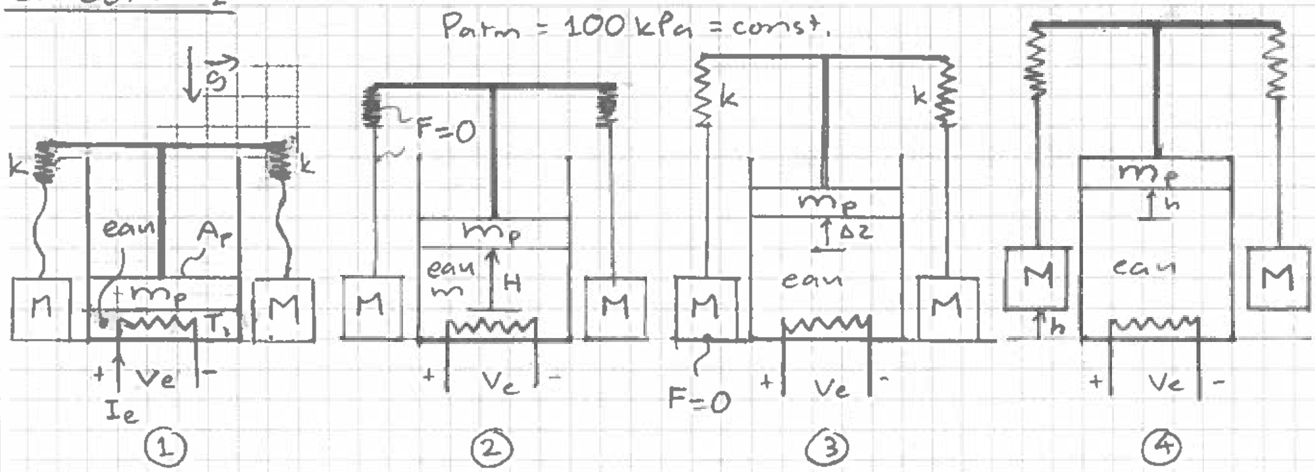
Réponses

Question 1



$m = 0{,}04$ kg
$T_1 = 25°C$

$H = 14.17142$ cm $= 0.1417142$ m

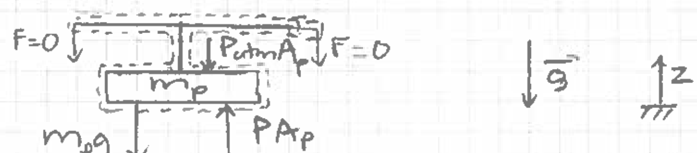
$h = 4.5102$ cm $= 0.045102$ m
$\Delta t_{14} = 60$ min

a) P, phase à ①
b) P, T, phase (& x) à ②, ③, ④
c) Diagramme P-v
d) $W_{\text{par eau}} = ?$
e) $I_e = ?$

- $m_p = 500$ kg
- $A_p = 0.0981\ m^2$
- $M = 750$ kg
- $k = 70.1394$ kN/m (ressort linéaire)
- Processus quasi-statique
- friction négligeable
- masses cordes, ressorts $\simeq 0$
- $\Delta E_{p\,eau} \simeq 0$
- déformations négligeables
- $Q_{eau} = 0$
- $\Delta U_{solides} \simeq 0$

Suppositions additionnelles : aucune

a) P_1, phase$_1$ = ? : de ① à ②



$$\sum F_z = PA_p - P_{atm}A_p - m_p g = m_p \cancel{a_p} \xrightarrow{} 0 \text{ quasi-statique}$$

$$P = P_{atm} + \frac{m_p g}{A_p} \quad (= \text{const.} = P_1 = P_2)$$

$$P_1 = P_2 = 100\text{ kPa} + \frac{(500\text{ kg})(9.81\ \frac{m}{s^2})}{(0.0981\ m^2)} \times \frac{1\text{ kPa}}{10^3\ \frac{kg\cdot m/s^2}{m^2}}$$

$$\boxed{P_1 = P_2 = 150\text{ kPa}}$$

$\left.\begin{array}{l} P_1 = 150\text{ kPa} \\ T_1 = 25°C \end{array}\right\}$ $T_1 < T_{sat@150kPa} \overset{A-5}{=} 111.35°C$

$\boxed{\text{phase}_1 = \text{liquide comprimé}}$

$\left(\begin{array}{l} v_1 \simeq v_{f@25°C} \overset{A-4}{=} 0.001003\ m^3/kg \\ u_1 = u_{f@25°C} = 104.83\ kJ/kg \end{array} \right)$

Réponses

b) i) état ②: $\boxed{P_2 = P_1 = 150\ \text{kPa}}$ (voir partie a)

$$v_2 = \frac{V_2}{m} = \frac{V_1 + A_p H}{m} = v_1 + \frac{A_p H}{m} \quad \Rightarrow v_1 = 0.001003\ \text{m}^3/\text{kg} \ \text{(voir partie a)}$$

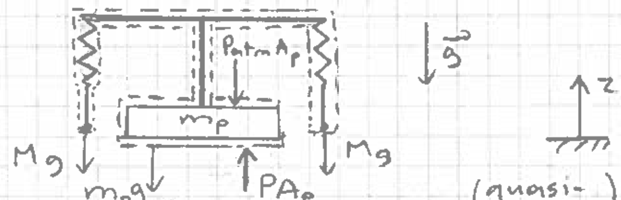
$$v_2 = 0.001003\ \frac{\text{m}^3}{\text{kg}} + \frac{(0{,}0981\ \text{m}^2)(0.1417142\ \text{m})}{(0{,}04\ \text{kg})} = 0.348557\ \frac{\text{m}^3}{\text{kg}}$$

$$\left.\begin{array}{l} P_2 = 150\ \text{kPa} \\ v_2 = 0.348557\ \frac{\text{m}^3}{\text{kg}} \end{array}\right\} \quad \begin{array}{ccc} v_{f@150\text{kPa}} & < v_2 < & v_{g@150\text{kPa}} \\ (0.001053\ \frac{\text{m}^3}{\text{kg}}) & & (1.1594\ \text{m}^3/\text{kg}) \end{array}$$

phase$_2$ = mélange saturé
$T_2 = T_{sat@150\text{kPa}} \overset{A-5}{=} 111.35\ °\text{C}$

$$x_2 = \frac{v_2 - v_f}{v_g - v_f} = \frac{0.348557 - 0.001053}{1.1594 - 0.001053} = \boxed{0.30}$$

ii) état ③: $P_3 = ?$: de ③ à ④



$$\Sigma F_z = PA_p - P_{atm}A_p - m_p g - 2Mg = m_p \cancel{a_p}^{\,0\ \text{(quasi-statique)}}$$

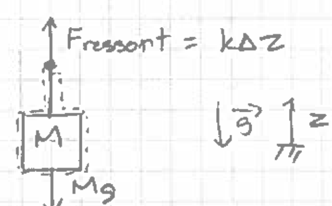
$$P = P_{atm} + \frac{(m_p + 2M)g}{A_p} \quad (= \text{const.} = P_3 = P_4)$$

$$P_3 = P_4 = 100\ \text{kPa} + \frac{(500 + 2\times 750)\text{kg}\,(9.81\ \frac{\text{m}}{\text{s}^2})}{(0.0981\ \text{m}^2)} \times \frac{1\ \text{kPa}}{\frac{10^3\ \text{kg}\cdot\frac{\text{m}}{\text{s}^2}}{\text{m}^2}}$$

$$\boxed{P_3 = P_4 = 300\ \text{kPa}}$$

$$v_3 = \frac{V_3}{m} = \frac{V_2 + A_p \Delta z}{m} = v_2 + \frac{A_p \Delta z}{m} \quad \left(= v_1 + \frac{A_p(H + \Delta z)}{m} \right)$$

$\Rightarrow \Delta z = ?$: à l'état ③ (& ④)



$$\Sigma F_z = k\Delta z - Mg = M \cancel{a_M}^{\,0\ \text{(quasi-statique)}}$$

$$\Delta z = \frac{Mg}{k} = \frac{(750\ \text{kg})(9.81\ \frac{\text{m}}{\text{s}^2}) \times \frac{1\ \text{kN}}{10^3\ \text{kg}\cdot\text{m/s}^2}}{(70.1394\ \text{kN/m})}$$

$$\Delta z = 0.104898\ \text{m}$$

$$v_3 = 0.348557\ \frac{\text{m}^3}{\text{kg}} + \frac{(0.0981\ \text{m}^2)(0{,}104898\ \text{m})}{(0.04\ \text{kg})} = 0{,}60582\ \text{m}^3/\text{kg}$$

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$$\left.\begin{array}{l} P_3 = 300\,kPa \\ v_3 = 0.60582\ \frac{m^3}{kg} \end{array}\right\} \quad v_3 = v_{g@300kPa} \overset{A-5}{=} 0.60582\ m^3/kg$$

$$\boxed{phase_3 = \text{vapeur saturée}}$$

$$\boxed{T_3 = T_{sat@300kPa} \overset{A-5}{=} 133.52°C}$$

iii) état ④ : $\boxed{P_4 = P_3 = 300\ kPa}$ (voir partie b) ii))

$$v_4 = \frac{\bar{V}_4}{m} = \frac{\bar{V}_3 + A_p h}{m} = v_3 + \frac{A_p h}{m} \quad \left(= v_1 + \frac{A_p(H + \Delta z + h)}{m}\right)$$

$$v_4 = 0.60582\ \frac{m^3}{kg} + \frac{(0.0981\ m^2)(0.045102\ m)}{(0.04\ kg)} = 0.71643\ \frac{m^3}{kg}$$

$$\left.\begin{array}{l} P_4 = 300\,kPa \\ v_4 = 0.71643\ \frac{m^3}{kg} \end{array}\right\} \quad v_4 > v_{g@300kPa} \overset{A-5}{=} 0.60582\ m^3/kg$$

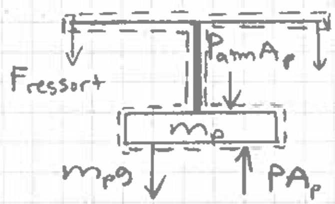
$$\boxed{phase_4 = \text{vapeur surchauffée}}$$

Table A-6 : $\boxed{T_4 = 200°C}$ $(u_4 = 2651.0\ \frac{kJ}{kg})$

c) Diagramme P-v : $① \xrightarrow{P\ const.} ② \xrightarrow{②} ③ \xrightarrow{P\ const.} ④$

liq. comp — mél. sat — vap. sat. — vap. sur.

② → ③ : $P = f(\bar{V}) = ?$



$F_{ressort} = kz$ $(z : 0$ à $\Delta z)$

$\downarrow \vec{g}$ $\uparrow z$

(quasi-statique)

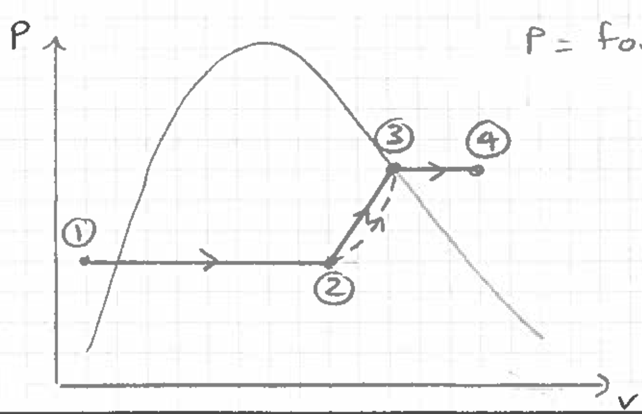
$$\sum F_z = PA_p - P_{atm}A_p - m_p g - 2kz = m_p \cancel{a_p}^{\,0}$$

$$P = \underbrace{P_{atm} + \frac{m_p g}{A_p}}_{= P_1} + \frac{2kz}{A_p} = P_1 + \frac{2kz}{A_p}$$

$$\Rightarrow \bar{V} - \bar{V}_2 = A_p z \longrightarrow z = \frac{\bar{V} - \bar{V}_2}{A_p}$$

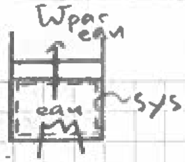
$$P = P_1 + \frac{2k}{A_p}\left(\frac{\bar{V} - \bar{V}_2}{A_p}\right) = \left(P_1 - \frac{2k\bar{V}_2}{A_p^2}\right) + \left(\frac{2k}{A_p^2}\right)\bar{V}$$

P = fonction linéaire de $\bar{V}$...



Réponses

d) $\overline{W}_{\substack{par\\eau}} = ?$:



$$\overline{W}_{\substack{par\\eau}} = \overline{W}_b = \int_{①}^{④} P\,d\overline{V}$$

$$\overline{W}_{\substack{par\\eau}} = \int_{①}^{②} P\,d\overline{V} + \int_{②}^{③} P\,d\overline{V} + \int_{③}^{④} P\,d\overline{V}$$

$$\overline{W}_{\substack{par\\eau}} = \int_{\overline{V}_1}^{\overline{V}_2} P_1\,d\overline{V} + \int_{②}^{③} \left(P_1 + \frac{2kz}{A_p}\right) d\overline{V} + \int_{\overline{V}_3}^{\overline{V}_4} P_3\,d\overline{V}$$

$$= P_1(\overline{V}_2 - \overline{V}_1) + \int_{\overline{V}_2}^{\overline{V}_3} P_1\,d\overline{V} + \int_0^{\Delta z} \frac{2kz}{A_p}(A_p dz) + P_3(\overline{V}_4 - \overline{V}_3)$$

$$= P_1 A_p H + P_1 A_p \Delta z + 2\frac{k}{2}\left[z^2\right]_0^{\Delta z} + P_3 A_p h$$

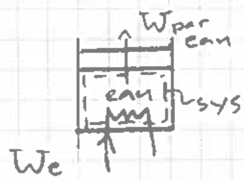
$$\overline{W}_{\substack{par\\eau}} = P_1 A_p (H + \Delta z) + k\Delta z^2 + P_3 A_p h$$

$$= (150\,kPa)(0.0981\,m^2)(0.1417142 + 0.104898)\,m$$
$$+ \left(70.1394\,\frac{kN}{m}\right)(0.104898\,m)^2$$
$$+ (300\,kPa)(0.0981\,m^2)(0.045102\,m)$$

$$\boxed{\overline{W}_{\substack{par\\eau}} = 5.7280\,kJ}$$

Solutions alternatives : voir pages 12-13

e) $I_e = ?$:



$1^{ère}$ loi : $\Delta E_{sys_{14}} = E_{in_{14}} - E_{out_{14}}$

$$\Delta \overline{U}_{eau_{14}} + \cancel{\Delta \overline{U}_{résistance_{14}}}^{\cong 0} + \cancel{\Delta E_{c_{sys_{14}}}}^{0} + \cancel{\Delta E_{p_{sys_{14}}}}^{\cong 0} = \overline{W}_{e_{14}} - \overline{W}_{\substack{par\\eau}}$$

$$m(u_4 - u_1) = V_e I_e \Delta t_{14} - \overline{W}_{\substack{par\\eau}}$$

$$I_e = \frac{m(u_4 - u_1) + \overline{W}_{\substack{par\\eau}}}{V_e \Delta t_{14}}$$

$\Rightarrow u_1 = 104.83\,kJ/kg$ (voir partie a)

$\Rightarrow u_4 = 2651.0\,kJ/kg$ (voir partie b)iii))

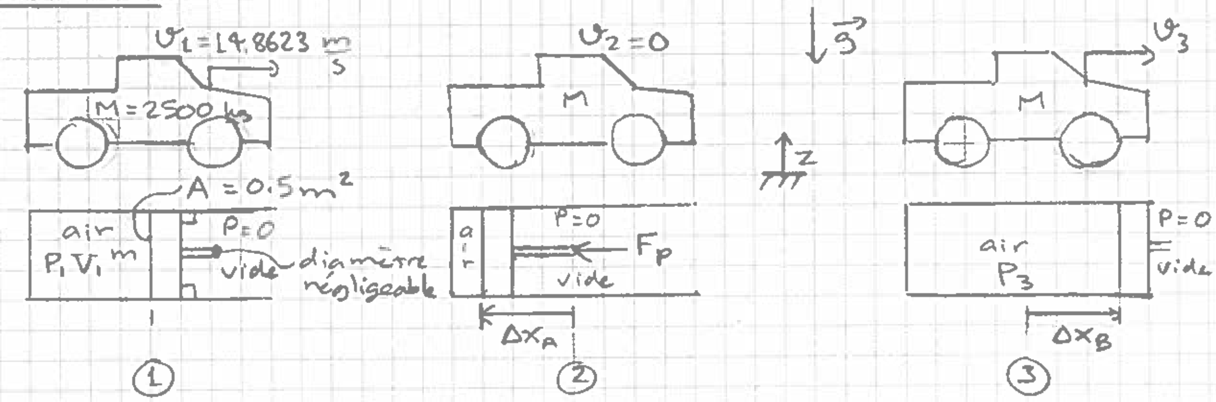
$$I_e = \frac{(0.04\,kg)(2651.0 - 104.83)\,kJ/kg + 5.7280\,kJ}{(12\,Volts)\left(60\,min \times \frac{60\,s}{min}\right)} \times \frac{1\,kJ}{10^3\,Volt \cdot Amp \cdot s}$$

$$\boxed{I_e = 2.430\,Amp.}$$

Solution alternative : voir page 13

Réponses

Question 2



$P_1 = 300\,kPa$

$V_1 = 0.507033\,m^3$

$m = 1\,kg$

$\Delta x_A = 70\,cm$

$= 0.7\,m$

$\Delta x_B = 1\,m$

$P_3 = 131.098\,kPa$

a) $T_1 = ?$

b) T_2, $F_p = ?$

c) $v_3 = ?$ si i) $\Delta z_{23} = 6\,m$

ii) $\Delta z_{23} = 0$

- air → gaz parfait à c_p, c_v variables avec $R = 0.287\,kPa \cdot m^3/kg \cdot K$
- évolutions adiabatiques
- $\Delta z_{12} = 0$
- friction, trainée $\simeq 0$
- pertes mécaniques $\simeq 0$
- $\Delta U_{solides} \simeq 0$
- ΔE_c rotationnelle, roues $\simeq 0$
- diamètre crémaillère $\simeq 0$ (force de Patm sur piston $\simeq 0$)

Suppositions additionnelles

aucune

a) $T_1 = ?$: $P_1 V_1 = m R T_1$

$$T_1 = \frac{P_1 V_1}{mR} = \frac{(300\,kPa)(0.507033\,m^3)}{(1\,kg)(0.287\,\frac{kPa \cdot m^3}{kg \cdot K})} = \boxed{530\,K}$$

b) i) $T_2 = ?$: $u_2 = f(T_2) = ?$ obtenue par 1ère loi ① → ②

$$\Delta E_{sys\,12} = \cancel{Q_{an\,sys\,12}}^{\,0 \text{ adiabatique}} - \cancel{W_{par\,sys\,12}}^{\,0 \text{ traînée, friction} \simeq 0}$$

$$\Delta U_{air\,12} + \cancel{\Delta U_{solides}}^{\simeq 0} + \Delta E_{c12} + \cancel{\Delta E_{c\,rotation\,roues\,12}}^{\simeq 0} + \cancel{\Delta E_{p12}}^{\simeq 0} = 0$$

$$m(u_2 - u_1) + \frac{1}{2} M(\cancel{v_2^2}^{\,0} - v_1^2) = 0$$

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$$u_2 = u_1 + \frac{1}{2}\frac{M}{m}v_1^2 \quad \Rightarrow u_1 = u(T_1 = 530K) \overset{A-17}{=} 381.84 \frac{kJ}{kg}$$

$$u_2 = 381.84 \frac{kJ}{kg} + \frac{1}{2}\frac{(2500 kg)}{(1 kg)}\left(14.8623 \frac{m}{s}\right)^2 \times \frac{1 kJ/kg}{10^3 m^2/s^2}$$

$$u_2 = 657.95 \frac{kJ}{kg} \xrightarrow{A-17} \boxed{T_2 = 880K}$$

Solution alternative : voir page 14

ii) $F_B = ?$:

$$\Sigma F_x = P_2 A - F_p = 0 \quad \text{(piston statique)}$$

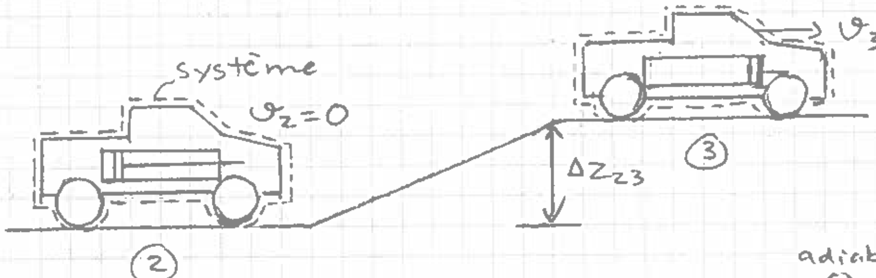
$$F_p = P_2 A$$

$P_2 = ?$: $$P_2 = \frac{mRT_2}{V_2} = \frac{mRT_2}{V_1 - A\Delta x_A}$$

$$P_2 = \frac{(1 kg)(0.287 \frac{kPa \cdot m^3}{kg \cdot K})(880K)}{0.507033 m^3 - (0.5 m^2)(0.7 m)} = 1608.324 kPa$$

$$F_p = (1608.324 kPa)(0.5 m^2) = \boxed{804.162 kN}$$

c) $v_3 = ?$:



$$\underline{1^{ère} \text{ loi entre ② et ③}} : \Delta E_{sys_{23}} = \underbrace{\cancel{Q_{au\,sys_{23}}}}_{\text{adiabatique } 0} - \underbrace{\cancel{W_{par\,sys_{23}}}}_{\text{traînée, friction } \simeq 0}$$

$$\Delta U_{air_{23}} + \underbrace{\cancel{\Delta U_{solides_{23}}}}_{\simeq 0} + \Delta E_{c_{23}} + \underbrace{\cancel{\Delta E_{c\,rotation\,roues_{23}}}}_{\simeq 0} + \Delta E_{p_{23}} = 0$$

$$m(u_3 - u_2) + \frac{1}{2}M(v_3^2 - \cancel{v_2^2}^{\,0}) + Mg\Delta Z_{23} = 0$$

$$\frac{1}{2}Mv_3^2 = m(u_2 - u_3) - Mg\Delta Z_{23}$$

$$v_3 = \sqrt{2\left[\frac{m}{M}(u_2 - u_3) - g\Delta Z_{23}\right]}$$

$\Rightarrow u_2 = 657.95$ kJ/kg (voir partie b)i)

$\Rightarrow u_3 = ?$: $u_3 = u(T_3)$

Réponses

$$\rightarrow T_3 = \frac{P_3 \bar{V}_3}{mR}$$

$$= \frac{P_3 (\bar{V}_1 + A\Delta x_B)}{mR}$$

$$T_3 = \frac{(131.098\,kPa)\left[(0.507033\,m^3) + (0.5\,m^2)(1\,m)\right]}{(1\,kg)\left(0.287\,\frac{kPa \cdot m^3}{kg \cdot K}\right)}$$

$$T_3 = 460\,K \xrightarrow{A-17} u_3 = 329.97\,\frac{kJ}{kg}$$

<u>Cas I</u> : $\Delta Z_{23} = 6\,m$

$$v_3 = \sqrt{2\left[\frac{(1\,kg)(657.95 - 329.97)\,\frac{kJ}{kg}}{(2500\,kg)} \times \frac{10^3\,m^2/s^2}{kJ/kg} - \left(9.81\,\frac{m}{s^2}\right)(6\,m)\right]}$$

$$\boxed{v_3 = 12.028\,m/s}$$

<u>Cas II</u> : $\Delta Z_{23} = 0$

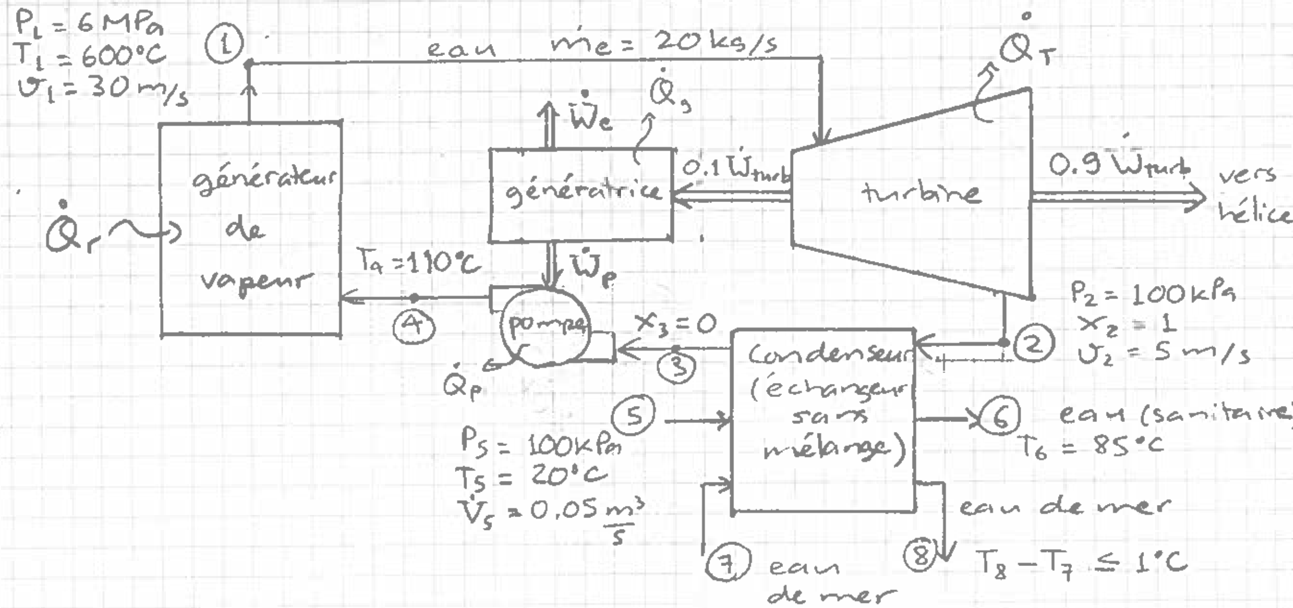
$$v_3 = \sqrt{2\left[\frac{(1\,kg)(657.95 - 329.97)\,\frac{kJ}{kg}}{(2500\,kg)} \times \frac{10^3\,m^2/s^2}{kJ/kg}\right]}$$

$$\boxed{v_3 = 16.198\,m/s}$$

<u>Solution alternative</u> : voir page 15

Réponses

Question 3



a) $\dot{W}_{turb} = ?$

b) $\dot{W}_e = ?$

c) $\dot{V}_7 = ?$

d) $\eta_{prop} = ?$

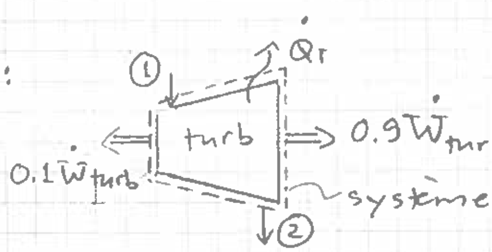
e) $v = ?$ (Bonus)

- Régime permanent, puissance max.
- $\dot{Q}_r$ & $\dot{Q}_p = 0.01\,\dot{m}_e \Delta\theta$, $\dot{Q}_g = 0.04\,\dot{W}_{in}$
- $\dot{W}_{propulsif} = 0{,}75\ \dot{W}_{hélice}$
- eau de mer ⇒ subs. incompressible avec $\rho = 1028\ kg/m^3$ et $C \doteq 4.00\ \frac{kJ}{kg \cdot K} = \text{const.}$
- $\dot{Q}_{cond \to ext}$, $\dot{Q}_{conduites \to ext} \simeq 0$
- $\Delta e_p \simeq 0$
- $\Delta e_c \simeq 0$ (excepté ① → ②)
- $\Delta P \simeq 0$ pour générateur de vapeur ($P_1 = P_4$) et condenseur ($P_3 = P_2$, $P_6 = P_5$; $P_8 = P_7$)

Suppositions additionnelles

aucune

a) $\dot{W}_{turb} = ?$:



i) Conservation de la masse

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

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

ii) 1ère loi : $\dot{E}_{in} = \dot{E}_{out}$

$$\dot{m}_1 \theta_1 = \dot{m}_2 \theta_2 + 0.1\dot{W}_{turb} + 0.9\dot{W}_{turb} + \dot{Q}_T$$

$$\dot{m}_e(\theta_1 - \theta_2) = \dot{W}_{turb} + 0.01\,\dot{m}_e(\theta_1 - \theta_2)$$

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$$\dot{W}_{turb} = 0.99\,\dot{m}_e(\theta_1 - \theta_2)$$

$$= 0.99\,\dot{m}_e\left(h_1 - h_2 + \frac{v_1^2 - v_2^2}{2} + \overset{\simeq 0}{\cancel{\Delta e_{p21}}}\right)$$

$$\dot{W}_{turb} = 0.99\,\dot{m}_e\left(h_1 - h_2 + \frac{v_1^2 - v_2^2}{2}\right)$$

$\Rightarrow h_1 = ?$: $\left.\begin{matrix} P_1 = 6\text{ MPa} \\ T_1 = 600°C \end{matrix}\right\}$ $T_1 > T_{sat@6MPa} \overset{A-5}{=} 275.59°C$ ① vap. surchauffée

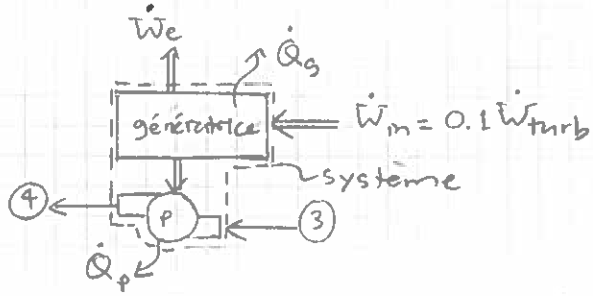
Table A-6 : $h_1 = 3658.8\ \frac{kJ}{kg}$

$\Rightarrow h_2 = ?$: $\left.\begin{matrix} P_2 = 100\text{ kPa} \\ x_2 = 1 \end{matrix}\right\}$ $h_2 = h_{g@100kPa}$ (table A-5) $h_2 = 2675.0$ kJ/kg

$$\dot{W}_{turb} = 0.99\left(20\,\frac{kg}{s}\right)\left[(3658.8 - 2675.0)\frac{kJ}{kg} + \frac{(30^2 - 5^2)}{2}\frac{m^2}{s^2} \times \frac{1\ kJ/kg}{10^3\ \frac{m^2}{s^2}}\right]$$

$$\boxed{\dot{W}_{turb} = 19\,487.9\text{ kW}}$$

b) $\dot{W}_e = ?$:



i) <u>conservation de la masse</u>

$$\Sigma \dot{m}_{in} = \Sigma \dot{m}_{out}$$

$$\dot{m}_3 = \dot{m}_4 = \dot{m}_e$$

ii) <u>1ère loi</u> : $\dot{E}_{in} = \dot{E}_{out}$

$$\dot{m}_3\theta_3 + 0.1\,\dot{W}_{turb} = \dot{m}_4\theta_4 + \dot{W}_e + \dot{Q}_g + \dot{Q}_p$$

$$\Rightarrow \dot{Q}_g = 0.04\,\dot{W}_{in} = 0.04(0.1\,\dot{W}_{turb}) = 0.004\,\dot{W}_{turb}$$

$$\Rightarrow \dot{Q}_p = 0.01\,\dot{m}_e(\theta_4 - \theta_3)$$

$$-\dot{m}_e(\theta_4 - \theta_3) + 0.1\,\dot{W}_{turb} = \dot{W}_e + 0.004\,\dot{W}_{turb} + 0.01\,\dot{m}_e(\theta_4 - \theta_3)$$

$$\dot{W}_e = 0.096\,\dot{W}_{turb} - 1.01\,\dot{m}_e(\theta_4 - \theta_3)$$

$$= 0.096\,\dot{W}_{turb} - 1.01\,\dot{m}_e(h_4 - h_3 + \overset{\simeq 0}{\cancel{\Delta e_{c34}}} + \overset{\simeq 0}{\cancel{\Delta e_{p34}}})$$

$$\dot{W}_e = 0.096\,\dot{W}_{turb} - 1.01\,\dot{m}_e(h_4 - h_3)$$

Réponses

$$\Rightarrow h_3 = ?:\quad \left.\begin{array}{l} P_3 = P_2 = 100\text{ kPa} \\ x_3 = 0 \end{array}\right\} \begin{array}{l} h_3 = h_{f@100kPa} \text{ (Table A-5)} \\ h_3 = 417.51 \text{ kJ/kg} \end{array}$$

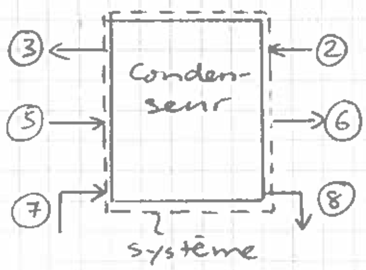
$$\Rightarrow h_4 = ?:\quad \left.\begin{array}{l} P_4 = P_1 = 6\text{ MPa} \\ T_4 = 110°C \end{array}\right\} \begin{array}{l} T_4 < T_{sat@6MPa} \overset{A-5}{=} 279.59°C \\ \text{④ liquide comprimé} \\ h_4 \simeq h_{f@110°C} \overset{A-4}{=} 461.42 \frac{kJ}{kg} \end{array}$$

$$\dot{W}_e = 0.096(19487.9\text{ kW}) - 1.01\left(20\frac{kg}{s}\right)(461.42 - 417.51)\frac{kJ}{kg}$$

$$\boxed{\dot{W}_e = 983.86 \text{ kW}}$$

Solution alternative: voir page 16

c) $\dot{V}_7 = ?$:



i) Conservation de la masse :

$$\Sigma \dot{m}_{in} = \Sigma \dot{m}_{out}$$

Pas de mélange, donc :

eau : $\dot{m}_2 = \dot{m}_3 = \dot{m}_e$

eau sanitaire : $\dot{m}_5 = \dot{m}_6 = \dfrac{\dot{V}_5}{v_5}$

eau de mer : $\dot{m}_7 = \dot{m}_8 = \rho \dot{V}_7$

ii) 1ère loi : $\dot{E}_{in} = \dot{E}_{out}$

$$\dot{m}_2\theta_2 + \dot{m}_5\theta_5 + \dot{m}_7\theta_7 = \dot{m}_3\theta_3 + \dot{m}_6\theta_6 + \dot{m}_8\theta_8$$

$$\dot{m}_e(\theta_2 - \theta_3) = \dot{m}_5(\theta_6 - \theta_5) + \dot{m}_7(\theta_8 - \theta_7)$$

$$\dot{m}_e(h_2 - h_3 + \underbrace{\cancel{\Delta e_{c32}}}_{\simeq 0} + \underbrace{\cancel{\Delta e_{p32}}}_{\simeq 0}) = \frac{\dot{V}_5}{v_5}(h_6 - h_5 + \overbrace{\cancel{\Delta e_{c56}}}^{\simeq 0} + \overbrace{\cancel{\Delta e_{p56}}}^{\simeq 0}) + \rho\dot{V}_7(h_8 - h_7 + \overbrace{\cancel{\Delta e_{c78}}}^{\simeq 0} + \overbrace{\cancel{\Delta e_{p78}}}^{\simeq 0})$$

$$\dot{m}_e(h_2 - h_3) = \frac{\dot{V}_5}{v_5}(h_6 - h_5) + \rho \dot{V}_7 c (T_8 - T_7)$$

$$\dot{V}_7 = \frac{\dot{m}_e(h_2 - h_3) - \dfrac{\dot{V}_5}{v_5}(h_6 - h_5)}{\rho c (T_8 - T_7)}$$

$$\Rightarrow h_5, v_5 = ?:\quad \left.\begin{array}{l} P_5 = 100\text{ kPa} \\ T_5 = 20°C \end{array}\right\} T_5 < T_{sat@100kPa} \overset{A-5}{=} 99.61°C$$

⑤ liquide comprimé

$$h_5 \simeq h_{f@20°C} \overset{A-4}{=} 83.915 \text{ kJ/kg}$$

$$v_5 \simeq v_{f@20°C} = 0.001002 \text{ m}^3\text{/kg}$$

Réponses

$$\Rightarrow h_6 = ? : \left.\begin{array}{l} P_6 = P_5 = 100\,kPa \\ T_6 = 85°C \end{array}\right\} \begin{array}{l} T_6 < T_{sat@100kPa} \overset{A-}{=} 99.61°C \\ ⑥ \text{ liquide comprimé} \end{array}$$

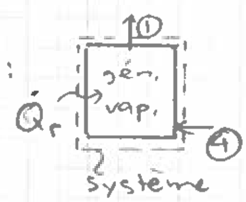
$$h_6 \simeq h_{f@85°C} \overset{A-4}{=} 356.02\ kJ/kg$$

$$\dot{V}_7 = \frac{(20\,\tfrac{kg}{s})(2675.0 - 417.51)\,kJ/kg - \dfrac{(0.05\,m^3/s)}{(0.001002\,m^3/kg)}(356.02 - 83.915)\,\tfrac{kJ}{kg}}{(1028\ kg/m^3)(4.00\ \tfrac{kJ}{kg\cdot K})(1°C)\cdot \tfrac{K}{°C}}$$

$$\boxed{\dot{V}_7 = 7.678\ \tfrac{m^3}{s}}$$

d) $\eta_{prop} = ?$: $\eta_{prop} \equiv \dfrac{\dot{W}_{propulsif}}{\dot{Q}_r} = \dfrac{0.75\,\dot{W}_{hélice}}{\dot{Q}_r} = \dfrac{0.75(0.9\,\dot{W}_{turb})}{\dot{Q}_r}$

$\Rightarrow \dot{Q}_r = ?$:



Cons. de la masse: $\dot{m}_4 = \dot{m}_1 = \dot{m}_e$

1ère loi : $\dot{m}_4\theta_4 + \dot{Q}_r = \dot{m}_1\theta_1$

$$\dot{Q}_r = \dot{m}_e(\theta_1 - \theta_4)$$

$$= \dot{m}_e(h_1 - h_4 + \underbrace{\cancel{\Delta e_{c41}}}_{\simeq 0} + \underbrace{\cancel{\Delta e_{p41}}}_{\simeq 0})$$

$$\dot{Q}_r = \left(20\,\tfrac{kg}{s}\right)(3658.8 - 461.42)\ \tfrac{kJ}{kg}$$

$$\dot{Q}_r = 63947.6\ kW$$

$$\eta_{prop} = \frac{(0.75)(0.9)(19487.9\ kW)}{(63947.6\ kW)} = \boxed{0.2057 = 20.57\%}$$

e) $v = ?$: $\dot{W}_{propulsif} = F_p \cdot v \quad \Rightarrow F_p = F_D = \frac{1}{2}\rho v^2 A C_D$

$0.75(0.9\,\dot{W}_{turb}) = \frac{1}{2}\rho v^2 A C_D v \quad \Rightarrow A = 100\,m^2$, $C_D = 0.25$

$\frac{1}{2}\rho v^3 A C_D = 0.75(0.9\,\dot{W}_{turb})$

$$v_3 = \sqrt[3]{\frac{1.5(0.9\,\dot{W}_{turb})}{\rho A C_D}} = \sqrt[3]{\frac{1.5(0.9)(19487.9\,\tfrac{kJ}{s})}{(1028\ kg/m^3)(100\,m^2)(0.25)} \times \frac{10^3\ m^2/s^2}{kJ/kg}}$$

$$\boxed{v_3 = 10.078\ m/s}$$

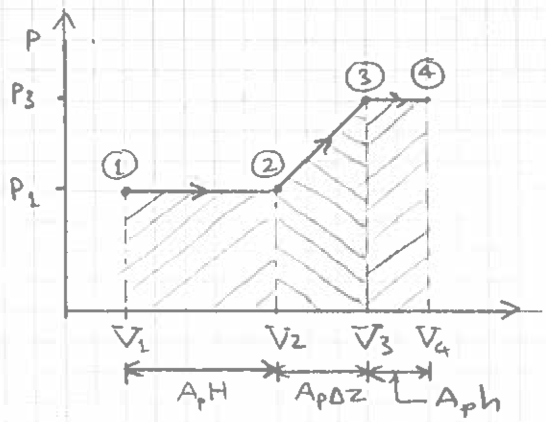
Réponses

Solutions alternatives

Question 1

d) Solution alternative 1

$$W_{\substack{par\\eau}} = \int_{①}^{④} P\,d\bar{V} = \text{aire sous courbe } P\text{-}\bar{V} \text{ entre } ① \text{ et } ④$$



Note : Il faut démontrer que $P = f(\bar{V})$ est linéaire entre ② & ③ (voir partie (c) sur page 3)

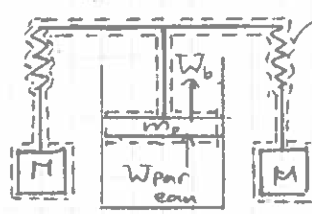
$$W_{\substack{par\\eau}} = P_1 A_p H + \frac{1}{2}(P_1 + P_3)A_p\Delta z + P_3 A_p h$$

$$= \left[P_1 H + \frac{1}{2}(P_1 + P_3)\Delta z + P_3\right] A_p$$

$$= \left[(150\,\text{kPa})(0.141714 2\,\text{m}) + \frac{1}{2}(150 + 300)\,\text{kPa}\,(0.104898\,\text{m}) + (300\,\text{kPa})(0.045102\,\text{m})\right](0.0981\,\text{m}^2)$$

$$\boxed{W_{\substack{par\\eau}} = 5.7280\ \text{kJ}}$$

Solution alternative 2



système = ressorts + cordes + 2M + m_p

1ère loi :

$$\Delta E_{sys_{14}} = E_{in_{14}} - E_{out_{14}}$$

$$\cancel{\Delta U_{solides_{14}}}^{\simeq 0} + \cancel{\Delta E_{c_{14}}}^{0} + \Delta E_{p_{piston_{14}}} + \Delta E_{p_{M_{14}}} + \Delta E_{p_{ressorts_{14}}} = W_{\substack{par\\eau_{14}}} - W_{b_{14}}$$

$$\Rightarrow W_{b_{14}} = \int_{①}^{④} P_{atm}\,d\bar{V} = \int_{0}^{H+\Delta z+h} P_{atm} A_p\,d\bar{V} = P_{atm} A_p (H + \Delta z + h)$$

$$m_p g (H + \Delta z + h) + 2Mgh + 2\left(\frac{k}{2}\Delta z^2\right) = W_{\substack{par\\eau}} - P_{atm} A_p (H + \Delta z + h)$$

$$W_{\substack{par\\eau}} = \underbrace{\left(P_{atm} + \frac{m_p g}{A_p}\right)}_{P_1} A_p (H + \Delta z + h) + 2Mgh + k\Delta z^2$$

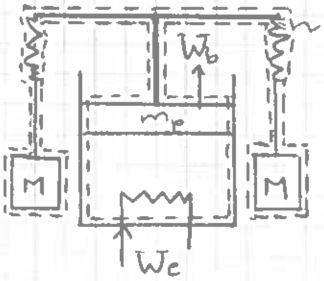
$$\therefore W_{\substack{par\\eau}} = P_1 A_p (H + \Delta z + h) + 2Mgh + k\Delta z^2$$

Réponses

$$W_{\substack{par\\eau}} = (150\,kPa)(0.0981\,m^2)(0.1417142 + 0.104898 + 0.045102)\,m$$
$$+\ 2(750\,kg)(9.81\,\tfrac{m}{s^2})(0.045102\,m) \times \frac{1\,kJ}{10^3\,kg\cdot\frac{m^2}{s^2}}$$
$$+\ (70.1394\,\tfrac{kN}{m})(0.104898\,m)^2$$

$$\boxed{W_{\substack{par\\eau}} = 5.7280\,kJ}$$

e) $I_e = ?$:



système = ressorts + cordes + 2M + mp + eau + résistance

1ère loi: $\Delta E_{sys,14} = E_{in,14} - E_{out,14}$

$$\Delta U_{eau,14} + \cancel{\Delta U_{solides,14}}^{\simeq 0} + \cancel{\Delta E_{c,14}}^{0} + \Delta E_{p,piston14} + \Delta E_{pM,14}$$
$$+\ \Delta E_{p,ressorts,14} = W_{e_{14}} - W_{b_{14}}$$

$$m(u_4 - u_1) + m_p g(H + \Delta z + h) + 2Mgh + 2\left(\frac{k}{2}\Delta z^2\right)$$
$$= V_e I_e \Delta t - P_{atm} A_p (H + \Delta z + h)$$

$$V_e I_e \Delta t = m(u_4 - u_1) + \overbrace{\left(P_{atm} + \frac{m_p g}{A_p}\right)}^{P_1} A_p (H + \Delta z + h) + 2Mgh + k\Delta z^2$$

$$I_e = \frac{m(u_4 - u_1) + P_1 A_p (H + \Delta z + h) + 2Mgh + k\Delta z^2}{V_e \Delta t}$$

$\Rightarrow u_1 = 104.83$ kJ/kg (voir partie a)

$\Rightarrow u_4 = 2651.0$ kJ/kg (voir partie b)iii))

$$I_e = \frac{\begin{aligned}&(0.04\,kg)(2651.0 - 104.83)\,kJ/kg \\ &+ (150\,kPa)(0.0981\,m^2)(0.1417142 + 0.104898 + 0.045102)\,m \\ &+ 2(750\,kg)(9.81\,\tfrac{m}{s^2})(0.045102\,m) \times \tfrac{1\,kJ}{10^3\,kg\cdot\frac{m^2}{s^2}} \\ &+ (70.1394\,kN/m)(0.104898\,m)^2\end{aligned}}{(12\,Volts)\left(60\,min \times \frac{60\,s}{min}\right) \times \frac{1\,kJ}{10^3\,Volt\cdot Amp\cdot s}}$$

$$\boxed{I_e = 2.490\,Amp.}$$

Réponses

Question 2

b) i) $T_2 = ?$: $u_2 = f(T_2) = ?$ obtenue par 1ère loi ① → ②

Système 1 = air

$W_{\substack{sur\\air\\12}}$ (travail de frontière)

système 1

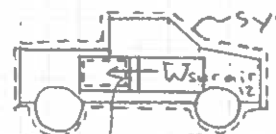
1ère loi sur système 1 : $\Delta E_{\substack{sys1\\12}} = E_{\substack{in\\12}} - E_{\substack{out\\12}}$

$$\Delta U_{\substack{air\\12}} + \Delta E_{\substack{c\,air\\12}} + \cancel{\Delta E_{\substack{p\,air\\12}}}^{\,0} = W_{\substack{sur\\air\\12}}$$

$$m(u_2 - u_1) + \frac{1}{2} m(v_2^2 - v_1^2) = W_{\substack{sur\\air\\12}}$$

$\Rightarrow W_{\substack{sur\\air\\12}} = ?$: Il faut définir un autre système

Système 2 = camionnette sans air



système 2

↓

$\text{masse}_{sys} = M - m$

le système 2 diminue de volume de ① → ② à cette frontière où la pression est celle de l'air via un travail $W_{\substack{sur\\air12}}$

1ère loi sur système 2 :

$$\Delta E_{\substack{sys2\\12}} = E_{\substack{in\\12}} - E_{\substack{out\\12}}$$

$$\cancel{\Delta U_{\substack{solides\\12}}}^{\,\simeq 0} + \Delta E_{\substack{c\,sys2\\12}} + \cancel{\Delta E_{\substack{c,\,rotation\\roues\,12}}}^{\,\simeq 0} + \cancel{\Delta E_{\substack{p\,sys2\\12}}}^{\,0} = -W_{\substack{sur\\air12}}$$

$$\frac{1}{2}(M-m)(v_2^2 - v_1^2) = -W_{\substack{sur\\air12}}$$

$$W_{\substack{sur\\air\\12}} = -\frac{1}{2}(M-m)(v_2^2 - v_1^2)$$

$$m(u_2 - u_1) + \frac{1}{2} m(v_2^2 - v_1^2) = -\frac{1}{2}(M-m)(v_2^2 - v_1^2)$$

$$m(u_2 - u_1) + \frac{1}{2} M(v_2^2 - v_1^2) = 0$$

→ même équation que sur page 5

⋮

Réponses

c) $v_3 = ?$: <u>système 1 = air</u>

$\rightarrow W_{\substack{par\\air\\23}}$ (travail de frontière)

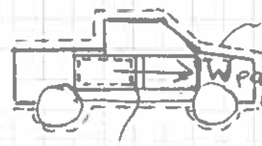
<u>1ère loi sur système 1</u> : $\Delta E_{\substack{sys1\\23}} = E_{\substack{in\\23}} - E_{\substack{out\\23}}$

$$\Delta U_{\substack{air\\23}} + \Delta E_{\substack{c\,air\\23}} + \Delta E_{\substack{p\,air\\23}} = -W_{\substack{par\\air\\23}}$$

$$m(u_3 - u_2) + \frac{1}{2} m (v_3^2 - v_2^2) + mg\Delta z_{23} = -W_{\substack{par\\air\\23}}$$

$\Rightarrow W_{\substack{par\\air\\23}} = ?$: Il faut définir un autre système

<u>système 2</u> = camionette <u>sans</u> air



<u>système 2</u> → masse $= M - m$

le système 2 augmente de volume de ② → ③ à cette frontière où la pression est celle de l'air via un travail $W_{\substack{par\\air\,23}}$

<u>1ère loi sur système 2</u> :

$$\Delta E_{\substack{sys2\\23}} = E_{\substack{in\\23}} - E_{\substack{out\\23}}$$

$$\underbrace{\cancel{\Delta U_{\substack{solides\\23}}}}_{\simeq 0} + \Delta E_{\substack{c\,sys2\\23}} + \underbrace{\cancel{\Delta E_{\substack{c,\,rotation\\roues\,23}}}}_{0} + \Delta E_{\substack{p\,sys2\\23}} = W_{\substack{par\\air\\23}}$$

$$\frac{1}{2}(M-m)(v_3^2 - v_2^2) + (M-m)g\Delta z_{23} = W_{\substack{par\\air\\23}}$$

$$m(u_3 - u_2) + \frac{1}{2} m (v_3^2 - v_2^2) + mg\Delta z_{23} = -\left[\frac{1}{2}(M-m)(v_3^2 - v_2^2) + (M-m)g\Delta z_{23}\right]$$

$$m(u_3 - u_2) + \frac{1}{2} M (v_3^2 - v_2^2) + Mg\Delta z_{23} = 0$$

↓

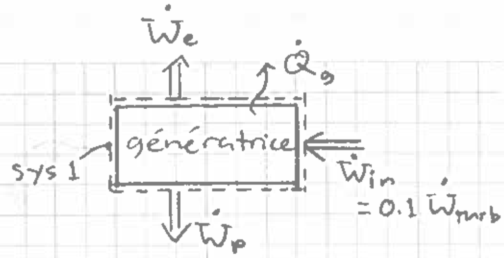
même équation que sur la page 6

⋮

Réponses

Question 3

b) $\dot{W}_e = ?$: Système 1 = génératrice



1ère loi sur système 1 : $\dot{E}_{in} = \dot{E}_{out}$

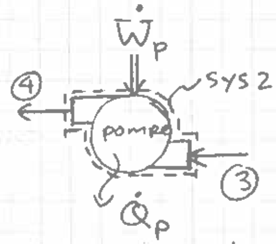
$$0.1\,\dot{W}_{turb} = \dot{W}_e + \dot{W}_p + \dot{Q}_g$$

$$\Rightarrow \dot{Q}_g = 0.04(0.1\,\dot{W}_{turb}) = 0.004\,\dot{W}_{turb}$$

$$0.1\,\dot{W}_{turb} = \dot{W}_e + \dot{W}_p + 0.004\,\dot{W}_{turb}$$

$$\dot{W}_e = 0.096\,\dot{W}_{turb} - \dot{W}_p$$

$\Rightarrow \dot{W}_p = ?$: système 2 = pompe



conservation de la masse (sys. 2) :

$$\dot{m}_3 = \dot{m}_4 = \dot{m}_e$$

1ère loi sur système 2 : $\dot{E}_{in} = \dot{E}_{out}$

$$\dot{m}_3\theta_3 + \dot{W}_p = \dot{m}_4\theta_4 + \dot{Q}_p$$

$$\Rightarrow \dot{Q}_p = 0.01\,\dot{m}_e(\theta_4 - \theta_3)$$

$$\dot{W}_p = \dot{m}_e(\theta_4 - \theta_3) + 0.01\,\dot{m}_e(\theta_4 - \theta_3)$$

$$\dot{W}_p = 1.01\,\dot{m}_e(\theta_4 - \theta_3)$$

$$= 1.01\,\dot{m}_e(h_4 - h_3 + \underbrace{\cancel{\Delta e_{c_{34}}}}_{\simeq 0} + \underbrace{\cancel{\Delta e_{p_{34}}}}_{\simeq 0})$$

$$\dot{W}_p = 1.01\,\dot{m}_e(h_4 - h_3)$$

$$\dot{W}_e = 0.096\,\dot{W}_{turb} - 1.01\,\dot{m}_e(h_4 - h_3)$$

$\downarrow$

même équation que sur page 9