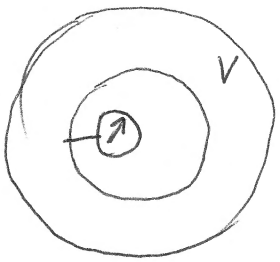
2.4



$V_1 = 0{,}015\ m^3$

$\begin{cases} T_1 = 30\,^\circ C \\ p_{m1} = 150\ KPa \end{cases} \rightarrow \begin{cases} T_2 = T_1 \\ V_2 = V_1 \\ p_{m2} = 200\ KPa \end{cases}$

$p_{atm} = 98\ KPa \qquad \Delta M = ?$

$p_1 = p_{m1} + p_{atm} = 150 + 98 = 248\ KPa$

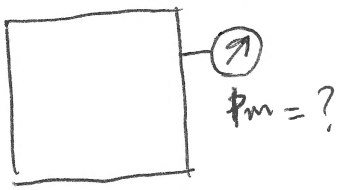
$p_2 = p_{m2} + p_{atm} = 200 + 98 = 298\ KPa$

$p_1 V_1 = M_1 R^* T_1 \rightarrow M_1 = \frac{p_1 V_1}{R^* T_1} = \frac{248000 \times 0{,}015}{287\ (273{,}15+30)} = 0{,}04276\ kg$

$p_2 V_2 = M_2 R^* T_2 \rightarrow M_2 = \frac{p_2 V_2}{R^* T_2} = \frac{298000 \times 0{,}015}{287\ (273{,}15+30)} = 0{,}05138\ kg$

$\Delta M = M_2 - M_1 = 0{,}0086\ Kg$

2.6



$V = 800\,L = 0{,}8\ m^3$

$M = 10\ Kg$

$T = 25\,^\circ C$

$p_{atm} = 97\ KPa$

$pV = MR^*T \rightarrow p = \frac{MR^*T}{V} = \frac{10 \times 287 \times (273{,}15+25)}{0{,}8} = 1069613\ Pa$

$p_m = p - p_{atm} = 972613\ Pa = 972{,}6\ KPa$

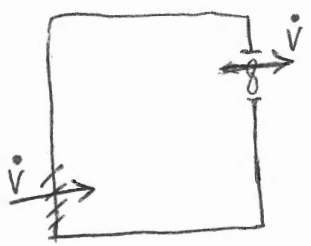
2.15

TABELLA A.6 Acqua satura – Tabella della temperatura

Temp., T, °C	Pressione satura, p_{sat}, kPa	Volume specifico, m³/kg: Liquido saturo, $v_{f\,sat}$	Volume specifico, m³/kg: Vapore saturo, $v_{g\,sat}$	Energia interna, kJ/kg: Liquido saturo, $u_{f\,sat}$	Energia interna, kJ/kg: Evap., $u_{fg\,sat}$	Energia interna, kJ/kg: Vapore saturo, $u_{g\,sat}$	Entalpia, kJ/kg: Liquido saturo, $h_{f\,sat}$	Entalpia, kJ/kg: Evap., $h_{fg\,sat}$	Entalpia, kJ/kg: Vapore saturo, $h_{g\,sat}$	Entropia, kJ/kg·K: Liquido saturo, $s_{f\,sat}$	Entropia, kJ/kg·K: Evap., $s_{fg\,sat}$	Entropia, kJ/kg·K: Vapore saturo, $s_{g\,sat}$
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7805
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
100	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470	7.3542
105	120.90	0.001047	1.4186	440.15	2071.8	2511.9	440.28	2243.1	2683.4	1.3634	5.9319	7.2952
110	143.38	0.001052	1.2094	461.27	2056.4	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2382
115	169.18	0.001056	1.0360	482.42	2040.9	2523.3	482.59	2216.0	2698.6	1.4737	5.7092	7.1829
120	198.67	0.001060	0.89133	503.60	2025.3	2528.9	503.81	2202.1	2706.0	1.5279	5.6013	7.1292
125	232.23	0.001065	0.77012	524.83	2009.5	2534.3	525.07	2188.1	2713.1	1.5816	5.4956	7.0771
130	270.28	0.001070	0.66808	546.10	1993.4	2539.5	546.38	2173.7	2720.1	1.6346	5.3919	7.0265
135	313.22	0.001075	0.58179	567.41	1977.3	2544.7	567.75	2159.1	2726.9	1.6872	5.2901	6.9773

→ CENGEL (2ª Ed.) → 198,53 [kPa]

2.18



$V = 10 \times 15 \times 2{,}4 = 360\ m^3$

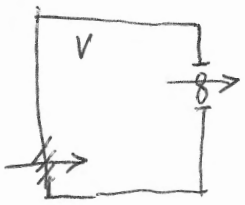
$\dot{V}_p = 30\ \frac{L}{s\ pers.} = 30 \times 10^{-3}\ \frac{m^3}{s\ pers.}$

$N_{Pers} = 25$

$\dot{V} = \dot{V}_p \times N_{Pers} = 30 \times 10^{-3} \times 25 = 0{,}75\ \frac{m^3}{s}$

$ACH = \frac{\dot{V}}{V} = \frac{0{,}75}{360}\left[\frac{1}{s}\right] = \frac{0{,}75}{360}\ 3600\left[\frac{1}{s}\cdot\frac{s}{h} = \frac{1}{h}\right] = 7{,}5\ [h^{-1}]$

2.19



$V = 2 \times 2{,}5 \times 3 = 15\ m^3$

$\dot{V}_{RIC.} = \frac{1\,V}{15\ min} = \frac{15\ m^3}{15 \times 60} = 0{,}01667\ \frac{m^3}{s}$

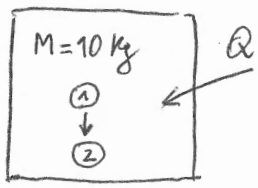
$\dot{V}_{VENT} = 25\ \frac{L}{s} = 25 \times 10^{-3}\ \frac{m^3}{s} = 0{,}025\ \frac{m^3}{s}$

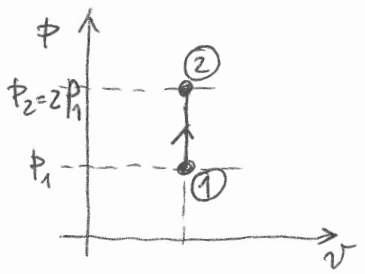
$\dot{V}_{VENT} > \dot{V}_{RIC}$

Ipotesi: $p = 10^5\ Pa$, $R^* = 287\ \frac{J}{kg\,K}$, $T = 18\ °C$ $\rightarrow$ $\rho = 1{,}197\ \frac{kg}{m^3} \simeq 1{,}2\ kg/m^3$

$\dot{m} = \rho\, \dot{V}_{VENT} = 0{,}03\ kg/s$

3.8





$p_1 = 200\ kPa$

$T_1 = 27\ °C$

$V = ?$

$Q = ?$

$p_1 V = M R^* T_1 \rightarrow V = \frac{M R^* T_1}{p_1} = \frac{10 \times 287 \times (27 + 273{,}15)}{200\,000} = 4{,}307\ m^3$

$V_1 = V_2 \rightarrow \frac{M R^* T_1}{p_1} = \frac{M R^* T_2}{p_2} \rightarrow \frac{T_1}{p_1} = \frac{T_2}{p_2} \rightarrow T_2 = \frac{p_2}{p_1} T_1 = 2 T_1 =$

$T_2 = 2 \times 300{,}15 = 600{,}3\ K = 327{,}15\ °C$

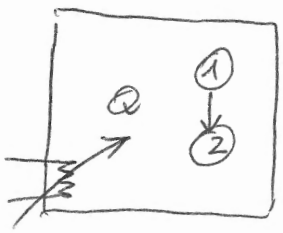
1° principio: $Q - L = \Delta U \rightarrow Q = \Delta U = M \Delta u = M c_v (T_2 - T_1)$

Assumendo per l'aria a $T_{media} = \frac{600 + 300}{2} = 450\ [K] \rightarrow c_v = 0{,}733\ \frac{kJ}{kg\,K}$

risulta:

$Q = 10 \times 0{,}733 \times (600{,}3 - 300{,}15) = 2200\ [kJ]$

3.9



$V = 4 \times 5 \times 6\ m^3 = 120\ m^3$

$p = 100\ kPa$

$T_1 = 7\ °C \rightarrow T_2 = 23\ °C$

$\Delta\tau = 15\ min$

$$Q - L = \Delta U \rightarrow Q = \Delta U = M \Delta u = M c_v (T_2 - T_1)$$

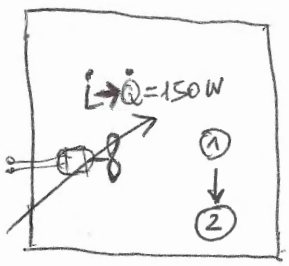
$M = \rho V$ $\qquad \rho_1 = \frac{p}{R^* T_1} = \frac{100000}{287 \times (273{,}15+7)} = 1{,}244\ kg/m^3$

$M = \rho_1 V = 149{,}25\ kg$

$c_v = 718\ \frac{J}{kg\,K}$ $\qquad Q = 149{,}25 \times 718\ (23-7) = 171584\ J$

$$\dot{Q} = \frac{Q}{\Delta\tau} = \frac{171584}{15 \times 60} = 1905\ W = 1{,}91\ kW$$

3.10



$\Delta\tau = 10\ h$

$V = 4 \times 6 \times 6\ m^3 = 144\ m^3$

$p = 100\ kPa$

$T_1 = 15\ °C$

$T_2 = ?$

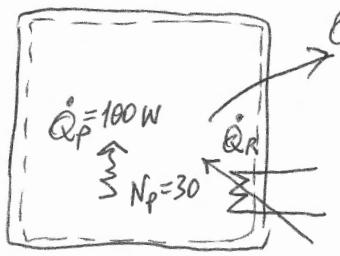
$$\begin{cases} Q = \dot{Q}\,\Delta\tau \\ Q = \Delta U = M \Delta u = M c_v (T_2 - T_1) \end{cases}$$

$$M = \rho V = \frac{p}{R^* T_1} V = \frac{100000}{287 \times (273{,}15+15)} \times 144 = 174{,}095\ kg$$

$$Q = \dot{Q}\,\Delta\tau = 150 \times 10 \times 3600 = 5400000\ [J]$$
$\quad J/s \quad h \quad s/h$

$$T_2 = T_1 + \frac{Q}{M c_v} = 15 + \frac{5400000}{174{,}095 \times 718} = 58{,}2\ °C$$

3.13



$$\dot{Q} = 20000\ \frac{kJ}{h} = \frac{20000}{3600}\ \frac{kJ}{s} = 5{,}555\ [kW]$$

1° principio: $\Sigma Q - \Sigma L = \Delta U$

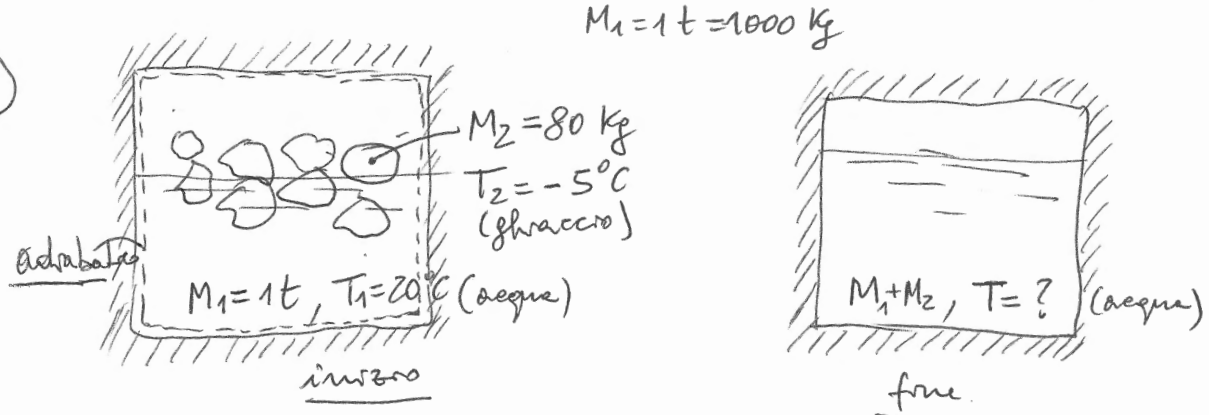
$\Sigma L = 0$

$\Delta U = 0$ se $T_{fine} = T_{inizio}$

$$\rightarrow \Sigma Q = \dot{Q}_p \times N_p + \dot{Q}_R - \dot{Q} = 0$$

$$100 \times 30 + \dot{Q}_R - 5555 = 0 \quad \rightarrow \dot{Q}_R = 2555\ W > 0$$

3.20



1° principio: $\Sigma Q - \Sigma L = \Delta U$

$\Sigma Q = 0$ (contorno adiabatico)
$\Sigma L = 0$
$\} \rightarrow \Delta U = 0$

$$\Delta U = (\Delta U)_{ghiaccio} + (\Delta U)_{acqua} = (\Delta U)_2 + (\Delta U)_1$$

per gli 80 kg di ghiaccio: $(\Delta U)_2 = M_2 c_{v_g}(0 - (-5)) + (\Delta U)_{fusione} + M_2 c_{v_a}(T - 0)$

$$(\Delta U)_2 = 80 \times 2110 \times 5 + 80 \times 333{,}7 \times 10^3 + 80 \times 4186\, T \quad [J]$$

essendo $c_{v_a} = c_{p_a} = 4186\ \frac{J}{kgK}$

e per il ghiaccio a 273 [k] dalla tab. A5 (pag. A6 del CENGEL):

$$\rho_g = 921\ kg/m^3 \quad c_{v_g} = c_{p_g} = 2110\ \frac{J}{kgK}$$

per i 1000 kg di acqua liquida:

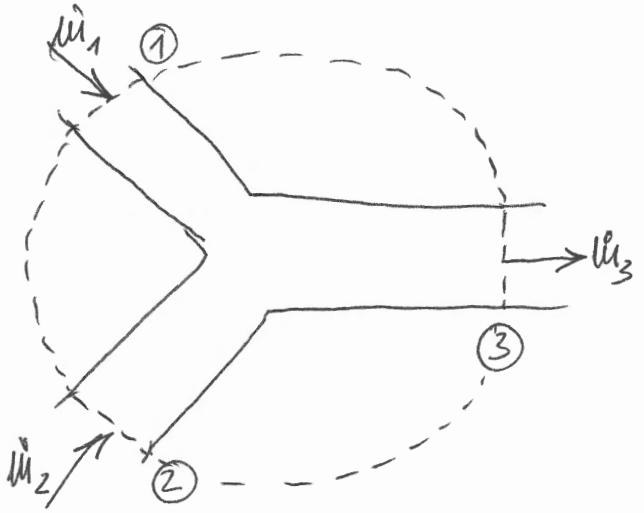
$$(\Delta U)_1 = M_1 c_{v_a}(T - 20) = 1000 \times 4186 \times (T - 20) \quad [J]$$

$$(\Delta U)_1 + (\Delta U)_2 = 0 \quad \rightarrow \quad T = 12{,}43\ °C$$

4.13

$\dot{m}_1 = 2\dot{m}_2$ $\quad T_1 = 12°C$

$p_1 = 1\ MPa = 10^6\ Pa = 10\ bar$



$\begin{cases} p_2 = p_1 \\ T_2 = 60°C \end{cases}$

$c_p = 1\ \frac{kJ}{kg\,K}$

sistema aperto a flusso stazionario:

$$\Sigma \dot{Q} - \Sigma \dot{L} + \Sigma \dot{m}\left(h + \frac{c^2}{2} + gz\right) = 0$$

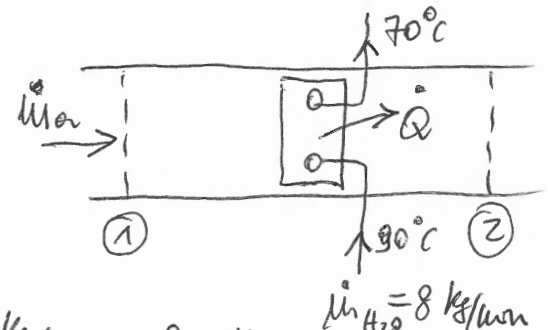
$$\Sigma \dot{m} h = 0 \qquad \begin{cases} \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3 = 0 & \text{CONSERV. ENERGIA} \\ \dot{m}_1 + \dot{m}_2 = \dot{m}_3 & \text{CONSERV. MASSA} \end{cases}$$

$\dot{m}_3 = 2\dot{m}_2 + \dot{m}_2 = 3\dot{m}_2$

$\dot{m}_1 c_p T_1 + \dot{m}_2 c_p T_2 - \dot{m}_3 c_p T_3 = 0$

$$T_3 = \frac{\dot{m}_1 T_1 + \dot{m}_2 T_2}{\dot{m}_3} = \frac{2\dot{m}_2 T_1 + \dot{m}_2 T_2}{3\dot{m}_2} = \frac{2T_1 + T_2}{3} = 28\ °C$$

4.14



$p_1 = 100\ kPa$

$T_1 = 25\ °C$

$T_2 = 47°C$

$\dot{V}_a = ?$

$\dot{m}_{H_2O} = 8\ kg/min = \frac{8}{60}\ kg/s$

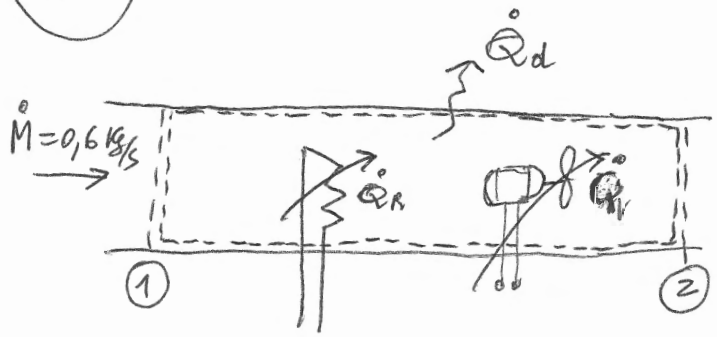
$\dot{Q} = \dot{m}_{H_2O} c_{p_{H_2O}} \Delta T = \frac{8}{60} 4186 (90-70) = 11162{,}67\ [W]$

$\dot{Q} = \dot{m}_a c_{p_a} (T_2 - T_1) \rightarrow \dot{m}_a = \frac{\dot{Q}}{c_{p_a}(T_2 - T_1)} = \frac{11162{,}67}{1000\,(47-25)} = 0{,}507\ kg/s$

$\rho_1 = \frac{p_1}{R^* T_1} = \frac{100000}{287 \times (273{,}15+25)} = 1{,}169\ kg/m^3$

$\dot{V} = \frac{\dot{m}}{\rho} = 0{,}434\ m^3/s$

4.15



$\dot{Q}_V = 300$ W

$\dot{M} = 0{,}6$ kg/s

$T_2 - T_1 = 5$ °C

$\dot{Q}_d = 400$ W

$\dot{Q}_R = ?$

sistema aperto a flusso stazionario

$$\Sigma \dot{Q} - \Sigma \dot{L} = \dot{M}\left(\Delta h + \Delta \frac{c^2}{2} + g\Delta z\right) \quad [W]$$

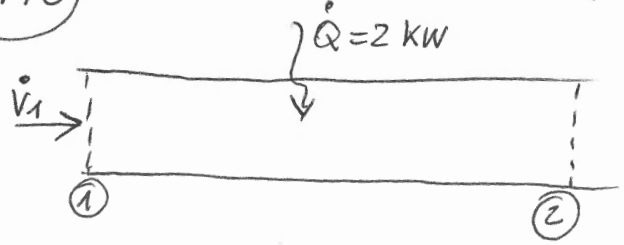
($\Sigma \dot{L} = 0$; $\Delta \frac{c^2}{2} \simeq 0$; $g\Delta z \simeq 0$)

$$\dot{Q}_R + \dot{Q}_V - \dot{Q}_d = \dot{M} c_{p_a} (T_2 - T_1)$$

$$\dot{Q}_R = 0{,}6 \times 1005 \times 5 - 300 + 400 = 3115 \ [W]$$

assumendo $c_{p_a} = 1005 \ \frac{J}{kg\,K}$

4.16



$D = 20$ cm

$\dot{V}_1 = 12 \ \frac{m^3}{min} = \frac{12}{60} \ \frac{m^3}{s}$

$p_1 = 105$ kPa

$T_1 = 12$ °C

$c_1 = ?$

$T_2 = ?$

$$A = \frac{\pi D^2}{4} = \frac{\pi\, 0{,}2^2}{4} = 0{,}0314 \ m^2$$

$$c_1 = \frac{\dot{V}_1}{A} = \frac{12}{60 \times 0{,}0314} = 6{,}366 \ m/s$$

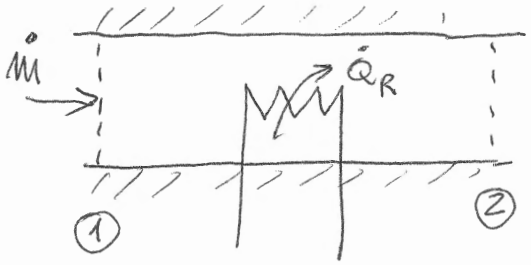
$$\dot{m} = \rho_1 \dot{V}_1 = \frac{p_1}{R^* T_1} \dot{V}_1 = \frac{105000}{287 \times (273{,}15+12)} \frac{12}{60} = 0{,}257 \ kg/s$$

$$\Sigma \dot{Q} - \Sigma \dot{L} = \dot{M}\left(\Delta h + \Delta \frac{c^2}{2} + g\Delta z\right)$$

$$\dot{Q} = \dot{M}(h_2 - h_1) \qquad \dot{Q} = \dot{M} c_{p_a} (T_2 - T_1)$$

$$2000 = 0{,}257 \times 1005 \times (T_2 - 12) \rightarrow T_2 = 19{,}74 \ °C$$

4.17



$\dot{Q}_R = 7\ kW$

$T_1 = 15\ °C$

$T_2 = 70\ °C$

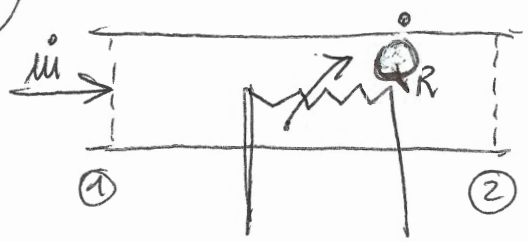
Sistema aperto a flusso stazionario:

$$\Sigma \dot{Q} + \Sigma \dot{L} = \dot{m}\left(\Delta h + \Delta \frac{c^2}{2} + g\Delta z\right)$$

$$\dot{Q}_R = \dot{m}\,\Delta h = \dot{m}\, c_{p_{H_2O}} (T_2 - T_1)$$

$$\dot{m} = \frac{\dot{Q}_R}{c_{p_{H_2O}}(T_2 - T_1)} = \frac{7}{4{,}186 \times (70-15)} = 0{,}030\ kg/s$$

4.19



$D = 5\ cm = 0{,}05\ m$

$T_1 = 15\ °C$

$\dot{V}_1 = 30\ \frac{L}{min}$

$T_2 = 50\ °C$

$\dot{Q}_R = ?$ $\quad c_1 = ?$

$$\dot{V}_1 = 30\ \frac{L}{min} = \frac{30 \times 10^{-3}}{60}\ \frac{m^3}{s} = 5 \times 10^{-4}\ \frac{m^3}{s}$$

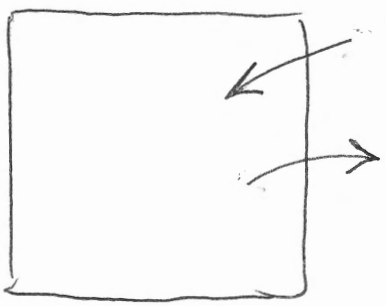
$\rho_{H_2O} \cong 1000\ kg/m^3 \rightarrow \dot{m} = \rho_{H_2O}\, \dot{V}_1 = 0{,}5\ kg/s$

$$\dot{Q}_R = \dot{m}\, c_{p_{H_2O}} (T_2 - T_1) = 0{,}5 \times 4{,}186 \times (50-15) = 73{,}255\ [kW]$$

$$\dot{V}_1 = A\, c_1 \rightarrow c_1 = \frac{\dot{V}}{A} = 0{,}255\ m/s$$

$$A = \frac{\pi D^2}{4} = \frac{\pi \times 0{,}05^2}{4} = 1{,}963 \times 10^{-3}\ m^2$$

4.20



$\dot{V}_e = 35 \frac{L}{s}$

$T_e = -10°C$

$\phi = 90 \text{ kPa}$

$T_i = 22°C$

$\dot{V}_e = 35 \frac{L}{s} = 35 \times 10^{-3} \frac{m^3}{s}$

$$\dot{Q}_r = \dot{m} c_{pa} (T_i - T_e)$$

$$\dot{m} = \rho_e \dot{V}_e = \frac{\phi}{R^* T_e} \dot{V}_e = \frac{90000}{287 \times 263{,}15} 35 \times 10^{-3} = 0{,}0417 \text{ kg/s}$$

$$c_{pa} = 1005 \frac{J}{kgK}$$

$$\dot{Q}_r = 0{,}0417 \times 1005 \times (22 - (-10)) = 1341 \text{ W} = 1{,}341 \text{ kW}$$

9.1

$T = 20°C$ $\quad \phi_a = ?$

$\phi = 98 \text{ kPa}$ $\quad x = ?$

$\psi = 0{,}85$ $\quad h = ?$

Dalla tab. vapor d'acqua: $\phi_{SAT}(20°C) = 2338{,}8 \text{ [Pa]}$

$$\phi_v = \psi P_{SAT} = 0{,}85 \times 2338{,}8 = 1987{,}98 \text{ [Pa]}$$

$$\phi_a = \phi - \phi_v = 96012{,}02 \text{ [Pa]}$$

$$x = 0{,}622 \frac{\phi_v}{\phi - \phi_v} = 0{,}0129$$

$$h = c_{pa} T + x (c_{pv} T + r_0) = 1{,}005\, T + 0{,}0129 (2501{,}3 + 1{,}82\, T)$$

$$h = 52{,}84 \frac{kJ}{kg}$$

9.2

$V = 240\ m^3$ $\quad m_a = ?$

$\phi = 98\ kPa$ $\quad m_v = ?$

$T = 23\ °C$

$\psi = 0,5$

Tabella $\rightarrow$ $p_{SAT}(23°C) = 2810,4\ [Pa]$

$p_v = \psi\, p_{SAT}(23°C) = 1405,2\ [Pa]$

$p_a = \phi - p_v = 96594,8\ [Pa]$

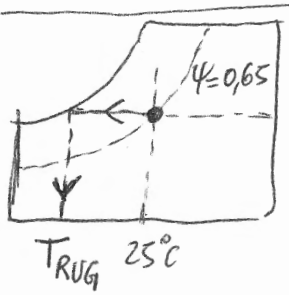
$$m_v = \frac{p_v V}{R_v^* T} = \frac{1405,2 \times 240}{462 \times 296,15} = 2,46\ [Kg]$$

$$m_a = \frac{p_a V}{R_a^* T} = \frac{96594,8 \times 240}{287 \times 296,15} = 272,75\ [Kg]$$

9.3

$T = 25°C$ $\quad T_{SUP} = 10°C > T_{RUG.}$?

$\psi = 0,65$



DA DIAGRAMMA ASHRAE:

$T_{RUG} = 18°C$

$T_{SUP} < T_{RUG} \Rightarrow$ CONDENSA

ALTRO PROCEDIMENTO:

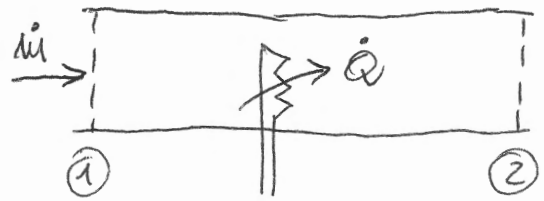
$p_{SAT}(25°C) = 3169,2\ [Pa]$ $\quad p_v = \psi\, p_{SAT} = 2059,98\ Pa$

$$X = 0,622\ \frac{p_v}{p - p_v} = 0,622\ \frac{2059,98}{10^5 - 2059,98} = 0,01308$$

Alla saturazione: $X = 0,622\ \frac{p_s}{\phi - p_s} = 0,01308 \rightarrow p_s = 2059,6\ [Pa]$

da tabella $p_s = 2059,6\ [Pa]$ per $T = T_{RUG} \cong 18°C$

9,8



$p = 95$ kPa

$T_1 = 15\ °C$

$\varphi_1 = 0{,}3$

$\dot{V} = 4 \frac{m^3}{min} = \frac{4}{60} \frac{m^3}{s}$

$T_2 = 25\ °C$

$\dot{Q} = ?$

$\varphi_2 = ?$

Da tabella $P_{SAT}(T_1) = 1705{,}5$ [Pa]

$P_{v1} = \varphi_1 P_{SAT}(T_1) = 511{,}05$ [Pa]

$P_{a1} = p - P_{v1} = 94488$ [Pa]

$$x_1 = 0{,}622 \frac{P_{v1}}{p - P_{v1}} = 0{,}003368$$

Conservazione massa $\sum \dot{m} = 0$

- ARIA SECCA: $\dot{m}_{a1} - \dot{m}_{a2} = 0 \rightarrow \dot{m}_{a1} = \dot{m}_{a2} = \dot{m}$
- vapore: $\dot{m}_{v1} - \dot{m}_{v2} = 0 \rightarrow \dot{m} x_1 - \dot{m} x_2 = 0 \rightarrow \boxed{x_1 = x_2}$

Conservazione energia $\sum \dot{Q} - \sum \dot{L} = \dot{m} (\Delta h + \Delta \frac{c^2}{2} + g \Delta z) \rightarrow \dot{Q} = \dot{m} (h_2 - h_1)$

$h_1 = c_{pa} T_1 + x_1 (r_0 + c_{pv} T_1) = 1{,}005 \times 15 + 0{,}003368 (2501{,}3 + 1{,}82 \times 15) = 23{,}59 \frac{kJ}{kg}$

$h_2 = c_{pa} T_2 + x_2 (r_0 + c_{pv} T_2) = 1{,}005 \times 25 + 0{,}003368 (2501{,}3 + 1{,}82 \times 25) = 33{,}70 \frac{kJ}{kg}$

$$\rho_1 = \frac{p_{a1}}{R^* T_1} = \frac{94488}{287 \times 288{,}15} = 1{,}143\ kg/m^3$$

$\dot{m} = \rho_1 \dot{V}_1 = 1{,}143 \times \frac{4}{60} = 0{,}0762$ kg/s

$\dot{Q} = \dot{m} (h_2 - h_1) = 0{,}0762 (33{,}70 - 23{,}59) = 0{,}770$ kW

$x_2 = x_1 \Rightarrow P_{v2} = P_{v1} = 511{,}65$ [Pa] $\qquad P_{s2} = P_{SAT}(25°C) = 3169{,}2$ [Pa]

$$\varphi_2 = \frac{P_{v2}}{P_{s2}} = 0{,}161$$

9.9

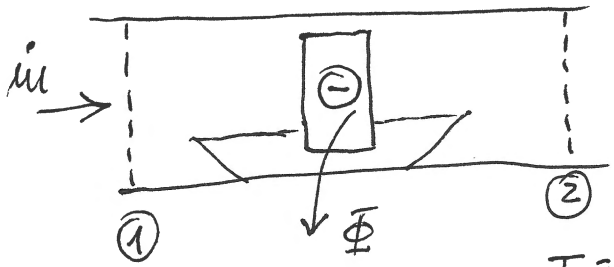
$D = 0{,}4\ m$

$P_1 = P_2 = 1\ atm = 101325\ [Pa]$

$T_1 = 32\ °C$

$\varphi_1 = 0{,}3$

$C_1 = 18\ m/s$



$T_2 = ?$

$\varphi_2 = ?$

$C_2 = ?$

$$\Phi = 1200\ \frac{kJ}{min} = \frac{1200}{60}\ \frac{kJ}{s} = 20\ [kW]$$

$$\dot{m} = \rho_a \dot{V} = \rho_a A C_1 \cong 1{,}2 \times \frac{\pi D^2}{4} C_1 = 1{,}2 \times \frac{\pi \times 0{,}4^2}{4} \times 18 = 2{,}71\ kg/s$$

dal diagramma dell'aria umida: $\left.\begin{matrix} T_1 = 32\ °C \\ \varphi_1 = 0{,}3 \end{matrix}\right\} \Rightarrow \begin{cases} x_1 = 0{,}009 \\ h_1 = 55\ \frac{kJ}{kg} \end{cases}$

$$-\Phi = \dot{m}(h_2 - h_1) \rightarrow \begin{cases} h_2 = h_1 - \frac{\Phi}{\dot{m}} = 47{,}63\ \frac{kJ}{kg} \\ T_2 = 24{,}4\ °C \\ UR_2 = 46{,}6\ \% \rightarrow \varphi_2 = 0{,}466 \end{cases}$$

$$\dot{m} = \rho_1 A C_1 = \rho_2 A C_2 \rightarrow \frac{P}{R^* T_1} A C_1 = \frac{P}{R^* T_2} A C_2 \rightarrow$$

$$\rightarrow C_2 = C_1 \frac{T_2}{T_1} = 18\ \frac{297{,}55}{305{,}15} = 17{,}55\ m/s$$

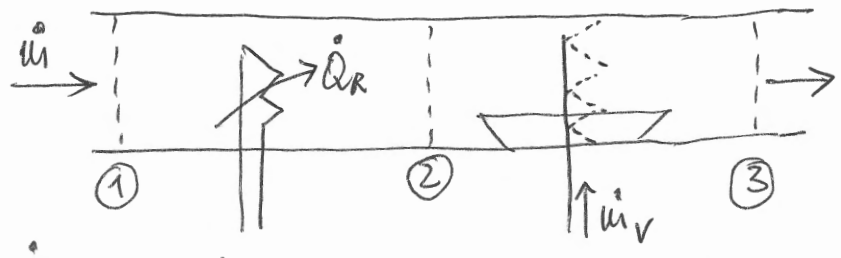
9.10

$p = 1\ atm = 101325\ [Pa]$

$T_1 = 15\,°C \xrightarrow{\text{Risc.}} T_2 = 20\,°C \xrightarrow{\text{Umid. vapore}} T_3 = 25\,°C$, $\varphi_3 = 0{,}65$

$\varphi_1 = 0{,}60$ — $\dot{Q}_R$ — $\dot{m}_v$

$\dot{m}_v = ?$ $\quad \dot{Q}_R = ?$



$$\dot{Q}_R = \dot{m}\,(h_2 - h_1) \longrightarrow q_R = \frac{\dot{Q}_R}{\dot{m}} = h_2 - h_1 \left[\frac{kJ}{kg_{a.s.}}\right]$$

$$\dot{m}_v = \dot{m}\,(x_3 - x_2) = \dot{m}\,(x_3 - x_1) \longrightarrow \frac{\dot{m}_v}{\dot{m}} = x_3 - x_1 \left[\frac{kg_{H_2O}}{kg_{a.s.}}\right]$$

① $\begin{cases} P_{SAT}(T_1) = 1705{,}5\ [Pa] \quad P_{v1} = \varphi_1 P_{SAT}(T_1) = 1023{,}3\ [Pa] \\ x_1 = 0{,}622\,\dfrac{P_{v1}}{P - P_{v1}} = 0{,}006\,33\,5 \quad h_1 = 1{,}005 \times 15 + 0{,}006\,33\,5\,(2501{,}3 + 1{,}82 \times 15) = 31{,}13 \left[\dfrac{kJ}{kg_{a.s.}}\right] \end{cases}$

② $\begin{cases} P_{SAT}(T_2) = 2338{,}8\ [Pa] \quad P_{v2} = P_{v1} \quad x_2 = x_1 \\ h_2 = 1{,}005 \times 20 + 0{,}006\,33\,5\,(2501{,}3 + 1{,}82 \times 20) = 36{,}21 \left[\dfrac{kJ}{kg_{a.s.}}\right] \end{cases}$

③ $P_{SAT}(T_3) = 3169{,}2\ [Pa] \quad P_{v3} = 2059{,}98\ [Pa] \quad x_3 = 0{,}012\,91 \left[\dfrac{kg_{H_2O}}{kg_{a.s.}}\right]$

$$q_R = h_2 - h_1 = 5{,}08 \left[\frac{kJ}{kg_{a.s.}}\right]$$

$$\frac{\dot{m}_v}{\dot{m}} = x_3 - x_1 = 0{,}006\,56 \left[\frac{kg_{H_2O}}{kg_{a.s.}}\right] = 6{,}56 \left[\frac{g_{H_2O}}{kg_{a.s.}}\right]$$

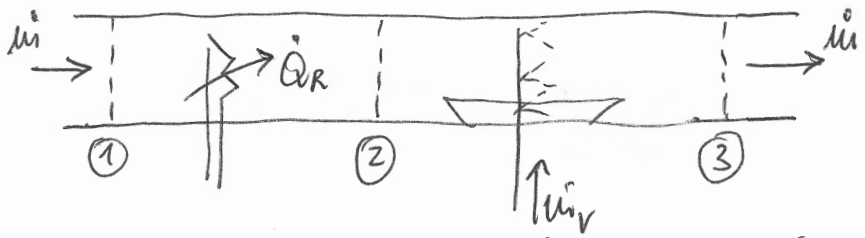
9.11 $p_1 = 1\ \text{atm} = 101325\ [Pa]$

$T_1 = 10\ ^\circ C$

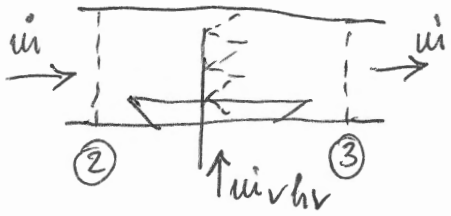
$\varphi_1 = 0{,}7$

$\dot V_1 = 35\ \frac{m^3}{min}$

$\xrightarrow[\dot Q_R]{\text{Risc.}}$ $T_2 = ?$, $\varphi_2 = ?$ $\xrightarrow[\text{a vap. saturo a } 100\ ^\circ C]{\text{Umidif.}}$ $\dot m_v$ $\rightarrow$ $T_3 = 20\ ^\circ C$, $\varphi_3 = 0{,}6$, $\dot Q_R = ?$, $\dot m_v = ?$



$h_v = 2676{,}1\ \frac{kJ}{kg}$ (da tab. per vapore sat. 100°C)



$$\begin{cases} \text{conserv. vapore} & \dot m x_2 + \dot m_v = \dot m x_3 \\ \text{conserv. energia} & \dot m h_2 + \dot m_v h_v = \dot m h_3 \end{cases}$$

$$\rightarrow \begin{cases} \dot m_v = \dot m (x_3 - x_2) \\ h_2 = \dfrac{\dot m h_3 - \dot m_v h_v}{\dot m} \end{cases}$$

$$\dot m = \rho_1 \dot V_1 = 1{,}236\ \frac{35}{60} = 0{,}721\ kg/s$$

(1)
$$\begin{cases} P_{SAT}(T_1) = 1228\ [Pa] & P_{v1} = \varphi_1 P_{SAT}(T_1) = 859{,}6\ [Pa] & P_{a1} = p_1 - P_{v1} = 100456{,}4\ [Pa] \\ \rho_1 = \dfrac{p_{a1}}{R^* T_1} = \dfrac{100465{,}4}{287 \times 283{,}15} = 1{,}236\ kg/m^3 \\ x_1 = 0{,}622\ \dfrac{859{,}6}{101325 - 859{,}6} = 0{,}005322 \\ h_1 = 1{,}005 \times 10 + 0{,}005322\,(2501{,}3 + 1{,}82 \times 10) = 23{,}46\ \frac{kJ}{kg_{a.s.}} \end{cases}$$

(3)
$$\begin{cases} P_{SAT}(T_3) = 2338{,}8\ [Pa] & P_{v3} = \varphi_3 P_{SAT}(T_3) = 1403{,}28\ [Pa] \\ x_3 = 0{,}622\ \dfrac{1403{,}28}{101325 - 1403{,}28} = 0{,}008735 \\ h_3 = 1{,}005 \times 20 + 0{,}008735\,(2501{,}3 + 1{,}82 \times 20) = 42{,}27\ \frac{kJ}{kg_{a.s.}} \end{cases}$$

(2)
$$\begin{cases} x_2 = x_1 = 0{,}005322 \\ \dot m_v = \dot m (x_3 - x_2) = 0{,}00246\ \dfrac{kg_{H_2O}}{kg_{a.s.}} = 2{,}46\ \dfrac{g_{H_2O}}{kg_{a.s.}} \\ h_2 = \dfrac{\dot m h_3 - \dot m_v h_v}{\dot m} = 33{,}14\ \dfrac{kJ}{kg_{a.s.}} \end{cases}$$

$$\dot Q_R = \dot m (h_2 - h_1) = 6{,}98\ [kW]$$

$$h_2 = 1{,}005\, T_2 + 0{,}005322\,(2501{,}3 + 1{,}82\, T_2) = 33{,}14 \rightarrow T_2 = 19{,}54\ ^\circ C$$

$$P_{SAT}(T_2) = 2273{,}9\ [Pa] \qquad P_{v2} = P_{v1} = 859{,}6\ [Pa] \rightarrow \varphi_2 = \frac{P_{v2}}{P_{SAT}(T_2)} = 0{,}378$$

9.12

$P = 1$ atm

$T_1 = 32\,^\circ C$, $\varphi_1 = 0{,}7$, $\dot V = 3\ \frac{m^3}{min}$

$T_2 = 12\,^\circ C$, $\varphi_2 = 1$, $\dot m_{H_2O}(12\,^\circ C) = ?$, $\dot Q_F = ?$

$P_{s1} = P_s(32\,^\circ C) = 4758{,}2$ Pa $P_{v1} = \varphi_1 P_{s1} = 3330{,}74$ Pa $x_1 = 0{,}622 \frac{P_{v1}}{P - P_{v1}} = 0{,}0214$

$h_1 = 1{,}005 \times 32 + 0{,}0214\,(2501{,}3 + 1{,}82 \times 32) = 87{,}01\ \frac{kJ}{kg}$

$\varphi_2 = 1 \rightarrow P_{v2} = P_{s2} = P_s(12) = 1402{,}6$ Pa $x_2 = 0{,}622 \frac{1402{,}6}{10^5 - 1402{,}6} = 0{,}00885$

$h_2 = 1{,}005 \times 12 + 0{,}00885\,(2501{,}3 + 1{,}82 \times 12) = 34{,}39\ \frac{kJ}{kg}$

$\dot m = \rho_1 \dot V = \frac{10^5}{287 \times 305{,}15} \cdot \frac{3}{60} = 0{,}0571\ kg/s$ $\dot Q_F = \dot m\,(h_1 - h_2) = 3\ kW$

$\dot m_{H_2O} = \dot m\,(x_1 - x_2) = 7{,}17 \times 10^{-4}\ kg/s = 0{,}7\ \frac{g}{s}$

9.20

① $T_1 = 32\,^\circ C$, $\varphi_1 = 0{,}4$, $\dot V_1 = 20\ \frac{m^3}{min}$

② $T_2 = 12\,^\circ C$, $\varphi_2 = 0{,}9$, $\dot V_2 = 25\ \frac{m^3}{min}$

$P = 1$ atm $x_3 = ?$, $\varphi_3 = ?$, $T_3 = ?$, $\dot V_3 = ?$

$\dot m_1 = \rho_1 \dot V_1 = \frac{10^5}{287 \times 305{,}15} \frac{20}{60} = 0{,}3806\ kg/s$ $\dot m_2 = \rho_2 \dot V_2 = \frac{10^5}{287 \times 285{,}15} \times \frac{25}{60} = 0{,}5091\ kg/s$

$\dot m_3 = \dot m_1 + \dot m_2 = 0{,}8897\ kg/s$

$P_{s1} = P_s(32) = 4758{,}2$ Pa $P_{v1} = \varphi_1 P_{s1} = 1903{,}28$ Pa $x_1 = 0{,}622 \frac{P_{v1}}{P - P_{v1}} = 0{,}01207$

$P_{s2} = P_s(12) = 1402{,}6$ Pa $P_{v2} = \varphi_2 P_{s2} = 1262{,}34$ Pa $x_2 = 0{,}622 \frac{P_{v2}}{P - P_{v2}} = 0{,}00795$

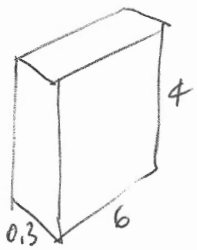
$h_1 = 1{,}005 \times 32 + 0{,}01207\,(2501{,}3 + 1{,}82 \times 32) = 63{,}05\ \frac{kJ}{kg}$ $h_2 = 32{,}12\ \frac{kJ}{kg}$

$h_3 = \frac{\dot m_1 h_1 + \dot m_2 h_2}{\dot m_3} = 45{,}35\ \frac{kJ}{kg}$ $x_3 = \frac{\dot m_1 x_1 + \dot m_2 x_2}{\dot m_3} = 0{,}00971$

$T_3 = \frac{45{,}35 - 0{,}00971 \times 2501{,}3}{1{,}005 + 1{,}82 \times 0{,}00971} = 20{,}6\,^\circ C$ $P_{s3} = P_s(20{,}6) = 2428{,}1$ Pa

$x_3 = 0{,}622 \frac{P_{v3}}{P - P_{v3}} \rightarrow (P - P_{v3})\,x_3 = 0{,}622\,P_{v3}$ $P_{v3} = \frac{P \cdot x_3}{0{,}622 + x_3} = 1537{,}1$ Pa $\varphi_3 = \frac{P_{v3}}{P_{s3}} = 0{,}633$

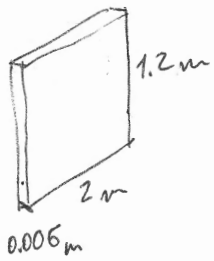
10.4



$\lambda = 0{,}8 \frac{W}{mK}$ $\quad T_1 = 14\,^\circ C$ $\quad T_2 = 6\,^\circ C$

$$\dot{Q} = \frac{\lambda}{d} A (T_1 - T_2) = \frac{0{,}8}{0.3} \times (4 \times 6)\,(14-6) = 512\ W$$

10.5



$\lambda = 0.78 \frac{W}{mK}$

$T_i = 24\,^\circ C$ $\quad h_i = 10 \frac{W}{mK}$

$T_e = -5\,^\circ C$ $\quad h_e = 25 \frac{W}{mK}$

$$\dot{Q} = U A (T_i - T_e)$$

$$U = \frac{1}{\frac{1}{h_i} + \frac{d}{\lambda} + \frac{1}{h_e}} = \frac{1}{\frac{1}{10} + \frac{0{,}006}{0.78} + \frac{1}{25}} = 6.77 \frac{W}{m^2 K}$$

$$\dot{Q} = 6.77\,(2 \times 1{,}2)\,[24 - (-5)] = 471\ W$$

$$\dot{Q} = h_i A (T_i - T_1) \qquad T_1 = T_i - \frac{\dot{Q}}{h_i A} = 24 - \frac{471}{10 \cdot (2 \times 1{,}2)} = 4{,}4\,^\circ C$$

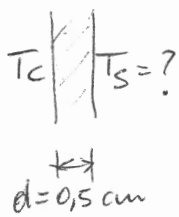
10.7

$T_i = 20\,^\circ C$ $\quad \dot{Q} = 150\ W$

$S = 1{,}7\ m^2$

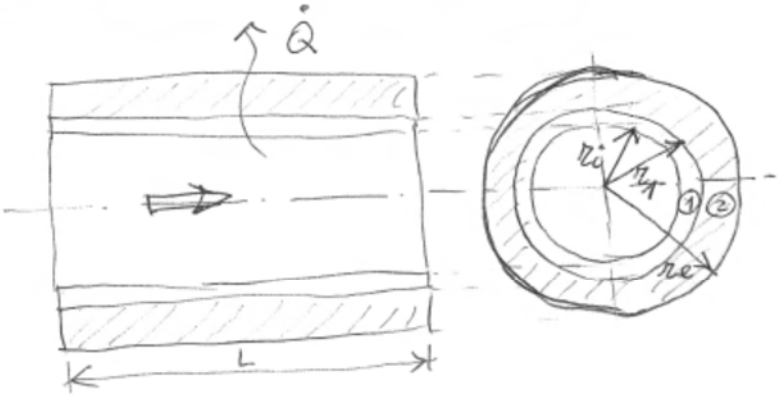
$T_c = 37\,^\circ C$

$\lambda = 0{,}3 \frac{W}{mK}$



$$\dot{Q} = \frac{\lambda}{d} S (T_c - T_s) \rightarrow T_s = T_c - \frac{\dot{Q} \cdot d}{\lambda S} = 37 - \frac{150 \times 0{,}005}{0{,}3 \times 1.7} = 35{,}5\,^\circ C$$

10.11



$r_i = \frac{0,05}{2} = 0,025\ m$ $\quad r_1 = \frac{0,055}{2} = 0,0275\ m$ $\quad r_e = r_1 + 0,03 = 0,0575\ m$

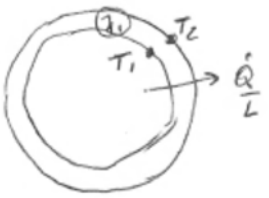
$\lambda_1 = 15\ \frac{W}{m\,K}$ $\quad \lambda_2 = 0,038\ \frac{W}{m\,K}$

$T_e = 5\ ^\circ C$ $\quad T_i = 320\ ^\circ C$ $\quad h_e = 15\ \frac{W}{m^2 K}$ $\quad h_i = 80\ \frac{W}{m^2 K}$

$$\dot{Q} = US(T_i - T_e) = \frac{2\pi L\ (T_i - T_e)}{\frac{1}{h_i r_i} + \frac{1}{\lambda_1} \ln\frac{r_1}{r_i} + \frac{1}{\lambda_2} \ln\frac{r_e}{r_1} + \frac{1}{h_e r_e}}$$

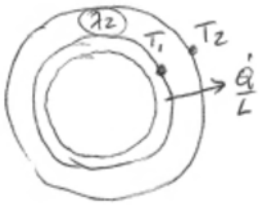
$$\frac{\dot{Q}}{L} = \frac{2\pi\ (320 - 5)}{\frac{1}{80 \cdot 0,025} + \frac{1}{15} \ln\frac{0,0275}{0,025} + \frac{1}{0.038} \ln\frac{0,0575}{0.0275} + \frac{1}{15 \cdot 0,0575}}$$

$$\frac{\dot{Q}}{L} = 93,9\ \frac{W}{m}$$



$$\frac{\dot{Q}}{L} = \frac{2\pi\ (T_1 - T_2)}{\frac{1}{\lambda_1} \ln\frac{r_1}{r_i}} \rightarrow$$

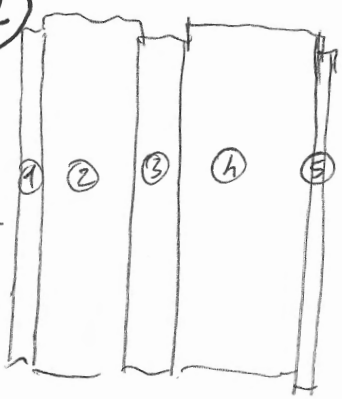
$$T_1 - T_2 = \frac{\dot{Q}}{2\pi L} \cdot \frac{1}{\lambda_1} \ln\frac{r_1}{r_i} = \frac{93,9}{2\pi} \frac{1}{15} \ln\frac{0.0275}{0.025} = 0,095\ ^\circ C$$



$$\frac{\dot{Q}}{L} = \frac{2\pi\ (T_1 - T_2)}{\frac{1}{\lambda_2} \ln\frac{r_e}{r_1}}$$

$$T_1 - T_2 = \frac{\dot{Q}}{2\pi L} \frac{1}{\lambda_2} \ln\frac{r_e}{r_1} = \frac{93.9}{2\pi} \frac{1}{0.038} \ln\frac{0.0575}{0.0275} = 290\ ^\circ C$$

10,12



$T_i = 20°C$

$\varphi_i = 0,5$

$T_e = 0°C$

$\varphi_e = 0,6$

$P_s(0°C) = 610$ [Pa]

$P_s(20°C) = 2336$ [Pa]

$\beta_i = \beta_e = 5 \times 10^{-8} \frac{s}{m}$

$s_1 = s_5 = 0,01$ m

$s_2 = 0,10$ m

$s_3 = 0,04$ m

$s_4 = 0,15$ m

$\delta_{P1} = 25 \times 10^{-12} \frac{kg}{m\,s\,Pa}$ $\quad \delta_{P2} = 20 \times 10^{-12} \frac{kg}{m\,s\,Pa}$ $\quad \delta_{P3} = 193 \times 10^{-12} \frac{kg}{m\,s\,Pa}$ $\quad \delta_{P4} = 2 \times 10^{-12} \frac{kg}{m\,s\,Pa}$

$g_v = ?$

$$g_v = U_v (P_{vi} - P_{ve}) \quad \left[\frac{kg}{m^2 s}\right]$$

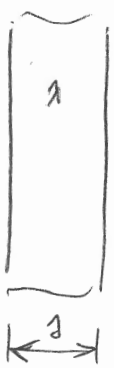
$$U_v = \frac{1}{\frac{1}{\beta_i} + \frac{s_1}{\delta_{P1}} + \frac{s_2}{\delta_{P2}} + \frac{s_3}{\delta_{P3}} + \frac{s_4}{\delta_{P4}} + \frac{1}{\beta_e}} = 1,234 \times 10^{-11} \frac{kg}{m^2 s\,Pa}$$

$$P_{vi} = \varphi_i P_s(20°C) = 0,5 \times 2336 = 1168 \text{ [Pa]}$$

$$P_{ve} = \varphi_e P_s(0°C) = 0,6 \times 610 = 366 \text{ [Pa]}$$

$$g_v = 9,9 \times 10^{-9} \left[\frac{kg}{m^2 s}\right]$$

10,13



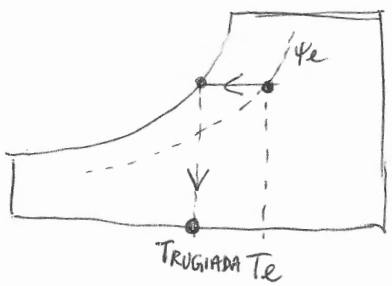
$\lambda = 0,04 \frac{W}{mK}$

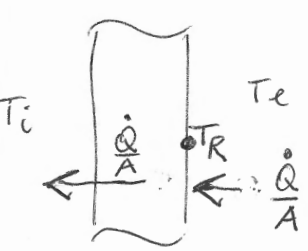
$h_i = 8 \frac{W}{m^2 K}$

$h_e = 20 \frac{W}{m^2 K}$

$T_i = -25°C$

$\begin{cases} T_e = 30°C \\ \varphi_e = 0,7 \end{cases} \rightarrow T_{RUGIADA} = 23,8°C$





$$\frac{\dot{Q}}{A} = h_e (T_e - T_R) = 20 (30 - 23,8) = 124 \frac{W}{m^2}$$

$$\frac{\dot{Q}}{A} = \frac{(T_R - T_i)}{\frac{s}{\lambda} + \frac{1}{h_i}} \Rightarrow \frac{s}{\lambda} + \frac{1}{h_i} = \frac{T_R - T_i}{\frac{\dot{Q}}{A}}$$

$$s = \lambda \left[\frac{T_R - T_i}{\frac{\dot{Q}}{A}} - \frac{1}{h_i}\right] = 0,011 \text{ m}$$