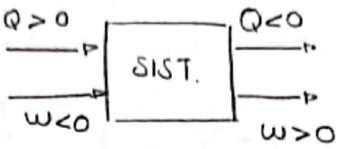
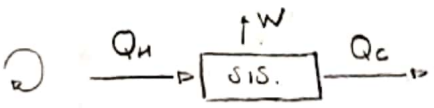
# 1.- DEFINIZIO ETA KONTZEPTUAK

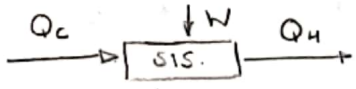
- $\Delta U = Q - W$




- ALDAGAIAK:
  - EXTENSIBOAK: masa kantitatearen menpekoak (V, U, H, S)
  - INTENSIBOAK: masarengandik independenteak (T, P)
  - ESPEZIFIKOAK: (EXTENSIBOAK/m) ($v, h, u, s$)
- EGOERA FUNTZIOAK: $\Delta U = u_f - u_i$
- OREKA: - MEKANIKOA: $P_1 = P_2$ - TERMIKOA: $T_1 = T_2$

# 2.- ENERGIA ETA 1. PRINTZ.

- POTENTZIA: $P = F\,v = M \cdot w = \dot{W}$
- LANA:
  - $W^{DIS}$: IRREVERSIBLE
  - $W^{VOL}$: REVERSIBLE
  - LAN BOLUMETRIKOA: $W^{VOL} = \int_{V_1}^{V_2} P\,dv$ [P=KTE] $\boxed{W^{VOL} = P(V_2 - V_1)}$
    - $W^{VOL} > 0$ EXPANSIOA
    - $W^{VOL} < 0$ KONPRESIOA
  - LAN MEKANIKOA ($W^{DIS}$): $\boxed{W^{DIS} = P\,\tau = \dot{W}\,\tau}$
  - LAN ELEKTRIKOA ($W^{DIS}$): $\boxed{W^{DIS} = I^2 R\,\tau = V_R \cdot \tau = \frac{V^2}{R}\tau}$
- ETEKINA:
  - ENERGIA ZIKLOAK: 

  - BERO PONPAK: 


$\Delta U = 0$

$Q = W$

- POTENTZIA ZIKLOA (ENERGIA): $\eta = \frac{W_{ziklo}}{Q_H}$ $\quad W_{ziklo} = Q_H - Q_C$

- FRIGO. MAKINA (BERO PONPA): $COP_F = \beta = \frac{Q_C}{W_{ziklo}}$ ; $W_{ziklo} = Q_C - Q_H$

- BERO MAKINA (BERO PONPA): $COP_F = \gamma = \frac{Q_H}{W_{ziklo}}$ ; $W_{ziklo} = Q_C - Q_H$

- PROZESU FUNDAMENTALAK: [GP. BETI $\Delta H = C_p \Delta T$ ∩ $\Delta U = C_v \Delta T$]

1) ISOBARO (P=Kte): [G.I/R] $\Delta H = m C_p (T_2 - T_1)$ $\quad \Delta H = Q_{12}$

$W^{VOL} = P \cdot (V_2 - V_1)$

2) ISOKORO (V=Kte): $W^{VOL} = 0$

[G.I./R] $\Delta U = m C_v (T_2 - T_1)$ $\quad \Delta U = Q_{12}$

3) ISOTERMO (T=Kte): [G.I./R] $\Delta U = 0$ $\quad P \cdot V = Kte$ $\quad W^{VOL} = Q_{12}$

$W = R_m T \ln \frac{P_2}{P_1}$

4) ADIABATIKO (Q=0): $\Delta U = W$

[G.I./R] $PV^{\gamma} = Kte$ $\quad \gamma = \frac{C_p}{C_v}$

$TV^{\gamma-1} = Kte$

$PT^{\frac{\gamma}{1-\gamma}} = Kte$

$\Delta U = C_v (T_1 - T_2)$

- MAYER: $C_p - C_v = R$

DIATOM: $\gamma = \frac{7}{5}$ $\quad C_p = \frac{7}{2} R$ $\quad C_v = \frac{5}{2} R$

MONOATOM: $\gamma = \frac{5}{3}$ $\quad C_p = \frac{5}{2} R$ $\quad C_v = \frac{3}{2} R$

- POLITROPIKO: $PV^n = Kte$ $\quad n = \frac{C - C_p}{C - C_v}$

- ADIABATIKO: $PV^{\gamma} = Kte$ $\quad \gamma = \frac{C_p}{C_v}$ $\quad C = 0$

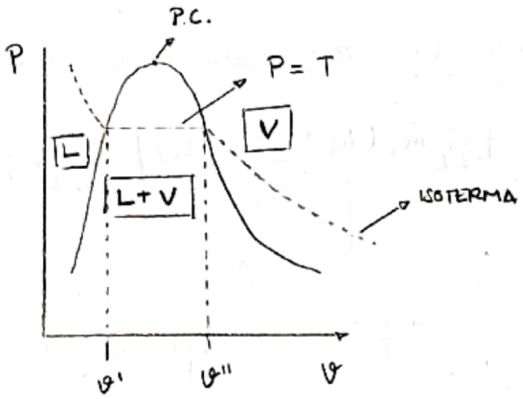
# 3.- SUBSTANTZIA PURU BATEN EZAUGARRIAK

- SUBSTANTZIA SINPLE: 2 ALDAGAI INDEPENDENTE

- TITULUA: $X = \frac{m_{LURRUN}}{m_{TOTALA}}$ $\quad X = \frac{v - v'}{v'' - v'}$ $\quad v = v' + X(v'' - v')$

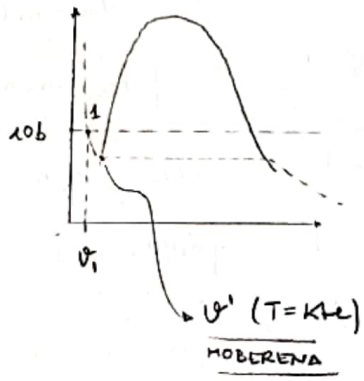
$v' = v_f \quad v'' = v_g$

- KANPAIA:




- KASU PARTIKULARRAK:

$P_0 < 25$ bar




$v_1 = v'$

$u_1 = u'$

$h_1 = u' + P v_1$

$S_1 = S'$

$P_0 > 25$ bar INTERPOLATU

- KONSTANTEAK:

$$R = 8{,}314 \frac{J}{K \cdot mol} = 8{,}31 \frac{m^3 KPa}{K \cdot mol} = 0{,}082 \frac{L \cdot atm}{K \cdot mol}$$

$$R_m \text{ (AIRE)} = 2{,}87 \frac{bar\ L}{K \cdot kg}$$

bar L = 0,1 kJ

1 bar $\simeq$ 1 atm

# 4.- KONTROL - BOLUMENEN ANALISIA

• DEF:

- FLUIDO INKONPRESIBLE: $\dot{V} = kte$
- EDOZEIN FLUIDO: $\dot{m} = kte$

$$\dot{m} = \rho \dot{V} = \rho \, v A = \frac{vA}{v}$$

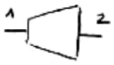
- REGIMEN GELDIKORRA: $\dot{m}_1 = \dot{m}_2$
- LAN TEKNIKOA: $\dot{W}^T = \int v \, dP$
- ENTALPIA: $h = u + pv$
- ENERGIAREN ERKAZIOA: (VC: VOLUMEN DE CONTROL)

$$\frac{dE_{VC}}{dt} = 0 = \dot{Q}_{VC} - \dot{W}_{VC} + \left[\sum_{i=1} \dot{m}_i \left(h_i + \frac{c_i^2}{2} + g z_i\right)\right] - \left[\sum_{j=1} \dot{m}_j \left(h_j + \frac{c_j^2}{2} + g z_j^2\right)\right]$$

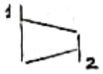
• ELEMENTUAK:

- **TOBERA** <ABIADURA HANDITU> 

$$h_2 - h_1 = \frac{1}{2}(C_1^2 - C_2^2)$$

- **HEDAZAILEA** <ABIADURA TXIKITU> 

$$h_2 - h_1 = \frac{1}{2}(C_1^2 - C_2^2)$$

- **KONPRESOREA** <PRESIOA HANDITU> (GAS) 

$$\dot{W}_{VC} = \dot{m}(h_1 - h_2)$$

- **PONPA** <PRESIOA HANDITU> (LIKIDO) 

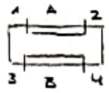
$$\dot{W}_{VC} = \dot{m}(h_1 - h_2)$$

- **TURBINA** <PRESIOA TXIKITU> 

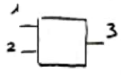
$$\dot{W}_{VC} = \dot{m}(h_1 - h_2)$$

- **BALBULA** <PRESIOA GALDU> 

$$\dot{m}(h_1 - h_2) = 0$$

- **BERO TRUKAGAILUA** <BEROA TRUKATU> 

$$\dot{m}_A(h_1 - h_2) + \dot{m}_B(h_3 - h_4) = 0$$
$$\Delta H_A = -\Delta H_B \;\wedge\; \dot{Q}_A = -\dot{Q}_B$$

- **FLAS GANBERA** <NAHASKETAK EGIN> 

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$$
$$m_1 + m_2 = m_3 \;\wedge\; P_1 = P_2 = P_3$$

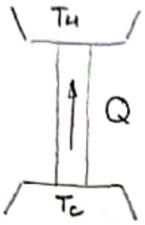
- **BERO ALDAGAILUA** <HOZKETA / BEROKETA> 

$$\dot{Q} = \dot{m}(h_2 - h_1)$$

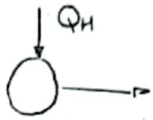
# 5. TERMODINAMIKAREN 2 LEGEA

- CLAUSIUS: Ezinezkoa FOKU HOTZETIK FOKU BERORA beroa transferitzea espontaneoki.

- KELVIN-PLANCK: Ezinezkoa BERO guztia LANEAN bihurtzea




CLAUSIUS




KELVIN-PLANCK

$Q_C = 0$

$\eta = 1$

- ONDORIOAK: $\boxed{W_{ZIKLO} \leq 0}$

- CARNOTEN KOROLARIOAK:

1) $\boxed{\eta_{IRR.} < \eta_{REV}}$ (REAL) (IDEAL) $\qquad \boxed{W_{IRR} < W_{REV.}}$

2) [FOKO TERMIKO ∈ ∩ MAKINAK Ⓡ]

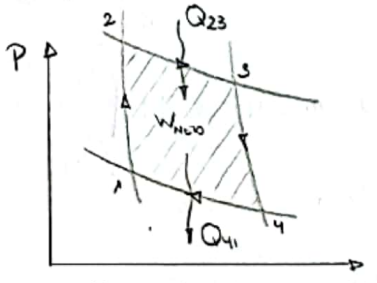
$\boxed{\eta_A = \eta_B} \qquad \boxed{W_A = W_B}$

- CARNOTEN ZIKLOA ETA ERRENDIMENDU MAX:

• POTENTZIA $\boxed{\eta_{max} = \frac{T_H - T_C}{T_H}}$ BERO MAK. $\boxed{\gamma_{max} = \frac{T_H}{T_H - T_C}}$ HOTZ MAK $\boxed{\beta_{max} = \frac{T_C}{T_H - T_C}}$

• CARNOT (ZIKLO IDEALA): $\eta = \frac{T_H - T_C}{T_H}$

2 ISOTERMO
2 ADIABATIKO
} ITZULGARRIAK




POTENTZIA

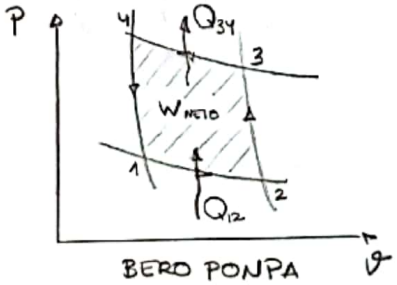
KELVIN

(I) $v_1 v_3 = v_2 v_4$

(II) $\frac{T_3}{T_2} = \left(\frac{P_3}{P_2}\right)^{\frac{K-1}{K}}$

(III) $\frac{T_3}{T_2} = \left(\frac{v_2}{v_3}\right)^{K-1}$

$W_{2-3}$ (ADIABATIKO Ⓐ) $= \frac{mR(T_3 - T_2)}{1-n}$




BERO PONPA

# 6. ENTROPIA ERABILTZEN

- SISTEMA ITXIA:

- PROZESU ITZULGARRIA:

$$S_2 - S_1 = \int_1^2 \frac{\delta Q}{T}$$

ANALISI MATEMATIKOA

$T\,ds = du + p\,dv$

$T\,ds = dh - v\,dp$

G.I / Q=0 / ITZULGARRI

$$\frac{P_2}{P_1} = \frac{P_2^r}{P_1^r} \quad \wedge \quad \frac{v_2}{v_1} = \frac{v_2^r}{v_1^r}$$

1) GAS IDEALAK

1.1) $$s_2 - s_1 = \int_{T_1}^{T_2} C_v(T)\,\frac{dT}{T} + R\ln\left(\frac{v_2}{v_1}\right)$$

1.2) $$s_2 - s_1 = \int_{T_1}^{T_2} C_p(T)\,\frac{dT}{T} - R\ln\left(\frac{P_2}{P_1}\right) \qquad \left[\int_{T_1}^{T_2} C_p\,\frac{dT}{T} = s_2^\circ(T_2) - s_1^\circ(T_1)\right]$$

2) GAS PERFEKTUAK

2.1) $$s_2 - s_1 = C_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{v_2}{v_1}\right)$$

2.2) $$s_2 - s_1 = C_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$$

2.3) $$s_2 - s_1 = C_v \ln\left(\frac{P_2}{P_1}\right) + C_p \ln\left(\frac{v_2}{v_1}\right)$$ [KONBINAZIOA]

3) SUBSTANTZIA KONPRIMAGAITZA

3.1) $$s_2 - s_1 = \int_{T_1}^{T_2} \frac{C(T)}{T}\,dT$$

- PROZESU ITZULEZINA:

$$S_2 - S_1 = \int_1^2 \frac{\delta Q}{T} + \sigma$$

$\sigma$ : PRODUZITUTAKO ENTROPIA

$\int_1^2 \frac{\delta Q}{T}$ : TRANSFERITUTAKO ENTROPIA

$S_2 - S_1$ : ENTROPIA DIFERENTZIA

PRODUZITUTAKO $\sigma$

$\sigma > 0 \rightarrow$ (I)

$\sigma = 0 \rightarrow$ (R)

$[\delta Q = m\,c\,dT = C\,dT]$

- SISTEMA IREKIA

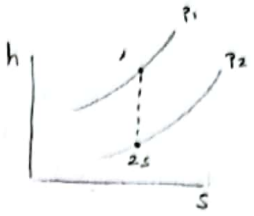
$$\frac{dS_{cv}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{\sigma}_{cv}$$

- ENTROPIA EZ DA KONTS.

EGOERA EGONKOR: $\frac{dS_{cv}}{dt} = 0$

- PROZESU ISOENTROPIKOA:

$$S_2 - S_1 = 0 \quad \text{n} \quad S_2 = S_1$$




- ERRENDIMENDU ISOENTROPIKOA:

- TURBINA

$$\eta_{TU} = \frac{\dot{W}_{cv}/\dot{m}}{(\dot{W}_{cv}/\dot{m})_s} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

- TOBERA

$$\eta_{TO} = \frac{V_2^2/2}{(V_2^2/2)_s}$$

- KONPRESOREA

$$\eta_{KO} = \frac{(-\dot{W}_{cv}/\dot{m})_s}{(-\dot{W}_{cv}/\dot{m})} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

- PONPA

$$\eta_{PO} = \frac{(-\dot{W}_{cv}/\dot{m})_s}{(-\dot{W}_{cv}/\dot{m})} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

# 7. EXERGIA

- [USO]: SISTEMA BATEK EMAN DIEZAGUKEN LANA, EZ DA KONTSERBAKORRA

- SISTEMA ITXIA:

$$B_2 - B_1 = (U_2 - U_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)$$

$$B_2 - B_1 = \int_1^2 \left(1 - \frac{T_0}{T}\right) \delta Q - \left[W - P_0(V_2 - V_1)\right] - T_0 \sigma$$

ΔB ASOCIADA AL Q | ΔB ASOCIADA AL W | EXERGIA DESTRUIDA

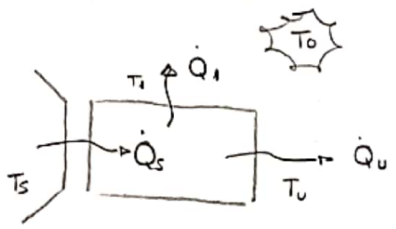
- SISTEMA IREKIA:

$$\frac{dB_{vc}}{d\tau} = \sum_j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j - \left(\dot{W}_{vc} - P_0 \frac{dV_{vc}}{d\tau}\right) + \sum_i \dot{m}_i b_i - \sum_e \dot{m}_e b_e - T_0 \dot{\sigma}$$

- $$0 = \sum_j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j - \dot{W}_{vc} + \sum_c \dot{m}_i b_i - \sum_e \dot{m}_e b_e - T_0 \dot{\sigma}$$

- $$b_{f1} - b_{f2} = (h_1 - h_2) - T_0(s_1 - s_2) + \frac{v_1^2 - v_2^2}{2} + g(z_1 - z_2)$$

- EFIZIENTZIA:




$$\varepsilon = \frac{\left(1 - \frac{T_0}{T_U}\right) \dot{Q}_u}{\left(1 - \frac{T_0}{T_S}\right) \dot{Q}_S}$$

$\varepsilon < 1$ ITZULGAITZ

$\varepsilon = 1$ ITZULGARRI

· ELEMENTUETAN:

TURBINA $$\varepsilon = \frac{\dot{W}_{vc}/\dot{m}}{b_{f1} - b_{f2}}$$

KONPRESOREA $$\varepsilon = \frac{b_{f1} - b_{f2}}{\dot{W}_{vc}/\dot{m}}$$

BONBA $$\varepsilon = \frac{b_{f1} - b_{f2}}{\dot{W}_{vc}/\dot{m}}$$

BT $$0 = \dot{m}_h(b_{f1} - b_{f2}) + \dot{m}_c(b_{c4} - b_{c3}) - \dot{B}_u$$

$$\varepsilon = \frac{\dot{m}_c(b_{c4} - b_{c3})}{\dot{m}_h(b_{f1} - b_{f2})}$$