SOLUTION

Unit Settings: SI C Pa J mass deg

α_o = 31,84 [W/m^2-K]
α_{vz} = 78,28 [W/m^2-K]
Ar_{ksuma} = 121,1
a_2 = 0,5
a_{vz} = 0,00002765 [m^2/s]
B = 1,3
b_{zebra} = 0,0015 [m]
cp_{Ar} = 521
cp_{H2O} = 1893
cp_{O2} = 940,3 [J/kg-K]
cp_{vz} = 1004 [J/kg-K]
c_2 = 0,866
$c_{z,2}$ = 7
d_1 = 0,06 [m]
$D_{Ar,CO2}$ = 0,00001945 [m^2/s]
$D_{Ar,N2}$ = 0,0003803 [m^2/s]
$D_{CO2,H2O}$ = 0,00004154 [m^2/s]
$D_{CO2,O2}$ = 0,00002488 [m^2/s]
$D_{H2O,O2}$ = 0,00006861 [m^2/s]
d_p = 0,066 [m]
$D_{pl,2}$ = 0,33 [m]
D_s = 0,2993 [m]
η_{Ar} = 0,00002784
η_{H2O} = 0,0000131
η_{O2} = 0,00002509 [kg/m-s]
η_{vz} = 0,00002045 [kg/m-s]
G = 1,063 [-]
$h_{Ar,in}$ = 52812
$h_{Ar,out}$ = 50418
$h_{CO2,nul}$ = -8,962E+06
$h_{H2O,in}$ = -1,323E+07
$h_{H2O,out}$ = 181228
$h_{N2,nul}$ = -25945
$h_{O2,in}$ = 94465
$h_{O2,out}$ = 89034
$h_{sp,in}$ = 139631 [J/kg]
h_{vz} = 87362
$h_{vz,out}$ = 112466 [J/kg]
k_L = 6,16 [W/m-K]
k_S = 30,96 [W/m^2-K]
k_v = 31,12 [m^2]
λ_{11} = 0,02824 [-]
λ_{Ar} = 0,02184
λ_{H2O} = 0,02527
λ_{O2} = 0,03344
λ_{trub} = 49,91 [W/m-K]
l_{tn} = 0,23 [m]
L_{ze} = 1 [m]
MW_{Ar} = 39,95
MW_{H2O} = 18,02
MW_{O2} = 32
m_{vz} = 0,167 [kg/s]
Nus_{lam} = 99,33
Nus_{turb} = 115,4
Nus_{zebra} = 109,8
n_p = 10
n_{rp} = 1,994
n_t = 9,965
n_{zebra} = 400 [-]

α_{sp} = 54,33 [W/m^2-K]
α_{zebra} = 25,47 [W/m^2-K]
a_1 = -0,123
a_{sp} = 0,00003208 [m^2/s]
a_z = 0,03596
β = 31,95
$CO2_{ksuma}$ = 116,1
cp_{CO2} = 927,1
cp_{N2} = 1042
cp_{sp} = 1110 [J/kg-K]
c_1 = 1
$c_{z,1}$ = 0,372
δ_{zebra} = 0,001 [m]
d_2 = 0,063 [m]
$D_{Ar,H2O}$ = 0,00005999 [m^2/s]
$D_{Ar,O2}$ = 0,00003385 [m^2/s]
$D_{CO2,N2}$ = 0,0000285 [m^2/s]
$D_{H2O,N2}$ = 0,00007596 [m^2/s]
$D_{N2,O2}$ = 0,00004626 [m^2/s]
$D_{pl,1}$ = 0,32 [m]
D_{pr} = 0,318 [m]
D_{zebra} = 0,067 [m]
η_{CO2} = 0,00001894
η_{N2} = 0,00002143
η_{sp} = 0,00002135 [kg/m-s]
η_{ze} = 0,9986 [-]
$H2O_{ksuma}$ = -8,255
$h_{Ar,nul}$ = -13236
$h_{CO2,in}$ = -8,850E+06
$h_{CO2,out}$ = 83681
$h_{H2O,nul}$ = -1,347E+07
$h_{N2,in}$ = 105746
$h_{N2,out}$ = 100424
$h_{O2,nul}$ = -22777
h_p = 0,228 [m]
$h_{sp,out}$ = 106316 [J/kg]
$h_{vz,in}$ = 25104 [J/kg]
h_{zebra} = 0,002 [m]
k_{r1} = 0,0025 [-]
k_{trub} = 0,00015 [m]
k_{zebra} = 25,55 [W/m^2-K]
λ_{22} = 0,1062 [-]
λ_{CO2} = 0,0235
λ_{N2} = 0,03168
λ_{sp} = 0,03034 [W/m-K]
λ_{vz} = 0,02869 [W/m-K]
L_{trub} = 6,594 [m]
L_{zebra} = 2,976 [m]
MW_{CO2} = 44,01
MW_{N2} = 28,01
m_{sp} = 0,438 [kg/s]
$N2_{ksuma}$ = -1,126
Nus_{sp} = 107,4
Nus_{vz} = 270
n_{CH} = 1 [-]
n_{rc} = 17,95
n_{rv} = 10,53
n_{tv} = 1,264
$O2_{ksuma}$ = 70,77

$\omega_{Ar,CO2}$ = 1,175 [-]
$\omega_{Ar,N2}$ = 0,101 [-]
$\omega_{CO2,H2O}$ = 1,908 [-]
$\omega_{CO2,O2}$ = 1,197 [-]
$\omega_{H2O,O2}$ = 1,65 [-]
$\phi_{Ar,CO2}$ = 2,444
$\phi_{Ar,N2}$ = 0,125
$\phi_{CO2,Ar}$ = 1,509
$\phi_{CO2,N2}$ = 1,03
$\phi_{H2O,Ar}$ = 0,8265
$\phi_{H2O,N2}$ = 0,6527
$\phi_{N2,Ar}$ = 0,1372
$\phi_{N2,H2O}$ = 0,6871
$\phi_{O2,Ar}$ = 1,58
$\phi_{O2,H2O}$ = 0,7797
ϕ_{vp} = 129,7 [rad]
Pr_{sp} = 0,7814
$\psi_{Ar,CO2}$ = -35,32
$\psi_{Ar,N2}$ = 0,5723
$\psi_{CO2,Ar}$ = 22,92
$\psi_{CO2,N2}$ = 3,879
$\psi_{H2O,Ar}$ = -1,438
$\psi_{H2O,N2}$ = -1,999
$\psi_{N2,Ar}$ = -0,5241
$\psi_{N2,H2O}$ = 2,634
$\psi_{O2,Ar}$ = -9,768
$\psi_{O2,H2O}$ = 2,168
ψ_{t} = 0,3717
p_{m1} = 297,9 [Pa]
p_{t1} = 169,4 [Pa]
p_{to} = 35,17 [Pa]
p_{z1} = 467,3 [Pa]
Q = 14592 [W]
q_{out} = -92,4 [W/m]
Re_{sp} = 43689 [-]
ρ_{Ar} = 1,265
ρ_{H2O} = 0,5705
ρ_{O2} = 1,013
ρ_{vz} = 1,034 [kg/m^3]
S = 13,01 [m^2]
σ_{CO2} = 3,941E-10 [m]
σ_{N2} = 3,798E-10 [m]
$suma_{Ar}$ = 65,01
$suma_{H2O}$ = 3,281
$suma_{O2}$ = 6,917
S_{2Z} = 0,017 [m^2]
s_p = 0,004 [m]
S_{tp} = 0,002837 [m^2]
S_{trubka} = 0,1188
s_{tt} = 0,01575 [m]
S_{V23} = 15,76 [m^2]
S_{vz} = 0,01518 [m^2]
S_{zebra} = 0,4109 [m^2]
t_{nul} = 0 [°C]
$t_{sp,in}$ = 126,7 [°C]
$t_{str,sp}$ = 111,7
$t_{str,S,in}$ = 85,63
$t_{S,ex,in}$ = 65,44 [°C]
$t_{S,in,in}$ = 65,53 [°C]
t_t = 0,07875 [m]

$\omega_{Ar,H2O}$ = 1,587 [-]
$\omega_{Ar,O2}$ = 1,069 [-]
$\omega_{CO2,N2}$ = 1,122 [-]
$\omega_{H2O,N2}$ = 1,482 [-]
$\omega_{N2,O2}$ = 1,03 [-]
$\phi_{Ar,H2O}$ = 0,7925
$\phi_{Ar,O2}$ = 1,405
$\phi_{CO2,H2O}$ = 0,7066
$\phi_{CO2,O2}$ = 1,18
$\phi_{H2O,CO2}$ = 1,194
$\phi_{H2O,O2}$ = 0,7227
$\phi_{N2,CO2}$ = 1,831
$\phi_{N2,O2}$ = 1,128
$\phi_{O2,CO2}$ = 2,15
$\phi_{O2,N2}$ = 1,156
ϕ_{vs} = 109,7 [rad]
Pr_{vz} = 0,747
$\psi_{Ar,H2O}$ = 2,046
$\psi_{Ar,O2}$ = 9,728
$\psi_{CO2,H2O}$ = 1,724
$\psi_{CO2,O2}$ = 5,918
$\psi_{H2O,CO2}$ = -1,878
$\psi_{H2O,O2}$ = -1,707
$\psi_{N2,CO2}$ = -5,482
$\psi_{N2,O2}$ = -11,79
$\psi_{O2,CO2}$ = -7,806
$\psi_{O2,N2}$ = 7,301
ψ_{ze} = 0,06486
p_{nul} = 101325 [Pa]
p_{tn} = 846,6 [Pa]
p_{tv} = 1050 [Pa]
p_{z2} = 1932 [Pa]
q_{in} = 626,5 [W/m]
R = 8314 [J/kmol/K]
Re_{vz} = 27183 [-]
ρ_{CO2} = 1,394
ρ_{N2} = 0,8871
ρ_{sp} = 0,8518 [kg/m^3]
R_Z = 0,0001625 [m^2-K/W]
σ_{Ar} = 3,542E-10 [m]
σ_{H2O} = 2,641E-10 [m]
σ_{O2} = 3,467E-10 [m]
$suma_{CO2}$ = 29,16
$suma_{N2}$ = 0,5232
S_{2N} = 0,08 [m^2]
S_{celkem} = 0,5297 [m^2]
S_{ps} = 0,0006411 [m^2]
s_{trub} = 0,0015 [m]
s_{ts} = 0,02075 [m]
S_v = 13,01 [m^2]
S_{vN} = 0,01913 [m^2]
S_{ze} = 0,3267 [m^2]
t_{ln} = 36,24 [°C]
t_p = 0,254 [m]
$t_{sp,out}$ = 96,7 [°C]
$t_{str,S,ex}$ = 85,59
$t_{str,vz}$ = 68,35
$t_{S,ex,out}$ = 105,7 [°C]
$t_{S,in,out}$ = 105,7 [°C]
t_{t1} = 0,07875 [m]

t_{t2} = 0,0682 [m]
$t_{vz,out}$ = 111,7 [°C]
w_{CO2} = 0,05301 [-]
w_{N2} = 0,6595 [-]
w_{sp} = 18,25 [m/s]
$w_{vz,2}$ = 10,06 [m/s]
ξ_{12} = 0,4
x_{13} = 0,6223
x_7 = 1,083
x_9 = 4,150E+19
x_{CO2} = 0,03307
x_{H2O} = 0,1733
x_{N2} = 0,6464
y_2 = 1
y_4 = 1
y_6 = 0,9259
y_8 = 1,034
z_2 = 0,8526
z_3 = 1
z_5 = 8,327

$t_{vz,in}$ = 25 [°C]
w_{Ar} = 0,01108 [-]
w_{H2O} = 0,1137 [-]
w_{O2} = 0,1627 [-]
w_{vz} = 5,435 [m/s]
ξ_{11} = 0,7
x_{10} = 0,08793
x_6 = 1,25
x_8 = 0,1269
x_{Ar} = 0,007616
$x_{diagram,1}$ = 1,333
$x_{kontrola}$ = 0,2046
x_{O2} = 0,1396
y_3 = 1,616
y_5 = 1,144
y_7 = 1
z_1 = 49,59
z_{22} = 1,252
z_4 = 0,2414

No unit problems were detected. (101 disabled)

6.1 ZADÁNÍ

$t_{sp;in} = 126{,}7$ [°C] *teplota spalin na vstupu*

$t_{sp;out} = 96{,}7$ [°C] *teplota spalin na výstupu*

$$t_{str;vz} = \frac{t_{vz;in} + t_{vz;out}}{2}$$ *stYední teplota spalin*

$$t_{str;sp} = \frac{t_{sp;in} + t_{sp;out}}{2}$$ *stYední teplota vzduchu*

$t_{nul} = 0$ [°C]

$p_{nul} = 101325$ [Pa]

$t_{vz;in} = 25$ [°C]

$t_{vz;out} = 111{,}7$ [°C]

$m_{sp} = 0{,}438$ [kg/s] *hmot. tok spalin*

$w_{Ar} = 0{,}01108$ [-] *hm. kon. Ar v sp.*

$w_{CO2} = 0{,}05301$ [-] *hm. kon. CO2 v sp.*

$w_{H2O} = 0{,}1137$ [-] *hm. kon. H2O v sp.*

$w_{N2} = 0{,}6595$ [-] *hm. kon. N2 v sp.*

$w_{O2} = 0{,}1627$ [-] *hm. kon. O2 v sp.*

$MW_{Ar} = \textbf{MolarMass}(\text{Argon})$ *mol. hm. Ar*

$MW_{CO2} = \textbf{MolarMass}(\text{CO2})$ *mol. hm. CO2*

$MW_{H2O} = \textbf{MolarMass}(\text{h2o})$ *mol. hm. H2O*

$MW_{N2} = \textbf{MolarMass}(\text{N2})$ *mol. hm. N2*

$MW_{O2} = \textbf{MolarMass}(\text{O2})$ *mol. hm. O2*

6.3 TERMOFYZIKÁLNÍ VLASTNOSTI TEPLONOSNÝCH MÉDIÍ

PYevod hm. kon. na obj. kon.

$$x_{Ar} = \frac{\frac{w_{Ar}}{MW_{Ar}}}{\frac{w_{Ar}}{MW_{Ar}} + \frac{w_{CO2}}{MW_{CO2}} + \frac{w_{H2O}}{MW_{H2O}} + \frac{w_{N2}}{MW_{N2}} + \frac{w_{O2}}{MW_{O2}}}$$ *obj. kon. Ar v sp.*

$$x_{CO2} = \frac{\frac{w_{CO2}}{MW_{CO2}}}{\frac{w_{Ar}}{MW_{Ar}} + \frac{w_{CO2}}{MW_{CO2}} + \frac{w_{H2O}}{MW_{H2O}} + \frac{w_{N2}}{MW_{N2}} + \frac{w_{O2}}{MW_{O2}}}$$ *obj. kon. CO2 v sp.*

$$x_{H2O} = \frac{\frac{w_{H2O}}{MW_{H2O}}}{\frac{w_{Ar}}{MW_{Ar}} + \frac{w_{CO2}}{MW_{CO2}} + \frac{w_{H2O}}{MW_{H2O}} + \frac{w_{N2}}{MW_{N2}} + \frac{w_{O2}}{MW_{O2}}}$$ *obj. kon. H2O v sp.*

$$x_{N2} = \frac{\frac{w_{N2}}{MW_{N2}}}{\frac{w_{Ar}}{MW_{Ar}} + \frac{w_{CO2}}{MW_{CO2}} + \frac{w_{H2O}}{MW_{H2O}} + \frac{w_{N2}}{MW_{N2}} + \frac{w_{O2}}{MW_{O2}}}$$ *obj. kon. N2 v sp.*

$$x_{O2} = \frac{\frac{w_{O2}}{MW_{O2}}}{\frac{w_{Ar}}{MW_{Ar}} + \frac{w_{CO2}}{MW_{CO2}} + \frac{w_{H2O}}{MW_{H2O}} + \frac{w_{N2}}{MW_{N2}} + \frac{w_{O2}}{MW_{O2}}}$$ *obj. kon. O2 v sp.*

Hustota spalin

$$\rho_{Ar} = \rho\left(\text{Argon} \; ; T = t_{str;sp} ; P = p_{nul}\right)$$

$$\rho_{CO2} = \rho\left(\text{CO2} \; ; T = t_{str;sp} ; P = p_{nul}\right)$$

$$\rho_{H2O} = \rho\left(\text{h2o} \; ; T = t_{str;sp} ; P = p_{nul}\right)$$

$$\rho_{N2} = \rho\left(\text{N2} \; ; T = t_{str;sp} ; P = p_{nul}\right)$$

$$\rho_{O2} = \rho\left(\text{O2} \; ; T = t_{str;sp} ; P = p_{nul}\right)$$

$$\rho_{sp} = x_{Ar} \cdot \rho_{Ar} + x_{CO2} \cdot \rho_{CO2} + x_{H2O} \cdot \rho_{H2O} + x_{N2} \cdot \rho_{N2} + x_{O2} \cdot \rho_{N2}$$ *hustota spalin*

Hustota vzduchu

$$\rho_{vz} = \rho\left(\text{Air} \; ; T = t_{str;vz} ; P = p_{nul}\right)$$

Viskozity prvko ve spalinách

$$\eta_{Ar} = \textbf{Visc}\left(\text{Argon} \; ; T = t_{str;sp} ; P = p_{nul}\right)$$

$$\eta_{CO2} = \textbf{Visc}\left(\text{CO2} \; ; T = t_{str;sp}\right)$$

$$\eta_{H2O} = \textbf{Visc}\left(\text{h2o} \; ; T = t_{str;sp}\right)$$

$$\eta_{N2} = \textbf{Visc}\left(\text{N2} \; ; T = t_{str;sp}\right)$$

$$\eta_{O2} = \textbf{Visc}\left(\text{O2} \; ; T = t_{str;sp}\right)$$

Collision diameters

$$\sigma_{Ar} = 3{,}542 \times 10^{-10} \quad \text{[m]}$$

$$\sigma_{CO2} = 3{,}941 \times 10^{-10} \quad \text{[m]}$$

$$\sigma_{H2O} = 2{,}641 \times 10^{-10} \quad \text{[m]}$$

$$\sigma_{N2} = 3{,}798 \times 10^{-10} \quad \text{[m]}$$

$$\sigma_{O2} = 3{,}467 \times 10^{-10} \quad \text{[m]}$$

Collision integral

$\omega_{Ar;CO2} = 1{,}175$ [-]

$\omega_{Ar;H2O} = 1{,}587$ [-]

$\omega_{Ar;N2} = 0{,}101$ [-]

$\omega_{Ar;O2} = 1{,}069$ [-]

$\omega_{CO2;H2O} = 1{,}908$ [-]

$\omega_{CO2;N2} = 1{,}122$ [-]

$\omega_{CO2;O2} = 1{,}197$ [-]

$\omega_{H2O;N2} = 1{,}482$ [-]

$\omega_{H2O;O2} = 1{,}65$ [-]

$\omega_{N2;O2} = 1{,}03$ [-]

Difuzivita prvko ve spalinách

$$D_{Ar;CO2} = \frac{1{,}858 \times 10^{-25} \cdot \left(t_{str;sp} + 273{,}15\right)^{(3/2)} \cdot \left[\frac{1}{MW_{Ar}} + \frac{1}{MW_{CO2}}\right]^2}{1 \cdot \left[\frac{\sigma_{Ar} + \sigma_{CO2}}{2}\right]^2 \cdot \omega_{Ar;CO2}}$$

$$D_{Ar;H2O} = \frac{1{,}858 \times 10^{-25} \cdot \left(t_{str;sp} + 273{,}15\right)^{(3/2)} \cdot \left[\frac{1}{MW_{Ar}} + \frac{1}{MW_{H2O}}\right]^2}{1 \cdot \left[\frac{\sigma_{Ar} + \sigma_{H2O}}{2}\right]^2 \cdot \omega_{Ar;H2O}}$$

$$D_{Ar;N2} = \frac{1{,}858 \times 10^{-25} \cdot \left(t_{str;sp} + 273{,}15\right)^{(3/2)} \cdot \left[\frac{1}{MW_{Ar}} + \frac{1}{MW_{N2}}\right]^2}{1 \cdot \left[\frac{\sigma_{Ar} + \sigma_{N2}}{2}\right]^2 \cdot \omega_{Ar;N2}}$$

$$D_{Ar;O2} = \frac{1{,}858 \times 10^{-25} \cdot \left(t_{str;sp} + 273{,}15\right)^{(3/2)} \cdot \left[\frac{1}{MW_{Ar}} + \frac{1}{MW_{O2}}\right]^2}{1 \cdot \left[\frac{\sigma_{Ar} + \sigma_{O2}}{2}\right]^2 \cdot \omega_{Ar;O2}}$$

$$D_{CO2;H2O} = \frac{1{,}858 \times 10^{-25} \cdot \left(t_{str;sp} + 273{,}15\right)^{(3/2)} \cdot \left[\frac{1}{MW_{CO2}} + \frac{1}{MW_{H2O}}\right]^2}{1 \cdot \left[\frac{\sigma_{CO2} + \sigma_{H2O}}{2}\right]^2 \cdot \omega_{CO2;H2O}}$$

$$D_{CO2;N2} = \frac{1{,}858 \times 10^{-25} \cdot \left(t_{str;sp} + 273{,}15\right)^{(3/2)} \cdot \left[\frac{1}{MW_{CO2}} + \frac{1}{MW_{N2}}\right]^2}{1 \cdot \left[\frac{\sigma_{CO2} + \sigma_{N2}}{2}\right]^2 \cdot \omega_{CO2;N2}}$$

$$D_{CO2;O2} = \frac{1{,}858 \times 10^{-25} \cdot (t_{str;sp} + 273{,}15)^{(3/2)} \cdot \left[\frac{1}{MW_{CO2}} + \frac{1}{MW_{O2}}\right]^2}{1 \cdot \left[\frac{\sigma_{CO2} + \sigma_{O2}}{2}\right]^2 \cdot \omega_{CO2;O2}}$$

$$D_{H2O;N2} = \frac{1{,}858 \times 10^{-25} \cdot (t_{str;sp} + 273{,}15)^{(3/2)} \cdot \left[\frac{1}{MW_{H2O}} + \frac{1}{MW_{N2}}\right]^2}{1 \cdot \left[\frac{\sigma_{H2O} + \sigma_{N2}}{2}\right]^2 \cdot \omega_{H2O;N2}}$$

$$D_{H2O;O2} = \frac{1{,}858 \times 10^{-25} \cdot (t_{str;sp} + 273{,}15)^{(3/2)} \cdot \left[\frac{1}{MW_{H2O}} + \frac{1}{MW_{O2}}\right]^2}{1 \cdot \left[\frac{\sigma_{H2O} + \sigma_{O2}}{2}\right]^2 \cdot \omega_{H2O;O2}}$$

$$D_{N2;O2} = \frac{1{,}858 \times 10^{-25} \cdot (t_{str;sp} + 273{,}15)^{(3/2)} \cdot \left[\frac{1}{MW_{N2}} + \frac{1}{MW_{O2}}\right]^2}{1 \cdot \left[\frac{\sigma_{N2} + \sigma_{O2}}{2}\right]^2 \cdot \omega_{N2;O2}}$$

Viskozita spalin

$R = 8314{,}3$ [J/kmol/K]

$$\phi_{Ar;CO2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{Ar}}{p_{nul} \cdot MW_{Ar} \cdot D_{Ar;CO2}}$$

$$\phi_{Ar;H2O} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{Ar}}{p_{nul} \cdot MW_{Ar} \cdot D_{Ar;H2O}}$$

$$\phi_{Ar;N2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{Ar}}{p_{nul} \cdot MW_{Ar} \cdot D_{Ar;N2}}$$

$$\phi_{Ar;O2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{Ar}}{p_{nul} \cdot MW_{Ar} \cdot D_{Ar;O2}}$$

$$\phi_{CO2;Ar} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{CO2}}{p_{nul} \cdot MW_{CO2} \cdot D_{Ar;CO2}}$$

$$\phi_{CO2;H2O} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{CO2}}{p_{nul} \cdot MW_{CO2} \cdot D_{CO2;H2O}}$$

$$\phi_{CO2;N2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{CO2}}{p_{nul} \cdot MW_{CO2} \cdot D_{CO2;N2}}$$

$$\phi_{CO2;O2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{CO2}}{p_{nul} \cdot MW_{CO2} \cdot D_{CO2;O2}}$$

$$\phi_{H2O;Ar} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{H2O}}{p_{nul} \cdot MW_{H2O} \cdot D_{Ar;H2O}}$$

$$\phi_{H2O;CO2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{H2O}}{p_{nul} \cdot MW_{H2O} \cdot D_{CO2;H2O}}$$

$$\phi_{H2O;N2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{H2O}}{p_{nul} \cdot MW_{H2O} \cdot D_{H2O;N2}}$$

$$\phi_{H2O;O2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{H2O}}{p_{nul} \cdot MW_{H2O} \cdot D_{H2O;O2}}$$

$$\phi_{N2;Ar} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{N2}}{p_{nul} \cdot MW_{N2} \cdot D_{Ar;N2}}$$

$$\phi_{N2;CO2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{N2}}{p_{nul} \cdot MW_{N2} \cdot D_{CO2;N2}}$$

$$\phi_{N2;H2O} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{N2}}{p_{nul} \cdot MW_{N2} \cdot D_{H2O;N2}}$$

$$\phi_{N2;O2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{N2}}{p_{nul} \cdot MW_{N2} \cdot D_{N2;O2}}$$

$$\phi_{O2;Ar} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{O2}}{p_{nul} \cdot MW_{O2} \cdot D_{Ar;O2}}$$

$$\phi_{O2;CO2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{O2}}{p_{nul} \cdot MW_{O2} \cdot D_{CO2;O2}}$$

$$\phi_{O2;H2O} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{O2}}{p_{nul} \cdot MW_{O2} \cdot D_{H2O;O2}}$$

$$\phi_{O2;N2} = 6/5 \cdot 1{,}8 \cdot \frac{R \cdot (t_{str;sp} + 273{,}15) \cdot \eta_{O2}}{p_{nul} \cdot MW_{O2} \cdot D_{N2;O2}}$$

$$suma_{Ar} = \phi_{Ar;CO2} \cdot \frac{x_{CO2}}{x_{Ar}} + \phi_{Ar;H2O} \cdot \frac{x_{H2O}}{x_{Ar}} + \phi_{Ar;N2} \cdot \frac{x_{N2}}{x_{Ar}} + \phi_{Ar;O2} \cdot \frac{x_{O2}}{x_{Ar}}$$

$$suma_{CO2} = \phi_{CO2;Ar} \cdot \frac{x_{Ar}}{x_{CO2}} + \phi_{CO2;H2O} \cdot \frac{x_{H2O}}{x_{CO2}} + \phi_{CO2;N2} \cdot \frac{x_{N2}}{x_{CO2}} + \phi_{CO2;O2} \cdot \frac{x_{O2}}{x_{CO2}}$$

$$suma_{H2O} = \phi_{H2O;CO2} \cdot \frac{x_{CO2}}{x_{H2O}} + \phi_{H2O;Ar} \cdot \frac{x_{Ar}}{x_{H2O}} + \phi_{H2O;N2} \cdot \frac{x_{N2}}{x_{H2O}} + \phi_{H2O;O2} \cdot \frac{x_{O2}}{x_{H2O}}$$

$$suma_{N2} = \phi_{N2;Ar} \cdot \frac{x_{Ar}}{x_{N2}} + \phi_{N2;CO2} \cdot \frac{x_{CO2}}{x_{N2}} + \phi_{N2;H2O} \cdot \frac{x_{H2O}}{x_{N2}} + \phi_{N2;O2} \cdot \frac{x_{O2}}{x_{N2}}$$

$$suma_{O2} = \phi_{O2;CO2} \cdot \frac{x_{CO2}}{x_{O2}} + \phi_{O2;H2O} \cdot \frac{x_{H2O}}{x_{O2}} + \phi_{O2;N2} \cdot \frac{x_{N2}}{x_{O2}} + \phi_{O2;Ar} \cdot \frac{x_{Ar}}{x_{O2}}$$

Viskozita spalin

$$\eta_{sp} = \frac{\eta_{Ar}}{1 + suma_{Ar}} + \frac{\eta_{CO2}}{1 + suma_{CO2}} + \frac{\eta_{H2O}}{1 + suma_{H2O}} + \frac{\eta_{N2}}{1 + suma_{N2}} + \frac{\eta_{O2}}{1 + suma_{O2}}$$

Viskozita vzduchu

$$\eta_{vz} = \textbf{Visc}\,(Air\ ;\ T = t_{str;vz})$$

M� rná tepelná kapacita spalin

$$cp_{Ar} = \textbf{Cp}\,(Argon\ ;\ T = t_{str;sp}\ ;\ P = p_{nul})$$

$$cp_{CO2} = \textbf{Cp}\,(CO2\ ;\ T = t_{str;sp})$$

$$cp_{H2O} = \textbf{Cp}\,(h2o\ ;\ T = t_{str;sp})$$

$$cp_{N2} = \textbf{Cp}\,(N2\ ;\ T = t_{str;sp})$$

$$cp_{O2} = \mathbf{Cp}\left(O2 ; T = t_{str;sp}\right)$$

$$cp_{sp} = w_{Ar} \cdot cp_{Ar} + w_{CO2} \cdot cp_{CO2} + w_{H2O} \cdot cp_{H2O} + w_{N2} \cdot cp_{N2} + w_{O2} \cdot cp_{O2}$$

m▯ rná tep. kapacita spalin

M▯ rná tepelná kapacita vzduchu

$$cp_{vz} = \mathbf{Cp}\left(Air ; T = t_{nul}\right)$$

Tepelná vodivost prvko ve spalinách

$$\lambda_{Ar} = \mathbf{k}\left(Argon ; T = t_{str;sp} ; P = p_{nul}\right)$$

$$\lambda_{CO2} = \mathbf{k}\left(CO2 ; T = t_{str;sp}\right)$$

$$\lambda_{H2O} = \mathbf{k}\left(h2o ; T = t_{str;sp}\right)$$

$$\lambda_{N2} = \mathbf{k}\left(N2 ; T = t_{str;sp}\right)$$

$$\lambda_{O2} = \mathbf{k}\left(O2 ; T = t_{str;sp}\right)$$

$$B = 1{,}3$$

$$\psi_{Ar;CO2} = \left[\phi_{Ar;CO2} \cdot \left[1 + \left[\frac{MW_{Ar} - MW_{CO2}}{MW_{Ar} + MW_{CO2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{CO2}}{MW_{Ar} - MW_{CO2}}\right]\right]$$

$$\psi_{Ar;H2O} = \left[\phi_{Ar;H2O} \cdot \left[1 + \left[\frac{MW_{Ar} - MW_{H2O}}{MW_{Ar} + MW_{H2O}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{H2O}}{MW_{Ar} - MW_{H2O}}\right]\right]$$

$$\psi_{Ar;N2} = \left[\phi_{Ar;N2} \cdot \left[1 + \left[\frac{MW_{Ar} - MW_{N2}}{MW_{Ar} + MW_{N2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{N2}}{MW_{Ar} - MW_{N2}}\right]\right]$$

$$\psi_{Ar;O2} = \left[\phi_{Ar;O2} \cdot \left[1 + \left[\frac{MW_{Ar} - MW_{O2}}{MW_{Ar} + MW_{O2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{O2}}{MW_{Ar} - MW_{O2}}\right]\right]$$

$$\psi_{CO2;Ar} = \left[\phi_{CO2;Ar} \cdot \left[1 + \left[\frac{MW_{CO2} - MW_{Ar}}{MW_{CO2} + MW_{Ar}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{Ar}}{MW_{CO2} - MW_{Ar}}\right]\right]$$

$$\psi_{CO2;H2O} = \left[\phi_{CO2;H2O} \cdot \left[1 + \left[\frac{MW_{CO2} - MW_{H2O}}{MW_{CO2} + MW_{H2O}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{H2O}}{MW_{CO2} - MW_{H2O}}\right]\right]$$

$$\psi_{CO2;N2} = \left[\phi_{CO2;N2} \cdot \left[1 + \left[\frac{MW_{CO2} - MW_{N2}}{MW_{CO2} + MW_{N2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{N2}}{MW_{CO2} - MW_{N2}}\right]\right]$$

$$\psi_{CO2;O2} = \left[\phi_{CO2;O2} \cdot \left[1 + \left[\frac{MW_{CO2} - MW_{O2}}{MW_{CO2} + MW_{O2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{O2}}{MW_{CO2} - MW_{O2}}\right]\right]$$

$$\psi_{H2O;Ar} = \left[\phi_{H2O;Ar} \cdot \left[1 + \left[\frac{MW_{H2O} - MW_{Ar}}{MW_{H2O} + MW_{Ar}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{Ar}}{MW_{H2O} - MW_{Ar}}\right]\right]$$

$$\psi_{H2O;CO2} = \left[\phi_{H2O;CO2} \cdot \left[1 + \left[\frac{MW_{H2O} - MW_{CO2}}{MW_{H2O} + MW_{CO2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{CO2}}{MW_{H2O} - MW_{CO2}}\right]\right]$$

$$\psi_{H2O;N2} = \left[\phi_{H2O;N2} \cdot \left[1 + \left[\frac{MW_{H2O} - MW_{N2}}{MW_{H2O} + MW_{N2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{N2}}{MW_{H2O} - MW_{N2}}\right]\right]$$

$$\psi_{H2O;O2} = \left[\phi_{H2O;O2} \cdot \left[1 + \left[\frac{MW_{H2O} - MW_{O2}}{MW_{H2O} + MW_{O2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{O2}}{MW_{H2O} - MW_{O2}}\right]\right]$$

$$\psi_{N2;Ar} = \left[\phi_{N2;Ar} \cdot \left[1 + \left[\frac{MW_{N2} - MW_{Ar}}{MW_{N2} + MW_{Ar}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{Ar}}{MW_{N2} - MW_{Ar}}\right]\right]$$

$$\psi_{N2;CO2} = \left[\phi_{N2;CO2} \cdot \left[1 + \left[\frac{MW_{N2} - MW_{CO2}}{MW_{N2} + MW_{CO2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{CO2}}{MW_{N2} - MW_{CO2}}\right]\right]$$

$$\psi_{N2;H2O} = \left[\phi_{N2;H2O} \cdot \left[1 + \left[\frac{MW_{N2} - MW_{H2O}}{MW_{N2} + MW_{H2O}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{H2O}}{MW_{N2} - MW_{H2O}}\right]\right]$$

$$\psi_{N2;O2} = \left[\phi_{N2;O2} \cdot \left[1 + \left[\frac{MW_{N2} - MW_{O2}}{MW_{N2} + MW_{O2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{O2}}{MW_{N2} - MW_{O2}}\right]\right]$$

$$\psi_{O2;Ar} = \left[\phi_{O2;Ar} \cdot \left[1 + \left[\frac{MW_{O2} - MW_{Ar}}{MW_{O2} + MW_{Ar}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{Ar}}{MW_{O2} - MW_{Ar}}\right]\right]$$

$$\psi_{O2;CO2} = \left[\phi_{N2;CO2} \cdot \left[1 + \left[\frac{MW_{O2} - MW_{CO2}}{MW_{O2} + MW_{CO2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{CO2}}{MW_{O2} - MW_{CO2}}\right]\right]$$

$$\psi_{O2;H2O} = \left[\phi_{N2;H2O} \cdot \left[1 + \left[\frac{MW_{O2} - MW_{H2O}}{MW_{O2} + MW_{H2O}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{H2O}}{MW_{O2} - MW_{H2O}}\right]\right]$$

$$\psi_{O2;N2} = \left[\phi_{H2O;N2} \cdot \left[1 + \left[\frac{MW_{O2} - MW_{N2}}{MW_{O2} + MW_{N2}}\right]^2\right] \cdot \left[\frac{15}{4 \cdot 1{,}8} - 1\right]\right] \cdot \left[1 + \left[\frac{12 \cdot B + 5}{30 - 8 \cdot 1{,}8}\right] \cdot \left[\frac{MW_{N2}}{MW_{O2} - MW_{N2}}\right]\right]$$

$$Ar_{ksuma} = 1 + \psi_{Ar;CO2} \cdot \frac{x_{CO2}}{x_{Ar}} + \psi_{Ar;H2O} \cdot \frac{x_{H2O}}{x_{Ar}} + \psi_{Ar;N2} \cdot \frac{x_{N2}}{x_{Ar}} + \psi_{Ar;O2} \cdot \frac{x_{O2}}{x_{Ar}}$$

$$CO2_{ksuma} = 1 + \psi_{CO2;Ar} \cdot \frac{x_{Ar}}{x_{CO2}} + \psi_{CO2;H2O} \cdot \frac{x_{H2O}}{x_{CO2}} + \psi_{CO2;N2} \cdot \frac{x_{N2}}{x_{CO2}} + \psi_{CO2;O2} \cdot \frac{x_{O2}}{x_{CO2}}$$

$$H2O_{ksuma} = 1 + \psi_{H2O;Ar} \cdot \frac{x_{Ar}}{x_{H2O}} + \psi_{H2O;CO2} \cdot \frac{x_{CO2}}{x_{H2O}} + \psi_{H2O;N2} \cdot \frac{x_{N2}}{x_{H2O}} + \psi_{H2O;O2} \cdot \frac{x_{O2}}{x_{H2O}}$$

$$N2_{ksuma} = 1 + \psi_{N2;Ar} \cdot \frac{x_{Ar}}{x_{N2}} + \psi_{N2;CO2} \cdot \frac{x_{CO2}}{x_{N2}} + \psi_{N2;H2O} \cdot \frac{x_{H2O}}{x_{N2}} + \psi_{N2;O2} \cdot \frac{x_{O2}}{x_{N2}}$$

$$O2_{ksuma} = 1 + \psi_{O2;Ar} \cdot \frac{x_{Ar}}{x_{O2}} + \psi_{O2;H2O} \cdot \frac{x_{H2O}}{x_{O2}} + \psi_{O2;N2} \cdot \frac{x_{N2}}{x_{O2}} + \psi_{O2;N2} \cdot \frac{x_{N2}}{x_{O2}}$$

Tepelná vodivost spalin

$$\lambda_{sp} = \frac{\lambda_{Ar}}{Ar_{ksuma}} + \frac{\lambda_{CO2}}{CO2_{ksuma}} + \frac{\lambda_{H2O}}{H2O_{ksuma}} + \frac{\lambda_{N2}}{N2_{ksuma}} + \frac{\lambda_{O2}}{O2_{ksuma}}$$

Tepelná vodivost vzduchu

$\lambda_{vz} = \mathbf{k}\left(Air ; T = t_{str;vz}\right)$

6.4 TEPELNÁ BILANCE

Entalpie spalin pYi 0 °C

$h_{Ar;nul} = \mathbf{h}\left(Argon ; T = t_{nul} ; P = p_{nul}\right)$

$h_{CO2;nul} = \mathbf{h}\left(CO2 ; T = t_{nul}\right)$

$h_{H2O;nul} = \mathbf{h}\left(h2o ; T = t_{nul}\right)$

$h_{N2;nul} = \mathbf{h}\left(N2 ; T = t_{nul}\right)$

$h_{O2;nul} = \mathbf{h}\left(O2 ; T = t_{nul}\right)$

*Výpo
et entalpie spalin na vstupu*

$h_{Ar;in} = \mathbf{h}\left(Argon ; T = t_{sp;in} ; P = p_{nul}\right)$

$h_{CO2;in} = \mathbf{h}\left(CO2 ; T = t_{sp;in}\right)$

$h_{H2O;in} = \mathbf{h}\left(h2o ; T = t_{sp;in}\right)$

$h_{N2;in} = \mathbf{h}\left(N2 ; T = t_{sp;in}\right)$

$h_{O2;in} = \mathbf{h}\left(O2 ; T = t_{sp;in}\right)$

$h_{sp;in} = w_{Ar} \cdot \left(h_{Ar;in} - h_{Ar;nul}\right) + w_{CO2} \cdot \left(h_{CO2;in} - h_{CO2;nul}\right) + w_{H2O} \cdot \left(h_{H2O;in} - h_{H2O;nul}\right) + w_{N2} \cdot \left(h_{N2;in} - h_{N2;nul}\right) + w_{O2} \cdot \left(h_{O2;in} - h_{O2;nul}\right)$

entalpie spalin vstup

*Výpo
et entalpie spalin na výstupu*

$h_{Ar;out} = \mathbf{h}\left(Argon ; T = t_{sp;out} ; P = p_{nul}\right) - h_{Ar;nul}$

$h_{CO2;out} = \mathbf{h}\left(CO2 ; T = t_{sp;out}\right) - h_{CO2;nul}$

$h_{H2O;out} = \mathbf{h}\left(h2o ; T = t_{sp;out}\right) - h_{H2O;nul}$

$h_{N2;out} = \mathbf{h}\left(N2 ; T = t_{sp;out}\right) - h_{N2;nul}$

$h_{O2;out} = \mathbf{h}\left(O2 ; T = t_{sp;out}\right) - h_{O2;nul}$

$h_{sp;out} = w_{Ar} \cdot h_{Ar;out} + w_{CO2} \cdot h_{CO2;out} + w_{H2O} \cdot h_{H2O;out} + w_{N2} \cdot h_{N2;out} + w_{O2} \cdot h_{O2;out}$ *entalpie spalin výstup*

$Q = m_{sp} \cdot \left(h_{sp;in} - h_{sp;out}\right)$

výkon vým níku

$h_{vz;in} = \mathbf{h}\left(Air ; T = t_{vz;in}\right) - \mathbf{h}\left(Air ; T = t_{nul}\right)$

$h_{vz;out} = \mathbf{h}\left(Air ; T = t_{vz;out}\right) - \mathbf{h}\left(Air ; T = t_{nul}\right)$

$h_{vz} = h_{vz;out} - h_{vz;in}$

$m_{vz} = \frac{Q}{h_{vz}}$ *hmot. tok vzduchu*

6.5 TRUBKOVÝ SVAZEK

$d_1 = 0{,}06$ [m] *vnitYní prom r trubky*

$d_2 = 0{,}063$ [m] *vn jaí prom r trubky*

$s_{trub} = 0{,}0015$ [m] *tlouaeka st ny trubky*

$\lambda_{trub} = \mathbf{k}('Carbon_{steel}' ; t_{str;sp})$ *tepelná vodivost trubky*

$k_{trub} = 0{,}00015$ [m] *drsnost trubek*

$w_{sp} = 18{,}25$ [m/s] *rychlost proud ní spalin - zvoleno po konzultaci*

$n_t = \frac{4 \cdot m_{sp}}{\pi \cdot d_1^2 \cdot w_{sp} \cdot \rho_{sp}}$ *celkový po*

$t_t = 1{,}25 \cdot d_2$ *et trubek* *rozte*

$t_{t1} = c_1 \cdot t_t$ *trubek zvoleno pYí*

ná rozte

$t_{t2} = c_2 \cdot t_t$ *trubek* *podélná rozte*

$c_1 = 1$ *trubek*

$c_2 = 0{,}866$

6.6 GEOMETRICKÉ PARAMETRY VÝM NÍKU

$D_{pl;2} = 0{,}33$ [m] *vn jaí prom r pláat*

$D_{pl;1} = 0{,}32$ [m] *vnitYní prom r pláat*

$D_s = 0{,}29925$ [m] *prom r svazku trubek, navrhnuto podle vztahu D_1-$D_{S<}$=>t_t-d_2*

$l_{tn} = 0{,}23$ [m]

6.7 PXEPÁ}KY

$s_p = 0{,}004$ [m] *tlouaeka pYepá~ky - zvoleno*

$t_p = 0{,}254$ [m] *rozte*

$d_p = 0{,}066$ [m] *pYepá~ek zvoleno* *prom r d r v pYepá~ce - zvoleno*

$D_{pr} = 0{,}318$ [m] *prom r pYepá~ky - zvoleno*

$n_{CH} = 1$ [-]

po
et chodo

$n_p = 10$ *po*

et pYepá~ek zvoleno
$h_p = 0{,}228$ [m] *výaka pYepá~ky*

$$n_{rc} = n_{rp} \cdot (n_p - 1)$$

$$n_{rp} = \frac{2 \cdot h_p - D_{pl;1}}{c_2 \cdot t_t}$$

po
et pYí
n obtékaných Yad trubek

6.8 SOU INITEL PXESTUPU TEPLA Z TRUBKOVÉ STRANY

$$Re_{sp} = \frac{w_{sp} \cdot d_1}{\frac{\eta_{sp}}{\rho_{sp}}}$$

Reynoldsovo
íslo -> turbulentní proudení

$$a_{sp} = \frac{\lambda_{sp}}{cp_{sp} \cdot \rho_{sp}}$$

sou
initel teplotní vodivosti

$$Pr_{sp} = \frac{\eta_{sp}}{\rho_{sp} \cdot a_{sp}}$$

Prandtlovo
íslo

$$Nus_{sp} = 0{,}023 \cdot Re_{sp}^{0{,}8} \cdot Pr_{sp}^{0{,}4}$$ *Nusseltovo*

íslo

$$\alpha_{sp} = Nus_{sp} \cdot \frac{\lambda_{sp}}{d_1}$$

Sou
initel pYestupu tepla spalin

6.9 SOU INITEL PXESTUPU TEPLA ZE STRANY MEZITRUBKOVÉHO PROSTORU

$$S_{2N} = (t_p - s_p) \cdot D_{pl;1}$$ *nezaplnný pYoYez mezi jednou rozte*

í pYepá~ek

$$\psi_t = 1 - \frac{\pi}{4 \cdot x_6}$$ *mezerovitost trubkového svazku*

$$w_{vz} = \frac{m_{vz}}{S_{2N} \cdot \rho_{vz} \cdot \psi_t}$$

rychlost vzduchu v MP

$$Re_{vz} = \frac{\frac{w_{vz} \cdot d_2 \cdot \pi}{2}}{\frac{\eta_{vz}}{\rho_{vz}}}$$

Reynoldsovo
íslo -> turbulentní proudení

$$a_{vz} = \frac{\lambda_{vz}}{cp_{vz} \cdot \rho_{vz}}$$

sou
initel teplotní vodivosti

$$Pr_{vz} = \frac{\eta_{sp}}{\rho_{vz} \cdot a_{vz}}$$

Prandtlovo
íslo

$$Nus_{lam} = 0{,}664 \cdot Re_{vz}^{0,5} \cdot Pr_{vz}^{(1/3)}$$

$$Nus_{turb} = \frac{0{,}037 \cdot Re_{vz}^{0,8} \cdot Pr_{vz}}{1 + 2{,}443 \cdot Re_{vz}^{-0,1} \cdot \left(Pr_{vz}^{(2/3)} - 1\right)}$$

Výpo
et kore
ních faktoro

$$y_2 = 1$$

zm na látkových vlastností v mezní vrstv

$$y_3 = 1 + \frac{2}{3 \cdot x_7}$$ *pYevod sou*

initele pYestupu tepla z Yady na svazek trubek

$$x_7 = \frac{t_{t2}}{d_2}$$

$$x_6 = \frac{t_{t1}}{d_2}$$

$$y_4 = 1$$ *$Re_{vz} > 100$*

$$x_8 = \frac{n_{tv}}{n_t}$$

$$n_{tv} = \frac{(D_s - d_2)^2}{8 \cdot t_t^2 \cdot 0{,}866} \cdot \left[\phi_{vs} \cdot \frac{\pi}{180} - \textbf{sin}\left(\phi_{vs}\right)\right]$$

po
et trubek ve výYezu pYepá~ky

$$\phi_{vs} = 2 \cdot \textbf{arccos}\left[\left[\frac{2}{D_s - d_2}\right] \cdot \left[h_p - \frac{D_{pl;1}}{2}\right]\right]$$

úhel výYezu svazku

$y_5 = 1 - x_8 + 0{,}524 \cdot x_8^{0{,}32}$ *podíl podéln obtékaných trubek na pYí*

ném proud ní ve výYezu

$y_6 = 0{,}4 \cdot \left[\frac{S_{tp}}{S_{tp} + s_p}\right] + 1 - \left[0{,}4 \cdot \left[\frac{S_{tp}}{S_{tp} + S_{ps}}\right] \cdot \mathbf{exp}\left[-1{,}5 \cdot \left[\frac{S_{tp} + S_{ps}}{S_{2Z}}\right]\right]\right]$ *vliv zkratových proudo*

$S_{tp} = \left[n_t - \frac{n_{tv}}{2}\right] \cdot \frac{\pi \cdot (d_p^2 - d_2^2)}{4}$ *proto*

ný proYez v pYepá~ce (mezi trubkou otvorem v pYepá~ce)

$S_{ps} = \frac{\pi}{4} \cdot (D_{pl;1}^2 - D_{pr}^2) \cdot \left[\frac{360 - \phi_{vp}}{360}\right]$ *proto*

ný proYez mezi pYepá~kou a pláat m

$\phi_{vp} = 2 \cdot \mathbf{arccos}\left[2 \cdot \frac{h_p}{D_{pl;1}} - 1\right]$

$S_{2Z} = \left[s_{ts} + \left[\frac{D_s - d_2}{t_{t1}}\right] \cdot s_{tt}\right] \cdot (t_p - s_p)$ *proto*

ný proYez zapln ného prostoru mezi jednou rozte

ú pYepáDek

$s_{ts} = D_{pl;1} - D_s$

$s_{tt} = t_t - d_2$

vzdálenost mezi trubky

$x_{kontrola} = \frac{S_{tp} + S_{ps}}{S_{2Z}}$ *musí být menaí nebo rovno 0,8 -> SPLGUJE!*

$y_7 = 1$

$D_{pl,1}$ - D_s je velikostn blízko s_{tt} -> y_7=1

$$y_8 = \frac{n_p - 1 + 2 \cdot \left[\frac{l_{tn}}{2 \cdot t_p}\right]^{(1 - 0{,}4)}}{n_p - 1 + \frac{l_{tn}}{t_p}}$$

vliv neopYepá~kovaného prostorp

$Nus_{vz} = (0{,}3 + (Nus_{turb}^2 + Nus_{lam}^2)^{0{,}5}) \cdot y_2 \cdot y_3 \cdot y_4 \cdot y_5 \cdot y_6 \cdot y_7 \cdot y_8$

$\alpha_{vz} = \frac{Nus_{vz} \cdot \lambda_{vz}}{\frac{\pi \cdot d_2}{2}}$ *sou*

initel pYestupu tepla vn trubu

Stup 10 SOU INITEL PXESTUPU TEPLA A VELIKOST TEPLOSM NNÉ PLOCHY

$R_Z = 0{,}0001625$

sou

initel zanáaení spalin pYi rychlosti 18 m/s - diagram

Sou
initelé prostupu tepla a velikost teplosm nné plochy

$$k_L = \frac{\pi}{\frac{1}{\alpha_{sp} \cdot d_1} + \frac{1}{2 \cdot \lambda_{trub}} \cdot \ln\left[\frac{d_2}{d_1}\right] + \frac{1}{\alpha_{vz} \cdot d_2}}$$ sou

initel prostupu tepla na délku

$$k_v = \frac{1}{\frac{d_2}{d_1} \cdot \frac{1}{\alpha_{sp}} + \frac{d_2}{2 \cdot \lambda_{trub}} \cdot \ln\left[\frac{d_2}{d_1}\right] + \frac{1}{\alpha_{vz}}}$$ sou

initel prostupu tepla na plochu - bez zanáaení

$$t_{ln} = \frac{t_{sp;in} - t_{vz;out} - (t_{sp;out} - t_{vz;in})}{\ln\left[\frac{t_{sp;in} - t_{vz;out}}{t_{sp;out} - t_{vz;in}}\right]}$$ LMTD

$$S_v = \frac{Q}{k_S \cdot t_{ln}}$$

velikost teplosm nné plochy bez uva~ování zanáaení

$$k_S = \frac{1}{\frac{d_2}{d_1} \cdot \left[\frac{1}{\alpha_{sp}} + R_Z\right] + \frac{d_2}{2 \cdot \lambda_{trub}} \cdot \ln\left[\frac{d_2}{d_1}\right] + \frac{1}{\alpha_{vz}}}$$ sou

initel prostupu tepla na plochu - se zanáaení

$$S = \frac{Q}{k_S \cdot t_{ln}}$$

velikost teplosm nné plochy

Délka trubek ve svazku

$$L_{trub} = \frac{S}{n_t \cdot \pi \cdot d_2}$$ délka vychází cca 6 metro -> zavádím vn jaí ~ebrování trubek pro sní~ení délky

6.11 }EBROVÁNÍ

$L_{ze} = 1$ [m]

1 metr ~ebrované trubky

$\delta_{zebra} = 0,001$ [m] tlouaeka ~ebra

$n_{zebra} = 400$ [-] po

et ~eber

$D_{zebra} = 0,067$ [m] prom r ~ebra

$$h_{zebra} = \frac{D_{zebra} - d_2}{2 \text{ [m]}}$$ výaka ~ebra

$b_{zebra} = 0,0015$ [m] rozte

mezi ~ebry

$$x_{diagram;1} = \frac{h_{zebra}}{b_{zebra}}$$

$$G = \frac{D_{zebra}}{d_2}$$

$$\alpha_{zebra} = 0,8 \cdot \alpha_o$$ *sou*

initel pYestupu tepla ze strany ~eber

$$Nus_{zebra} = 0,24 \cdot Re_{vz}^{0,6}$$

$$\alpha_o = \frac{Nus_{zebra} \cdot \lambda_{vz}}{\frac{\pi \cdot d_2}{2}}$$ *sou*

initel pYestupu tepla z hladké strany trubky

$$\eta_{ze} = \frac{\tanh\left[\beta \cdot \frac{d_2}{2} \cdot \psi_{ze}\right]}{\beta \cdot \frac{d_2}{2} \cdot \psi_{ze}}$$

ú
innost ~eber

$$\beta = \left[\frac{2 \cdot \alpha_{zebra}}{\lambda_{trub} \cdot \delta_{zebra}}\right]^{0,5}$$

$$\psi_{ze} = (G - 1) \cdot (1 + 0,35 \cdot \ln(G))$$

$$S_{ze} = \pi \cdot n_{zebra} \cdot \left[\frac{D_{zebra}^2 - d_2^2}{2}\right]$$ *plocha ~eber na 1 metru trubky*

$$S_{zebra} = n_{zebra} \cdot 2 \cdot \frac{\pi}{4} \cdot (D_{zebra}^2 - d_2^2) + \pi \cdot D_{zebra} \cdot \delta_{zebra} \cdot n_{zebra}$$

$$S_{trubka} = \pi \cdot n_{zebra} \cdot d_2 \cdot b_{zebra}$$ *hladká plocha na 1 metru trubky*

$$S_{celkem} = S_{zebra} + S_{trubka}$$ *celková vn jaí plocha na 1 metru ~ebrované trubky*

$$k_{zebra} = \frac{1}{S_{celkem} \cdot \frac{1}{\alpha_{zebra} \cdot (S_{celkem} - (1 - \eta_{ze}) \cdot S_{ze})} + \frac{1}{\pi \cdot d_2 \cdot L_{ze}} \cdot \left[\frac{1}{\alpha_{sp}} + \frac{s_{trub}}{\lambda_{trub}}\right]}$$ *sou*

initel prostupu tepla ~ebrovanou trubkou

$$S_{V23} = \frac{Q}{k_{zebra} \cdot t_{ln}}$$ *teplosm nná plocha pro sou*

initel prostupu tepla ~ebrovanou trubkou

$$L_{zebra} = \frac{S_{V23}}{S_{celkem} \cdot 10}$$ *délka ~ebrované trubky*

6.12 HYDRAULICKÝ VÝPO ET

$$p_{z1} = p_{t1} + p_{m1}$$ *tlakové ztráty v trubkovém prostoru*

$$p_{t1} = \lambda_{11} \cdot \frac{\rho_{sp} \cdot w_{sp}^2}{2} \cdot n_{CH} \cdot z_1 \cdot z_2$$

tlakové ztráty tYením v TP

$$\lambda_{11} = 8 \cdot \left[\left[\frac{8}{Re_{sp}} \right]^{12} + \frac{1}{(x_9 + x_{10})^{(3/2)}} \right]^{\left[\frac{1}{12} \right]}$$

ztrátový sou
initel pro turbulentní proud ní

$$x_9 = \left[2{,}457 \cdot \ln \left[\frac{1}{\left[\frac{7}{Re_{sp}} \right]^{0,9} + 0{,}27 \cdot k_{r1}} \right] \right]^{16}$$ *substitu*

ní faktor

$$x_{10} = \left[\frac{37530}{Re_{sp}} \right]^{16}$$ *substitu*

ní faktor

$$k_{r1} = \frac{k_{trub}}{d_1}$$ *stYední absolutní drsnost st ny*

$$z_1 = \frac{L_{zebra}}{d_1}$$

$$z_2 = \left[\frac{t_{str;S;in}}{t_{str;sp}} \right]^{0,6}$$

$$q_{in} = \frac{\pi \cdot (t_{sp;in} - t_{vz;in})}{\frac{1}{\alpha_{sp} \cdot d_1} + \frac{1}{2 \cdot \lambda_{trub}} \cdot \ln \left[\frac{d_2}{d_1} \right] + \frac{1}{\alpha_{vz} \cdot d_2}}$$ *teplota sd lená 1 metrem válcové st ny*

$$q_{out} = \frac{\pi \cdot (t_{sp;out} - t_{vz;out})}{\frac{1}{\alpha_{sp} \cdot d_1} + \frac{1}{2 \cdot \lambda_{trub}} \cdot \ln \left[\frac{d_2}{d_1} \right] + \frac{1}{\alpha_{vz} \cdot d_2}}$$

$$t_{S;in;in} = t_{sp;in} - \frac{q_{in}}{\pi} \cdot \frac{1}{\alpha_{sp} \cdot d_1}$$ *teplota vn jaí st ny trubky pYi vstupu*

$$t_{S;in;out} = t_{sp;out} - \frac{q_{out}}{\pi} \cdot \frac{1}{\alpha_{sp} \cdot d_1}$$ *teplota vn jaí st ny trubky na výstupu*

$$t_{str;S;in} = \frac{t_{S;in;in} + t_{S;in;out}}{2}$$ *stYední teplota vnitYní st ny trubek*

$$p_{m1} = (\xi_{11} \cdot n_{CH} + \xi_{12} \cdot (n_{CH} - 1) + 1{,}4) \cdot \frac{\rho_{sp} \cdot w_{sp}^{2}}{2}$$ *ztráty místní v TP*

$\xi_{11} = 0{,}7$ *ztrátový sou*

initel pro vstup a výstup z trubek v trubkovém svazku

$\xi_{12} = 0{,}4$ *ztrátový sou*

initel pro obrat proudu v komoYe

$p_{z2} = p_{to} + p_{tn} + p_{tv}$ *tlakové ztráty v mezitrubkovém prostoru*

$$p_{to} = 2 \cdot \lambda_{22} \cdot n_{rp} \cdot (n_p - 1) \cdot \rho_{vz} \cdot w_{vz}^{2} \cdot z_{22} \cdot z_3 \cdot z_4$$

tlakové ztráty pYi pYí
ném obtékání trubek v opYepá~kovaném prostoru

$$\lambda_{22} = c_{z;1} \cdot \left[\frac{1{,}33}{\frac{t_t}{d_2}} \right]^{a_z} \cdot Re_{vz}^{\ a_1}$$

$$c_{z;1} = 0{,}372$$

$$a_1 = -0{,}123$$

$$c_{z;2} = 7$$

$$a_2 = 0{,}5$$

$$a_z = \frac{c_2}{1 + 0{,}14 \cdot Re_{vz}^{\ a_2}}$$

$$z_{22} = \left[\frac{t_{str;S;ex}}{t_{str;vz}} \right]^1$$ *zm na látkových vlastností v mezní vrstv*

$$t_{S;ex;in} = t_{sp;in} - \frac{q_{in}}{\pi} \cdot \left[\frac{1}{\alpha_{sp} \cdot d_1} + \frac{1}{2 \cdot \lambda_{trub}} \cdot \mathbf{ln}\left[\frac{d_2}{d_1} \right] \right]$$ *teplota vn jaí st ny trubky pYi vstupu*

$$t_{S;ex;out} = t_{sp;out} - \frac{q_{out}}{\pi} \cdot \left[\frac{1}{\alpha_{sp} \cdot d_1} + \frac{1}{2 \cdot \lambda_{trub}} \cdot \mathbf{ln}\left[\frac{d_2}{d_1} \right] \right]$$ *teplota vn jaí st ny trubky na výstupu*

$$t_{str;S;ex} = \frac{t_{S;ex;in} + t_{S;ex;out}}{2}$$ *stYední teplota vn jaí st ny trubek*

$$z_3 = y_7$$

vliv obtokových proudo

$$z_4 = \mathbf{exp}\left[-1{,}33 \cdot \left[1 + \left[\frac{S_{ps}}{S_{ps} + S_{tp}} \right] \cdot \left[\frac{S_{ps} + S_{tp}}{S_{2Z}} \right]^{x_{13}} \right] \right]$$

vliv zkratových proudo

$$x_{13} = -0{,}15 \cdot \left[1 + \frac{S_{ps}}{S_{ps} + S_{tp}} \right] + 0{,}8$$

$$p_{tn} = 2 \cdot \lambda_{22} \cdot (n_{rp} + n_{rv}) \cdot \rho_{vz} \cdot w_{vz}^{\ 2} \cdot z_{22} \cdot z_3 \cdot z_5$$

tlakové ztráty pYi pYí
ném obtékáním trubek v neopYepá~kovém prostoru

$$z_5 = 2 \cdot \left[\frac{2 \cdot t_p}{l_{tn}} \right]^{(2 - 0{,}2)}$$ *vliv velikostí neopYepá~kovaných prostoro*

$$p_{tv} = n_p \cdot (2 + 0{,}6 \cdot n_{rv}) \cdot \rho_{vz} \cdot \frac{w_{vz;2}^{\ 2}}{2} \cdot z_4$$ *tlakové ztráty pYi pYí*

ném obtékání trubek v prostoru nad seYíznutí pYepá~ek

$$w_{vz;2} = \frac{m_{vz}}{(S_{2Z} \cdot S_{vz})^{0{,}5} \cdot \rho_{vz}}$$

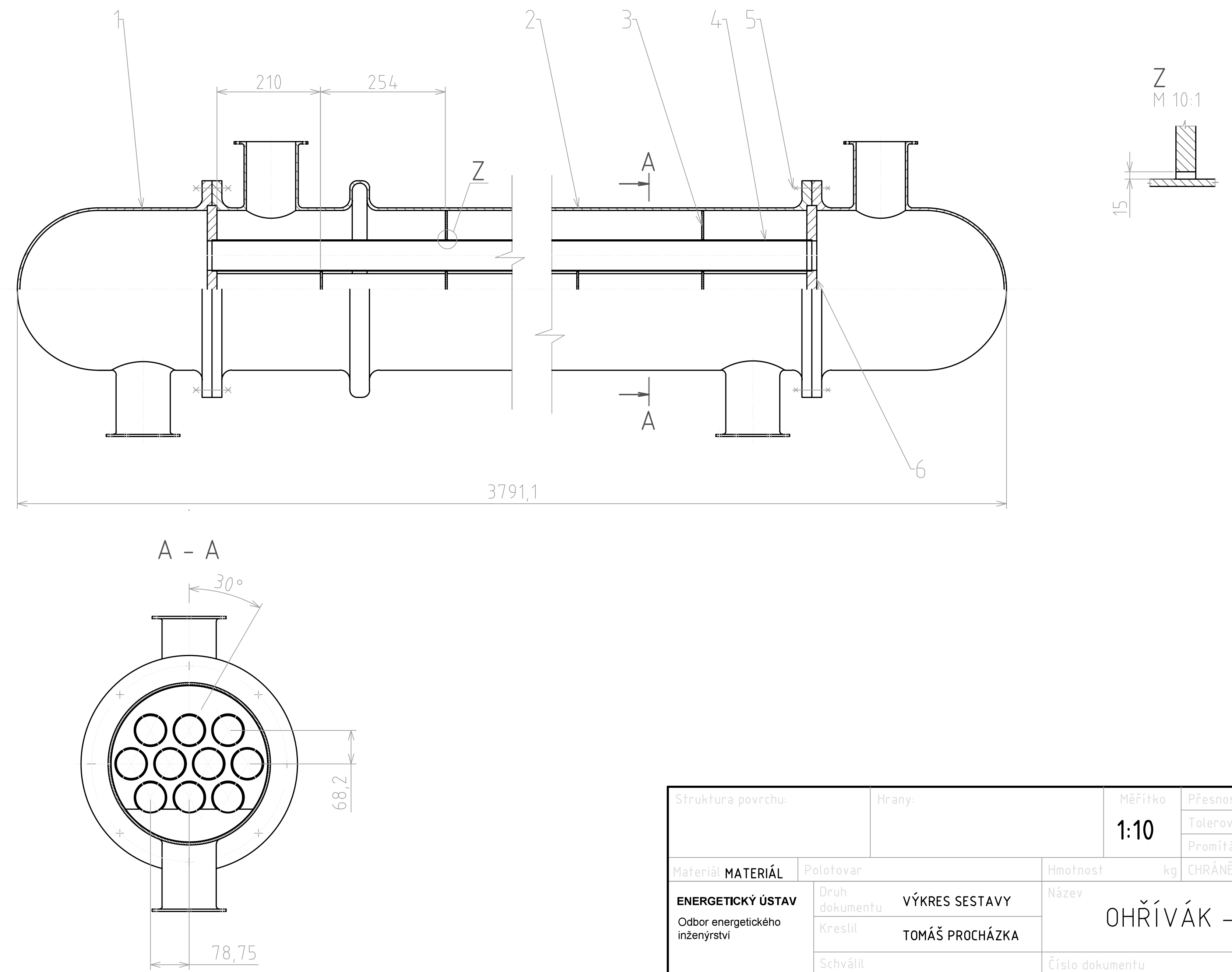
rychlost vzduchu vzta~ená ke stYednímu geometrickému pYoYezu S_{2Z} a S_{vZ}

$$S_{vZ} = S_{vN} - n_{tv} \cdot \pi \cdot \frac{d_2^{\ 2}}{4}$$ *proto*

ný proYez nad pYepá~kou

$$S_{vN} = \frac{\pi \cdot D_{pl;1}^{\ 2}}{4} \cdot \left[\frac{\phi_{vp}}{360} - \frac{\sin\left(\phi_{vp}\right)}{2 \cdot \pi} \right]$$ *nezaplnný pYoYez ve výYezu nad pYepá~kou*

$$n_{rv} = \frac{0{,}8}{t_t^{\ 2}} \cdot \left[\frac{D_{pl;1} + D_s}{2} - h_p \right]$$



Struktura povrchu:	Hrany:	Měřítko 1:10	Přesnost Tolerování Promítání
Materiál MATERIÁL	Polotovar	Hmotnost kg	CHRÁNĚNO PODLE ISO 16016

ENERGETICKÝ ÚSTAV

Odbor energetického inženýrství

Druh dokumentu	VÝKRES SESTAVY	Název	OHŘÍVÁK – BEM
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Schválil		Číslo dokumentu	1 – BEM – 1
Datum vydání	16.5.2018	List /	