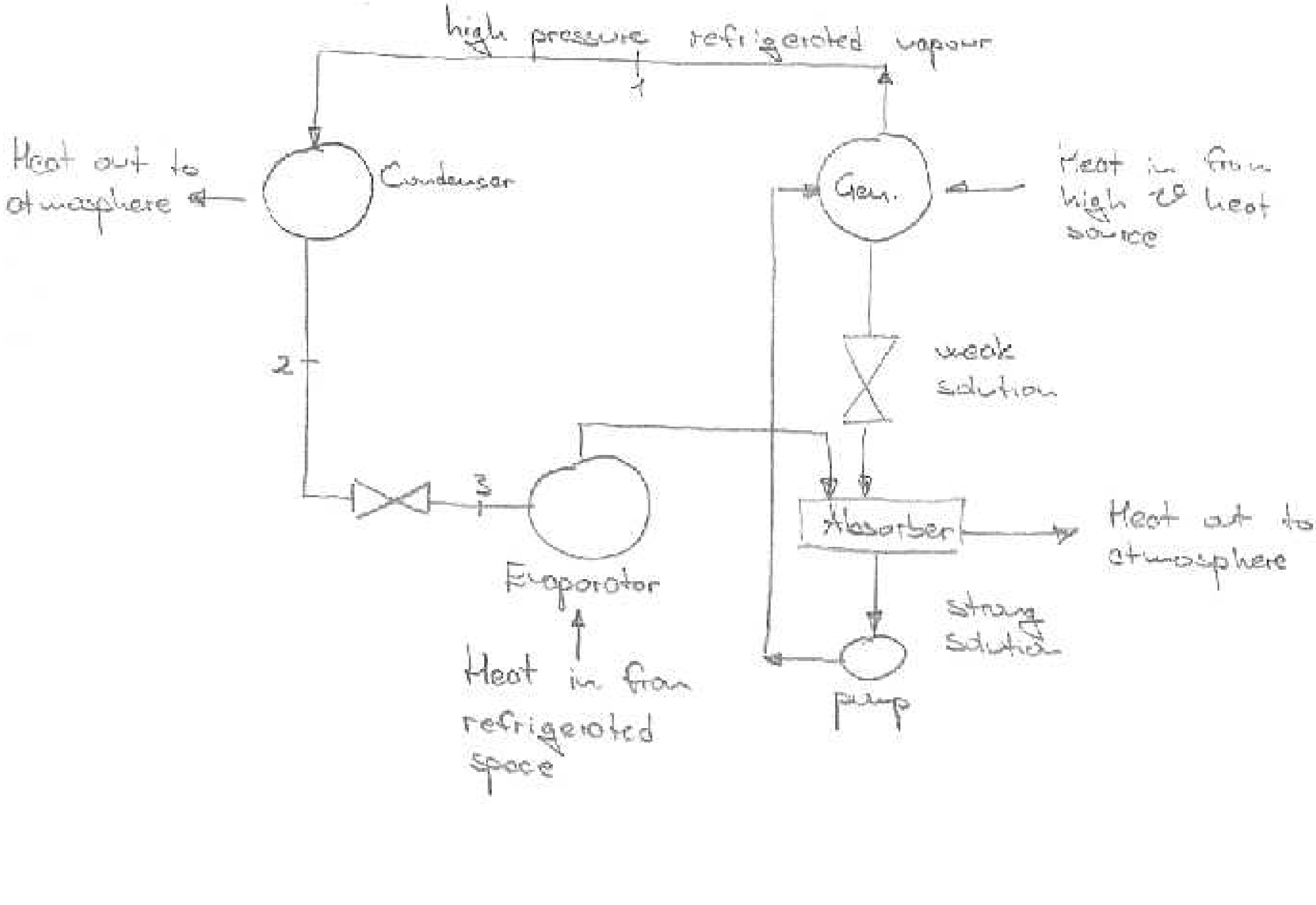
- maksimalna entalpija dimnih plinova

$$h_{max} = \frac{H_i + c_g |_0^{g} t_g + z_e v_{zr} |_0^{zr} t_{zr}}{D}$$

Simple asorbption refrigeration system



- energija se robi za obtočno črpalko



$x = \frac{m''}{m' + m''}$

$m = m' + m''$

$V = V' + V'' = m'v' + m''v''$

↳ $v = v' + x(v'' - v')$

$V = m'v' + m''v''$

$\frac{V}{m} = v = \frac{m'}{m}v' + \frac{(m - m')}{m}v''$

$v = \frac{m - m''}{m}v' + \frac{m''}{m}v''$

$v = (1 - x)v' + x v'' = v' + x(v'' - v')$

↳ analogno dobimo isto za

h

u

s

Termična enačba stanja za notranjo energijo $u = u(T,v)$

$$du = \left(\frac{\partial u}{\partial T}\right)_v dT + \left(\frac{\partial u}{\partial v}\right)_T dv$$

$$du = c_v \, dT + \left(\frac{\partial u}{\partial v}\right)_T dv$$

$$ds = \left(\frac{\partial s}{\partial T}\right)_v dT + \left(\frac{\partial s}{\partial v}\right)_T dv \qquad s = s(T,v)$$

$$du = T\left(\frac{\partial s}{\partial T}\right)_T + \left[T\left(\frac{\partial s}{\partial v}\right)_T - p\right] dv \qquad du = T ds - p dv$$

$$\left(\frac{\partial s}{\partial T}\right)_v = \frac{c_v}{T}$$

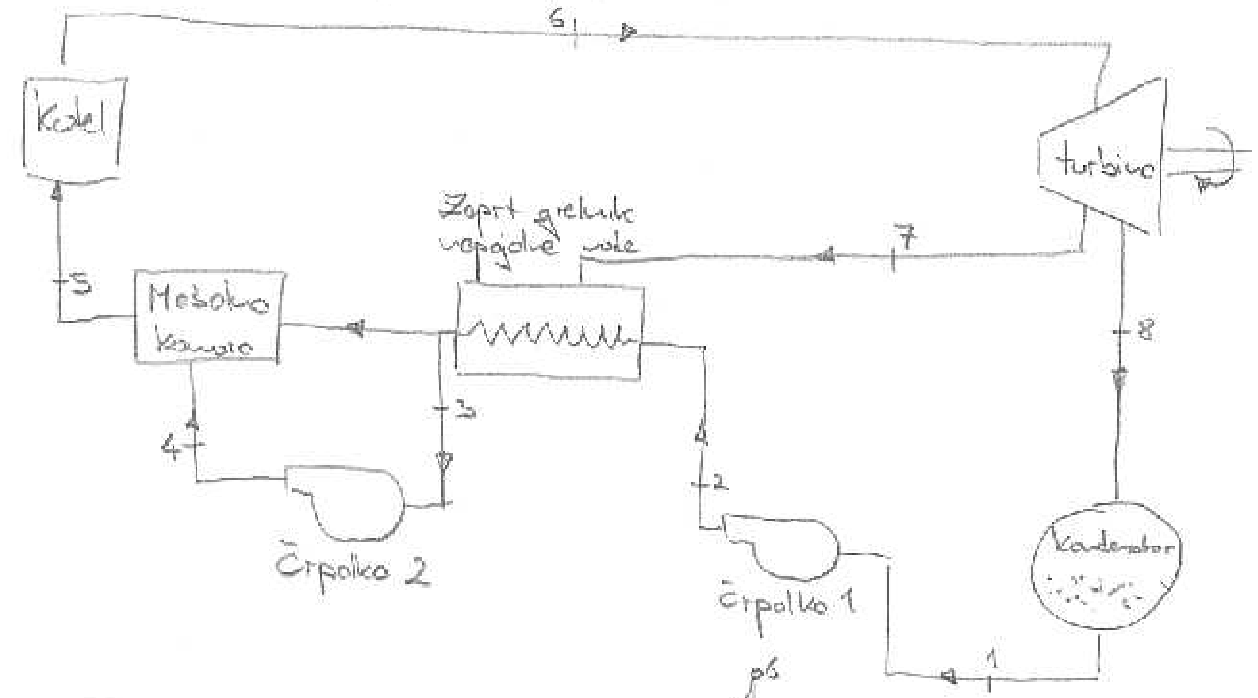
$$\left(\frac{\partial u}{\partial v}\right)_T = T\left(\frac{\partial s}{\partial v}\right) - p$$

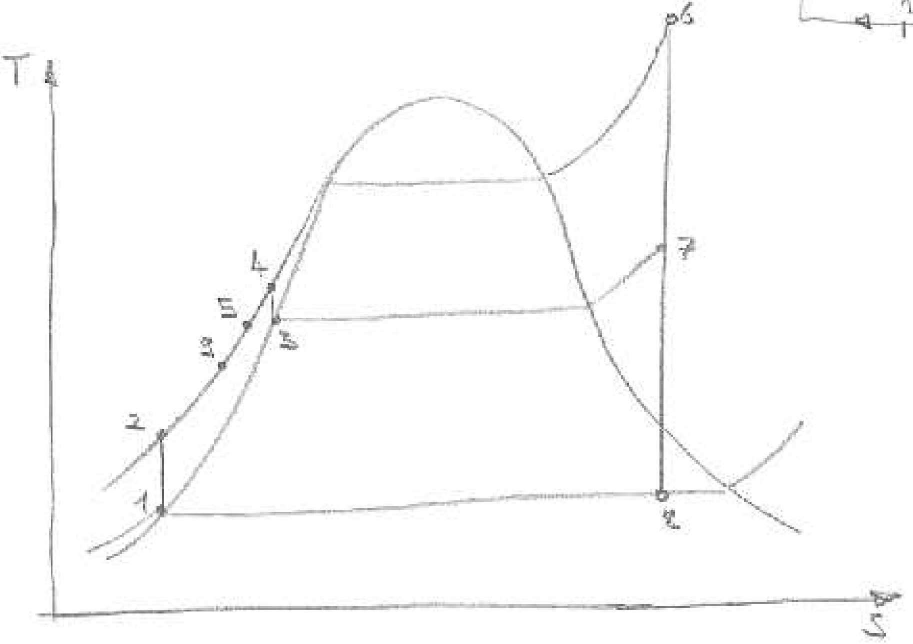
$$\left(\frac{\partial u}{\partial v}\right)_T = T\left(\frac{\partial p}{\partial T}\right) - p$$

$$du = c_v \, dT + \left[T + \left(\frac{\partial p}{\partial T}\right)_v - p\right] dv$$

$$u_2 - u_1 = \int_{T_1}^{T_2} c_v \, dT + \int_{v_1}^{v_2} \left[T\left(\frac{\partial p}{\partial T}\right)_v - p\right] dv$$

Zaprt sistem gretje napajalne vode





- regenerativno gretje napajalne vode - izkoristek