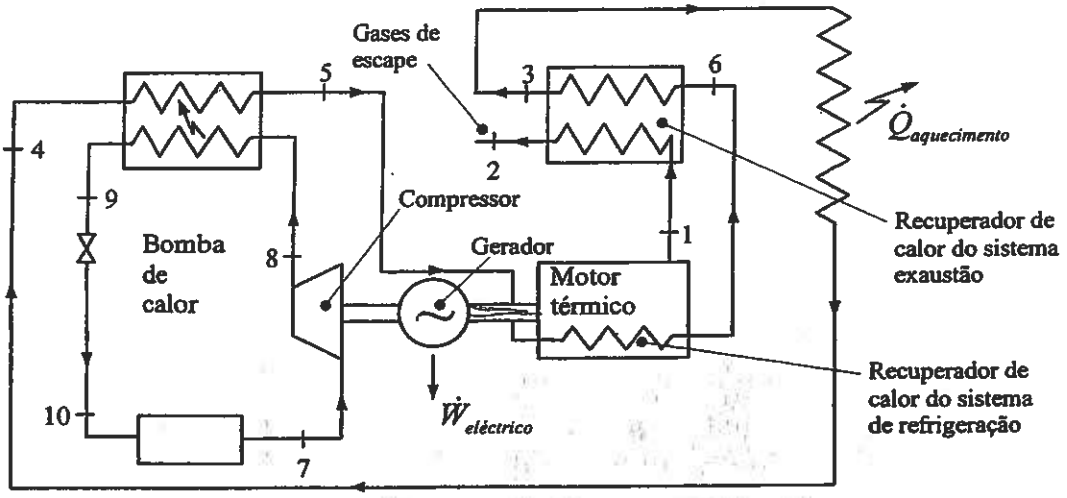
Universidade do Porto
Faculdade de Engenharia
FEUP

Exame de Máquinas Térmicas (parte prática)

DEMEGI 2005/2006

Duração 2h — 26/6/2006

A instalação experimental de trigeração (produção simultânea de electricidade, calor e frio) representada na figura, instalada numa habitação unifamiliar, está a funcionar no modo Inverno, ou seja, a máquina frigorífica passou a trabalhar como bomba de calor para assim contribuir para compensar as necessidades de aquecimento, $\dot{Q}_{aquec.}$, da habitação. O motor térmico, Honda GX 360 K1, acciona em simultâneo um gerador eléctrico e o compressor da bomba de calor.



Os dados conhecidos da instalação são os seguintes:

Motor térmico:	$(m_{ar}/m_{comb})_{esteq}$=17	PCI=44960 kJ/kg	$C_{p,\,produtos}$=1.08 kJ/(kg·K)
	$\dot{m}_{comb}$ =7.23×10^{-4} kg/s	Custo comb. 0.58 €/kg	Ciclo Otto
	$P_{admissão}$=760 mmHg	$T_{admissão}$=15 °C	Caudal de ar admitido no motor, 7.30 ×10^{-3} m^3/s (P=$P_{adm.}$, T=$T_{adm.}$)
	4 tempos	Gases escape, T_1= 617 °C, T_2= 119 °C	Cilindrada= 359 cm^3
	Taxa comp. ε =8.5	n = 2500 rpm	P.m.e.=962 kPa
Gerador:	$\eta_{Gerador}$= 77%		
Circuito de água, 3-4-5-6:	$\dot{Q}_{5-6}$ =11.1 kW	$\dot{m}_3$ = 0.123 kg/s (líq. comprimido em todo o circuito, 3-4-5-6)	T_6=80 °C
Bomba de calor, 7-8-9-10 (Fluido R134a)	h_7= 240.3 kJ/kg	h_8=282.7 kJ/kg	h_{10}= 93.03 kJ/kg
	$\dot{m}_{R134a}$ = 0.0785 kg/s	$\eta_{mec.\,comp.}$=90%	Cilindrada do compressor 161 cm^3

Determine:

a) (4.0 val.) Relativamente ao motor térmico: a potência efectiva, o binário motor, o rendimento volumétrico, o defeito de ar e o consumo específico.
b) (3.0 val.) A eficiência do permutador de calor 1-2-3-6.
c) (2.5 val.) O rendimento teórico e o quociente trabalho efectivo/trabalho teórico do motor.
d) (2.0 val.) O COP da bomba de calor.
e) (4 val.) A potência calorífica disponível para aquecimento da casa, $\dot{Q}_{aquec.}$, e a potência eléctrica produzida, $\dot{W}_{eléctrico}$.
f) (2 val.) A eficiência global da instalação.
g) (2.5 val.) O custo do kWh da energia útil produzida, $\dot{Q}_{aquec.} + \dot{W}_{eléctrico}$.

dados do exercício

$AC = 17$ $PCI = 44960$ $Cp = 1.08$ $m_{comb} = 0.000723$

$custo_{comb} = 0.58$ $P_{adm} = 760$ $T_{adm} = 15$ $V_{ar} = 0.0073$

$T_1 = 617$ $T_2 = 119$ $cilind = 359$ $pme = 962$ $TaxaC = 8.5$

$n = 2500$ $Rend_{geral} = 0.77$ $Q_{ss} = 11.1$ $m_3 = 0.123$ $T_6 = 80$

$h_7 = 240.3$

$h_8 = 282.7$ $h_{10} = 93.03$ $m_{refri} = 0.0785$ $Rend_{comp} = 0.9$

$cilin_{comp} = 161$

Alínea a)

$$Ne = pme \cdot \left|0.000001 \cdot \frac{m^3}{cm^3}\right| \cdot cilind \cdot \frac{n}{2} \cdot \left|0.016667 \cdot \frac{s^{-1}}{min^{-1}}\right|$$

$$Bin \cdot \pi \cdot 2 \cdot n \cdot \left|0.016667 \cdot \frac{s^{-1}}{min^{-1}}\right| = Ne$$

$$Rend_{volu} = \frac{V_{ar}}{\left|0.000001 \cdot \frac{m^3}{cm^3}\right| \cdot cilind \cdot \frac{n}{2} \cdot \left|0.016667 \cdot \frac{s^{-1}}{min^{-1}}\right|}$$

$$1 - d = \frac{1}{r} \qquad r = \frac{AC}{AC_{real}} \qquad AC_{real} = V_{ar} \cdot \frac{\rho_{ar}}{m_{comb}}$$

$$\rho_{ar} = \rho\left['Air', T = T_{adm}, P = P_{adm} \cdot \left|0.133322 \cdot \frac{kPa}{mmHg}\right|\right]$$

$$Ce = m_{comb} \cdot \left|1000 \cdot \frac{g/s}{kg/s}\right| \cdot \frac{t}{Ne \cdot t \cdot \left|0.000277778 \cdot \frac{kWh}{kJ}\right|} \qquad t = 3600$$

Alínea b)

$m_{produtos} = m_{comb} + V_{ar} \cdot \rho_{ar}$ o fluido com o m*cp mínimo é o proveniente dos produtos de combustão logo

$$efici_{permut} = \frac{m_{produtos} \cdot Cp \cdot [T_1 - T_2]}{m_{produtos} \cdot Cp \cdot [T_1 - T_6]}$$

Alínea c)

$$Rend_{Otto} = 1 - \frac{1}{TaxaC^{[\gamma - 1]}} \qquad \gamma = 1.4$$

$$WeWt = \frac{Rend_{global}}{Rend_{Otto}} \qquad Rend_{global} = \frac{\left|1000 \cdot \frac{g}{kg}\right|}{Ce \cdot PCI \cdot \left|0.000277778 \cdot \frac{kWh}{kJ}\right|}$$

Alínea d)

$$COP_{BC} = \left[\frac{h_8 - h_9}{h_8 - h_7}\right] \cdot Rend_{comp} \qquad h_9 = h_{10} \qquad Q_{89}/W_{78}$$

Alínea e)

$$Q_{aquec} = Q_{45} + Q_{56} + Q_{63} \qquad Q_{45} = m_{refri} \cdot [h_8 - h_9]$$

$$Q_{63} = m_{produtos} \cdot Cp \cdot [T_1 - T_2]$$

$$Pot_{eléct} = [Ne - Pot_{comp}] \cdot Rend_{gerad} \qquad Pot_{comp} = m_{refri} \cdot \left[\frac{h_8 - h_7}{Rend_{comp}}\right]$$

Alínea f)

$$Efic_{instalação} = \frac{Q_{aquec} + Pot_{eléct}}{m_{comb} \cdot PCI}$$

Alínea g)

$$Custo_{Eutil} = \frac{Custo_{Ebruta}}{Efic_{instalação}} \qquad Custo_{Ebruta} = \frac{custo_{comb}}{PCI \cdot \left|0.000277778 \cdot \frac{kWh}{kJ}\right|}$$

SOLUTION

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

AC = 17 [-]	AC_{real} = 12.37 [-]	Bin = 0.02748 [kN*m]
Ce = 361.7 [g/kWh]	cilind = 359 [cm^3]	$cilin_{comp}$ = 161 [cm^3]
COP_{BC} = 4.026 [-]	Cp = 1.08 [kJ/kg-K]	$custo_{comb}$ = 0.58 [€/kWh]
$Custo_{Ebruta}$ = 0.046 [€/kWh]	$Custo_{Eutil}$ = 0.0446 [€/kWh]	d = 0.2724 [-]
$efici_{permut}$ = 0.927 [-]	$Efic_{instalação}$ = 1.042 [-]	γ = 1.4 [-]
h_{10} = 93.03 [kJ/kg]	h_7 = 240.3 [kJ/kg]	h_8 = 282.7 [kJ/kg]
h_9 = 93.03 [kJ/kg]	m_3 = 0.123 [kg/s]	m_{comb} = 0.000723 [kg/s]
$m_{produtos}$ = 0.009666 [kg/s]	m_{refri} = 0.0785 [kg/s]	n = 2500 [min^{-1}]
Ne = 7.195 [kW]	PCI = 44960 [kJ/kg]	pme = 962 [kPa]
Pot_{comp} = 3.698 [kW]	$Pot_{eléct}$ = 2.69 [kW]	P_{atm} = 760 [mmHg]
Q_{45} = 14.89 [kW]	Q_{56} = 11.1 [kW]	Q_{63} = 5.199 [kW]
Q_{aquec} = 31.2 [kJ/s]	r = 1.374 [-]	$Rend_{comp}$ = 0.9 [-]
$Rend_{gerad}$ = 0.77 [-]	$Rend_{global}$ = 0.221 [-]	$Rend_{Otto}$ = 0.575 [-]
$Rend_{volu}$ = 0.976 [-]	ρ_{ar} = 1.225 [kg/m^3]	t = 3600 [s]
TaxaC = 8.5 [-]	T_1 = 617 [C]	T_2 = 119 [C]
T_6 = 80 [C]	T_{atm} = 15 [C]	V_{ar} = 0.0073 [m^3/s]
WeWt = 0.385 [-]		

2 potential unit problems were detected.

KEY VARIABLES

Ne = 7.195 [kW]	*a) Ne*
Bin = 0.02748 [kN*m]	*a) binário*
$Rend_{volu}$ = 0.976 [-]	*a) Rendimento volumétrico*
d = 0.2724 [-]	*a) defeito de ar*
Ce = 361.7 [g/kWh]	*a) consumo específico*
$efici_{permut}$ = 0.927 [-]	*b) eficiência do permutador*
$Rend_{Otto}$ = 0.575 [-]	*c) Rendimento teórico*

$We_{Wt} = 0.385$ [-]	*c) quociente Wefectivo/Wteórico*
$COP_{BC} = 4.026$ [-]	*d) COP bomba de calor*
$Q_{aquec} = 31.2$ [kJ/s]	*e) Calor de aquecimento da casa*
$Pot_{eléct} = 2.69$ [kW]	*e) potência eléctrica gerada*
$Efic_{instalação} = 1.042$ [-]	*f) eficiência da instalação*
$Custo_{Eútil} = 0.0446$ [€/kWh]	*g) custo da energia útil*

EXAME 26.06.2006.

a.

Ne?

$$Ne = pme \cdot \text{CILINDRADA} \cdot \frac{n}{60A} = 962 \times 359 \times 10^{-6} \times \frac{2500}{60 \times 2} \simeq 7,195 \text{ kW}$$

BINÁRIO?

$$Ne = \text{BINÁRIO} \times \omega \rightarrow 7,195 = \text{BINÁRIO} \times \frac{2\pi \cdot 2500}{60}$$

$$\text{BINÁRIO} \simeq 0,02748 \text{ kN.m}$$

η_V ?

$$\eta_V = \frac{\dot{V}_{AR,ADMITIDO}}{\text{CILINDRADA} \cdot \frac{n}{60.A}} = \frac{7,30 \times 10^{-3}}{359 \times 10^{-6} \cdot \frac{2500}{60 \times 2}} \simeq 0,976 = 97,6\%$$

d?

$$1 - d = \frac{1}{R} \rightarrow 1 - d = \frac{1}{1,375} \rightarrow d \simeq 0,273 = 27,3\%$$

R?

$$R = \frac{\left(\dot{m}_{ar}/\dot{m}_{comb}\right)_{esteq}}{\left(\dot{m}_{ar}/\dot{m}_{comb}\right)_{real}} = \frac{17}{\frac{8,94 \times 10^{-3}}{7,23 \times 10^{-4}}} \simeq 1,375$$

$\dot{m}_{ar}$ = ?

$$\dot{m}_{ar} = \dot{V}_{ar}\, \rho_{ar} = 7,3 \times 10^{-3} \times 1,225 \simeq 8,94 \times 10^{-3} \text{ kg/s}$$

$$\downarrow$$

$$P = \rho_{ar} R T \rightarrow \rho_{ar} = \frac{0,760 \times 13600 \times 9,8}{287 \times (273,15 + 15)} \simeq 1,225 \text{ kg/m}^3$$

ce ?

$$Ce = \frac{\dot{m}_{comb} \cdot 3600}{Ne} = \frac{7,23 \times 10^{-4} \times 10^3 \cdot 3600}{7,195} \simeq 361,8 \text{ g/Kwh}$$

b. $\varepsilon_{\text{PERMUTADOR}}$?

$$\varepsilon_{\text{PERMUTADOR}} = \frac{\dot{m}_{prod.}\, c_p\, [T_1 - T_2]}{\dot{m}_{prod}\, c_p\, (T_3 - T_6)} = \frac{T_1 - T_2}{T_3 - T_6} = \frac{617 - 119}{617 - 80} \simeq 0{,}927 = \underline{\underline{92{,}7\%}}$$

$T_3 = T_1$

c. η_t ?

$$\eta_t = 1 - \frac{1}{\varepsilon^{\gamma - 1}} = 1 - \frac{1}{8{,}5^{0{,}4}} \simeq 0{,}575 = \underline{\underline{57{,}5\%}}$$

$\gamma \simeq 1{,}4$

$\frac{Ne}{Nt}$ $\frac{We}{Wt}$? $\qquad \frac{We}{Wt} = \frac{\eta_G}{\eta_t} = \frac{0{,}221}{0{,}575} \simeq \underline{\underline{0{,}384}}$

$$\eta_G = \frac{3600 \times 100}{Ce\ \ PCI} = \frac{3600 \times 100}{361{,}8 \times 44960} \simeq 0{,}221 \ \ 22{,}1\%$$

d. COP_{BC} ?

$$COP_{BC} = \frac{Q_A}{W} \cdot \eta_{mec,c} = \frac{{}_8Q_9}{{}_7W_8}\, \eta_{mec,c} = \frac{h_8 - h_9}{h_8 - h_7}\, \eta_{mec,c}$$

"$\dot{Q}_A + \dot{m}_9 h_9 = \dot{m}_8 h_8$" $\qquad h_9 = h_{10}$

$Q_A = \dot{m}_8 (h_8 - h_9)$

$$COP_{BC} = \frac{282{,}7 - 93{,}03}{282{,}7 - 240{,}3} \times 0{,}90 = \underline{\underline{4{,}026}}$$

e. $\dot{Q}_{aq}$?

$$\dot{Q}_{AQ} = {}_4\dot{Q}_5 + {}_5\dot{Q}_6 + {}_6\dot{Q}_3$$

$${}_4\dot{Q}_5 = {}_8\dot{Q}_9 = \dot{m}_8 (h_8 - h_9)$$

$\dot{m}_8 \;!!\; \dot{m}_{R134a}$

$${}_6\dot{Q}_3 = {}_1\dot{Q}_2 = \dot{m}_{prod} \cdot c_{p\,prod} (T_1 - T_2)$$

c. $\dot{m}_{COMB/cil/ciclo}$?

$\dot{m}_{COMB} = 0{,}61$ g/s

$$\dot{m}_{COMB/cil/ciclo} = \frac{\dot{m}_{COMB}}{i \cdot \frac{n}{60A}} = \frac{0{,}61}{2 \cdot \frac{2480}{60 \times 2}} = 0{,}0148 \text{ g}$$

d. Ne_2 ?

$$Ne_2 = Ne \cdot \frac{P_2}{P_{AMB_1}} \left(\frac{T_{AMB_1}}{T_{AMB_2}}\right)^{1/2} = 4{,}2 \cdot \frac{714{,}7}{760} \left(\frac{273{,}15+15}{273{,}15+35}\right)^{1/2} \simeq 6{,}27 \text{ kW}$$

$P_2 = P_{AMB_2} - \phi \cdot P_{SAT}(T_{AMB_2})$ ($T_{AMB_2} \simeq 35°C$)

$= 740 - 0{,}60 \times \frac{0{,}05733 \times 9{,}8 \times 10^4}{13600 \times 9{,}8 \times 10^{-3}}$

$\simeq 714{,}7$ mmHg

$P_{SAT}(T=35°) = 0{,}05733$ at

$Pa = \text{mmHg} \times 10^{-3} \times 13600 \times 9,$

$\text{mmHg} = \frac{Pa}{13600 \times 9{,}8 \times 10}$

e. $\dot{m}_{R134a}$?

$$Pot_{elect,C} \cdot \eta_{mec,C} = \dot{m}_{refr.}(h_8 - h_7)$$

$Pot_{elect,C} = {}_7\dot{W}_8$

$$Ne = \frac{Pot_{ELECT,G}}{\eta_{GER}} + Pot_{ELECT,C} \rightarrow Pot_{elect.comp} = 4{,}2 - \frac{2}{2{,}75} \simeq 4{,}53 \text{ kW}$$

$4{,}53 \times 0{,}91 = \dot{m}_{R134a}(285 - 2\cdot\cdot)$

$\dot{m}_{R134a} \simeq 0{,}0234$ kg/s

$\dot{V}_{R134a}$?

$$\eta_{V,COMP} = \frac{\dot{V}_{R134a}}{\text{CILINDRATA} \cdot \frac{n}{60}} \Rightarrow 0{,}80 = \frac{\dot{V}_{R134a}}{161 \times 10^{-6} \cdot \frac{2480}{60}} \rightarrow \dot{V}_{R134} = 5{,}32 \times 10^{-3} \text{ m}^3$$

f. ${}_{10}\dot{Q}_7$?

$${}_4\dot{Q}_5 = {}_7\dot{W}_8 \cdot \eta_{m.c} + {}_{10}\dot{Q}_7$$

$\parallel$ Pot_{comp}

${}_4\dot{Q}_5 = ?$

$$\dot{Q}_{AQ} = {}_4\dot{Q}_5 + {}_5\dot{Q}_6 + {}_6\dot{Q}_3 \rightarrow 31,1 = {}_4\dot{Q}_5 + 11,1 + 4,93 \rightarrow {}_4\dot{Q}_5 = 15,07 \text{ kW}$$

$${}_6\dot{Q}_3 = \dot{m}_{prod} \, C_{p\,produtos} \, (T_1 - T_2)$$

$$\dot{m}_{prod} = \dot{m}_{ar} + \dot{m}_{comb} = 8,55 \times 10^{-3} + 6,11 \times 10^{-4} = 9,161 \times 10^{-3} \text{ kg/s}$$

$${}_6\dot{Q}_3 = 9,161 \times 10^{-3} \times 1,08 \times (617 - 119) = 4,93 \text{ kW}$$

$$\therefore \quad 15,07 = 4,53 \times 0,91 + {}_{10}\dot{Q}_7 \rightarrow {}_{10}\dot{Q}_7 = \underline{10,95} \text{ kW}$$

g. $\dot{m}_{CO_2}/kWh$?

$$\dot{m}_{CO_2} = \dot{m}_{prod} \cdot Y_{CO_2} \cdot \frac{1}{W_{ELECT} + \dot{Q}_{AQ}}$$

$$= 9,161 \times 10^{-3} \times 3600 \times 0,08 \times \frac{1}{2 + 31,1} \simeq 0,0797 \text{ kg/kWh} = \underline{79,7} \text{ g/kWh}$$

Exame 26/06/2006

Maquina frigorifica → Bomba de calor

a) Motor térmico:

Potência efectiva: $Ne = pme \underbrace{\left(\frac{\pi d^2}{4}\right) \times l \times i}_{\text{cilindrada}} \times \left(\frac{n}{A}\right) \times \frac{1}{60}$ (A ↓ tempo)

cilindrada = 359 cm³

pme = 962 KPa $\quad Ne = 962 \times 359 \times 10^{-6} \times \frac{2500}{2 \times 60} = \underline{7,195\ KW}$

Binário:

$Ne = B \times w \ (\Leftrightarrow) \ 7,195 = B \times \frac{2\pi \times 2500}{60} \ (\Leftrightarrow) \ B = 0,027\ KNm$

Rendimento: $\eta vol = \frac{V real}{V max \rightarrow geom} = \frac{m real}{\rho real\ Vc} = \frac{\dot{m} real}{\dot{m} max} = \frac{\rho_e \dot{v}_e}{\rho_e Vc \frac{n}{A} \times 60}$

$\eta vol\ um = \frac{V\ admitido}{cilindrada \frac{n}{60.A}} = \frac{730 \times 10^{-3}}{359 \times 10^{-6} \times \frac{2500}{60 \times 2}} = \underline{97,6\%}$

d: $1 - d = \frac{1}{R} \ (\Leftrightarrow) \ 1 - d = \frac{1}{1,37} \ (\Leftrightarrow) \ d = 0,27 = \underline{27\%}$

$R = \frac{\left(\dot{m}_{ar}/\dot{m}_{comb}\right)_{estq}}{\left(\dot{m}_{ar}/\dot{m}_{comb}\right)_{real}} = \frac{17}{\frac{8,94 \times 10^{-4}}{7,23 \times 10^{-4}}} = 1,37$

$\dot{m}_{ar} = ?$ $\quad \dot{m} = \dot{v}_{ar} \cdot \rho = 7,3 \times 10^{-3} \times 1,225 = 8,94 \times 10^{-4}\ Kg/s$

$\rho = ?$ $\quad p = \rho R T \Leftrightarrow \rho = \frac{p}{RT} = \frac{0,76 \times 13600 \times 9,8}{287 \times (15 + 273,15)} = 1,225\ Kg/m^3$

Consumo específico (ce):

$ce = \frac{\dot{m} \times 3600}{Ne} = \frac{7,23 \times 10^{-4} \times 3600 \times 10^3}{7,195} = 361,8\ g/Kwh$

b) Eficiência do permutador de calor 1-2-3-4

$\varepsilon = \frac{Q\ trocado}{Q\ max} = \frac{\dot{m} \Delta h}{(\dot{m} cp)_{min} \times \Delta T} = \frac{\dot{m} cp \times \Delta T}{(\dot{m} cp)_{min} (T_{frio} - T_{frio})}$

$\varepsilon = \frac{\cancel{m_{prod}}\ \cancel{cp}\ (T_1 - T_2)}{\cancel{m_{prod}}\ \cancel{cp}\ (T_3 - T_6)} = \frac{T_1 - T_2}{T_3 - T_6} = \frac{617 - 119}{617 - 80} \simeq 0,927 = 92,7\%$

$T_1 = T_3$

c)

$\eta t = ?$ $\qquad \eta t = 1 - \frac{1}{\varepsilon^{\gamma-1}} = 1 - \frac{1}{8{,}5^{1{,}4-1}} = 57{,}5\%$

$\frac{W_{efec}}{W_{teorico}} = ?$ $\qquad \varepsilon = 8{,}5$

$\frac{W_{efec}}{W_{teorico}} = \frac{N_e}{N_t} = \frac{\eta_g}{\eta_t} = \frac{0{,}2213}{0{,}575} = 0{,}384$

$\eta_g = \frac{3600 \times 1000}{C_e \times PCI} = \frac{3600 \times 1000}{361{,}8 \times 44960} = 0{,}221 = 22{,}13\%$

d)

$COP_{BC} = ?$ $\qquad COP_{BC} = \frac{Q_A}{W} \cdot \eta_{mec} = \frac{{}_8Q_9}{{}_7W_8} \eta_{mec} = \frac{h_8 - h_9}{h_8 - h_7} \cdot \eta_{mec}$

$\dot{Q}_A + \dot{m}_9 h_9 = \dot{m}_8 h_8$

$Q_A = \dot{m}_8 (h_8 - h_9)$ $\qquad h_9 = h_{10}$

$COP_{BC} = \frac{282{,}7 - 93{,}03}{282{,}7 - 240{,}3} \times 0{,}9 = 4{,}026$

e) $\dot{Q}_{aquec} = ?$

$\dot{W}_{electrica} = ?$

$\dot{Q}_{AQ} = {}_4\dot{Q}_5 + {}_5\dot{Q}_6 + {}_6\dot{Q}_3$

${}_4\dot{Q}_5 = {}_8\dot{Q}_9 = \dot{m}_8 (h_8 - h_9) = 0{,}0785 (282{,}7 - 93{,}03) = 14{,}89$ KW

${}_6\dot{Q}_3 = {}_1\dot{Q}_2 = \dot{m}_{prod} \times c_p (T_1 - T_2) = (\dot{m}_{ar} + \dot{m}_{comb}) \times 1{,}08 \times (617 - 119)$

${}_6\dot{Q}_3 = (7{,}23 \times 10^{-4} + 8{,}94 \times 10^{-3}) \times 1{,}08 \times 498 = 5{,}19$ KW

$\dot{Q}_{AQ} = 14{,}84 + 11{,}1 + 5{,}19 = \underline{\underline{31{,}1 \text{ KW}}}$

$\dot{W}_{elec} = ?$

$\dot{W}_{elec} = (N_e - \dot{W}_c)\, \eta_{GER}$ $\qquad \eta_{GER} = \frac{\dot{W}_{elec}}{\dot{W}_{veio}}$

$\dot{W}_c \cdot \eta_m = \dot{m}_{R134} (h_8 - h_7) \rightarrow \dot{W}_c \times 0{,}9 = 0{,}0785 \Leftrightarrow \dot{W}_c = 3{,}698$ KW

$\dot{W}_{elec} = (7{,}195 - 3{,}698) \times 0{,}77 = \underline{\underline{2{,}69 \text{ KW}}}$

f) $\text{Eficiência}_{INST} = \frac{\dot{Q}_{AQ} + \dot{W}_{elec}}{\dot{W}_{comb} \cdot PCI} = \frac{31 + 2{,}69}{7{,}23 \times 10^{-4} \times 44960} \simeq 1{,}055$

g) $\dot{Q}_{aq} + \dot{W}_{elec}$

Custo da energia Bruta $= \frac{0{,}58 (€/Kg)}{\frac{4490}{3600}} = 0{,}046$ €/KWh

1KWh — 3600 Kg

$UM_2 = \frac{0{,}046}{1{,}055}$

d - defeito de ar

$1-d = \frac{1}{r} = 27,2\%$

$$r = \frac{\left(\frac{\dot{m}\,ar}{\dot{m}\,comb}\right)_{est}}{\left(\frac{\dot{m}\,ar}{\dot{m}\,comb}\right)_{real}} = 1,37$$

$$\left(\frac{\dot{m}\,ar}{\dot{m}\,comb}\right)_{real} = \frac{\dot{m}\,ar}{\dot{m}\,comb} = 12,37$$

$\dot{m}\,ar = \dot{V}\,\rho_{ar}$ $\qquad \rho_{ar} = \frac{P}{RT} = \frac{101325}{287 \times 288}$

$$Pe = \frac{\dot{m}\,comb \times 3600}{Ve} = 361,7\ g/kwh$$

b)

$$\varepsilon = \frac{\varphi\ trocado}{(\dot{m}\,cp)_{mínimo}\ \Delta T\ máx} = \frac{(\dot{m}\,cp)\ productos\ (T_1 - T_2)}{\dot{m}\,cp\ productos\ (T_1 - T_6)}$$

$$= \frac{617 - 111}{617 - 50}$$

$$= 92,7\%$$

água $\quad \dot{m} = 0,123\ kg/s$

$cp = 4,18$

gases $\quad \dot{m} = \dot{m}\,comb + \dot{m}\,ar$

$= 9,67\ g/s$

$cp = 1,08\ kg/kgK$

$\dot{m}\,cp_{productos} = \dot{m}\,cp_{mínimo}$

c)

$\eta_{teórico}$, $\frac{N_e}{N_t}$

$\eta_{otto} = 1 - \frac{1}{\varepsilon^{\gamma-1}} = 57,5\%$

$\gamma = 1,4$

$\eta_{global} = \eta_t \times \eta_i \times \eta_{mec} = \frac{N_t}{\varphi} \times \frac{N_i}{N_t} \times \frac{N_e}{N_i}$ → $\frac{N_e}{N_t}$

$\frac{N_e}{N_i} = \frac{\eta_{global}}{\eta_t} = 38,5$

$\eta_{global} = \frac{3600 \times 1000}{C_e \times PCI} = \frac{N_e}{\dot{m}_{comb} \times PCI} = 22,1\%$

d) $COP = \frac{{}_8\dot{\varphi}_9}{\dot{W}_{vcio\ compressor}} = 4,47 \times 0,9 = 4,023$

${}_8\dot{\varphi}_9 = (h_8 - h_9)\,\dot{m}$

$h_9 = h_{10}$

$\dot{W}_{vcio} = \frac{(h_8 - h_7)\,\dot{m}}{\eta_{mecânico}}$

e)

$\dot{W} = (N_e - \dot{W}_{vcio\ compressor}) \times \eta_{gerador} = 2,69\ kW$

$\dot{\varphi}_{aquecimento} = {}_4\dot{\varphi}_5 + {}_5\dot{\varphi}_6 + {}_6\dot{\varphi}_3 = 31,2\ kW$

${}_4\varphi_5 = \varphi_{89} = 14,89\ kW$

${}_5\varphi_6 = 11,1\ kW$

${}_6\varphi_3 = \dot{\varphi}_2 = \dot{m}_{produ\ c\ produto}\,(T_1 - T_2) = 5,20\ kW$

f) $\eta = \frac{W + Q_{aquec}}{m_{comb} \times PCI} = 1,04$

$0 < \eta < 100$

$0 < \eta < 1$

g) Custo da energia útil = $\frac{\text{Custo energia bruta}}{\text{Eficiência}} = \frac{0,047}{1,04} = 0,044 €/kWh$

0,58 €/kg

PCI = 44960

1 kW — 1 kg/h

1 kWh = 3600 kJ

$\frac{44960}{3600} = 12,49$ kWh/kg

Custo energia bruta = $\frac{0,58}{12,49} = 0,047 €/kWh$

E/h
Custo/hora

Resolução do exame de 02-07-1997

a)

n, P_{mi}, B, η_{ind}

$\nabla = \frac{2 l n}{60} \Rightarrow n =$

→ $N_e \times \eta_{generador}$ = Pot electrica

$N_e = P_{me} \cdot C \cdot \frac{n}{60 \times 2} \longrightarrow P_{me}$

$C = \phi^2 \frac{\pi}{4} l_i$

$P_{mi} = P_{me} + P_{mp}$

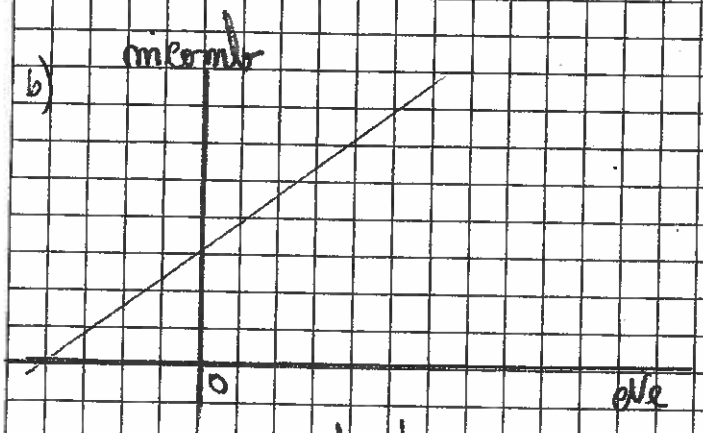
→ $B \cdot \omega = N_e \longrightarrow B = \frac{N_e}{\omega} = \frac{N_e}{\frac{2\pi n}{60}}$

→ $\eta_{ind} = \frac{N_i}{N_t}$, $\eta_{ind} = \frac{\eta_{global}}{\eta_t \times \eta_{mec}}$

$\eta_{mec} = \frac{P_{me}}{P_{mi}}$

$\eta_t = 1 - \frac{1}{\varepsilon^{\alpha-1}} \times \frac{\delta^{\gamma}(\rho-1)}{(\rho-1) + \gamma\rho(\delta-1)}$

b)



N_p = constante

$\eta_{Mec} = \frac{N_e}{N_i} = \frac{N_e}{N_e + N_P}$

$N_e = 0$ $\quad N_i = N_P$