GLOBAL MODEL - CMI - SD150414 - AUTRE FLUIDE

Equations

function $\Delta P_a\left(\dot{Q},\ \rho_v,\ \mu_v,\ A_v,\ d_v,\ l_a,\ h_{lv},\ Re\right)$ (1)

If $Re < 2300$ then (2)

$$\Delta P_a = \frac{32 \cdot \mu_v \cdot \dot{Q} \cdot l_a}{\rho_v \cdot A_v \cdot h_{lv} \cdot d_v^2} \tag{3}$$

else (4)

$$\Delta P_a = \left(\frac{0.3164}{Re^{0.25}}\right) \cdot \frac{\dot{Q}^2 \cdot l_a}{2 \cdot \rho_v \cdot A_v^2 \cdot h_{lv}^2 \cdot d_v} \tag{5}$$

endif (6)

end (7)

$SubprogramCaloduc\left(PipeMat\$,\ Fluid\$,\ ORCFluid\$,\ d_i,\ d_o,\ L_e,\ L_c,\ L_a,\ u_f,\ \dot{M}_f,\ \rho_f,\ T_{in,f},\ P_f,\ P_{atm},\ T_{ev,wf},\ h_{f,c} : \dot{Q}_c\right.$

Rayons

$$r_o = D_o/2 \tag{9}$$

$$r_i = D_i/2 \tag{10}$$

1. Evaporateur

1.1 Conduction paroi

$$T_{p,e} = \frac{T_{we,in} + T_{we,out}}{2} \tag{11}$$

$$\lambda_e = k\left(PipeMat\$,\ \mathrm{T} = T_{p,e}\right) \tag{12}$$

1.2 Evaporation (h_e)

Imura correlation

$$h_e = 0.32 \cdot \left(\frac{\rho_{l,e}^{0.65} \cdot k_{l,e}^{0.3} \cdot Cp_{l,e}^{0.7} \cdot g\#^{0.2} \cdot q_e^{0.4}}{\rho_{v,e}^{0.25} \cdot h_{lv,e}^{0.4} \cdot \mu_{l,e}^{0.1}}\right) \cdot \left(P_{sat,e}/P_{atm}\right)^{0.3} \tag{13}$$

$$q_e = \frac{\dot{Q}_e}{2 \cdot \pi \cdot L_e \cdot r_i} \tag{14}$$

$$T_{sat,e} = \mathrm{T_{sat}}\left(Fluid\$,\ \mathrm{P} = P_{sat,e}\right) \tag{15}$$

$$\rho_{l,e} = \rho\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 0\right) \tag{16}$$

$$k_{l,e} = \mathrm{k}\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 0\right) \tag{17}$$

$$cp_{l,e} = \mathrm{c_p}\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 0\right) \tag{18}$$

$$\rho_{v,e} = \rho\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 1\right) \tag{19}$$

$$h_{lv,e} = \mathrm{h}\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 1\right) - \mathrm{h}\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 0\right) \tag{20}$$

$$\mu_{l,e} = \mu\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 0\right) \tag{21}$$

$$\mu_{v,e} = \mu\left(Fluid\$,\ \mathrm{P} = P_{sat,e},\ \mathrm{X} = 1\right) \tag{22}$$

1.3 Convection et Rayonnement fumées (h_f)

Convection

Rayonnement idéal

$$h_{f,r} = sigma\# \cdot \frac{\left(T_{in,f} + 273.15\right)^4 - \left(T_{we,out} + 273.15\right)^4}{T_{in,f} - T_{we,out}} \tag{23}$$

Somme

$$h_f = h_{f,r} + h_{f,c} \tag{24}$$

1.4 Global

$$\dot{Q}_e = \frac{2 \cdot \pi \cdot L_e \cdot \lambda_e}{\ln\left(r_o / r_i\right)} \cdot \left(T_{we,out} - T_{we,in}\right) \tag{25}$$

$$\dot{Q}_e = 2 \cdot \pi \cdot L_e \cdot r_i \cdot h_e \cdot \left(T_{we,in} - T_{sat,e}\right) \tag{26}$$

$$\dot{Q}_e = 2 \cdot \pi \cdot L_e \cdot r_o \cdot h_f \cdot \left(T_{in,f} - T_{we,out}\right) \tag{27}$$

$$\dot{M}_v = \dot{Q}_e / h_{lv,e} \tag{28}$$

2 Pertes de charge vapeur

VDI

$$A_v = 0.9 \cdot \left(\pi \cdot r_i^2\right) \tag{29}$$

$$A_v = \pi \cdot \frac{d_v^2}{4} \tag{30}$$

$$Re_a = \frac{\dot{Q}_e \cdot d_v}{\mu_{v,c} \cdot A_v \cdot h_{lv,c}} \tag{31}$$

$$\Delta P_a = \Delta P_a\left(\dot{Q}_c,\ \rho_{v,c},\ \mu_{v,c},\ A_v,\ d_v,\ l_a,\ h_{lv,c},\ Re_a\right) \tag{32}$$

$$Re_{r,c} = \frac{\dot{Q}_c \cdot d_v / 2}{\mu_{v,c} \cdot A_c \cdot h_{lv,c}} \tag{33}$$

$$A_c = 2 \cdot \pi \cdot L_c \cdot r_i \tag{34}$$

$$\Delta P_c = \frac{\Delta P_a\left(\dot{Q}_c,\ \rho_{v,c},\ \mu_{v,c},\ A_v,\ d_v,\ l_c,\ h_{lv,c},\ Re_a\right)}{2} \tag{35}$$

$$Re_{r,e} = \frac{\dot{Q}_e \cdot d_v / 2}{\mu_{v,e} \cdot A_e \cdot h_{lv,e}} \tag{36}$$

$$A_e = 2 \cdot \pi \cdot L_e \cdot r_i \tag{37}$$

$$\Delta P_e = \frac{\Delta P_a \left(\dot{Q}_e,\ \rho_{v,e},\ \mu_{v,e},\ A_v,\ d_v,\ l_e,\ h_{lv,e},\ Re_a\right)}{2} \tag{38}$$

$$\Delta P_{ev,cd} = \frac{\Delta P_a + \Delta P_c + \Delta P_e}{100000} \tag{39}$$

$$P_{sat,c} = P_{sat,e} - \Delta P_{ev,cd} \tag{40}$$

3. Condenseur

3.1 Conduction paroi

$$T_{p,c} = \frac{T_{wc,in} + T_{wc,out}}{2} \tag{41}$$

$$\lambda_c = k\left(PipeMat\$,\ \mathrm{T} = \frac{T_{wc,in} + T_{wc,out}}{2}\right) \tag{42}$$

3.2 Condensation

Rohsenow, Wen and Guo correlation

$$h_N = 0.943 \cdot k_{l,c}/L_c \cdot \left(\frac{L_c^3 \cdot \rho_{l,c} \cdot (\rho_{l,c} - \rho_{v,c}) \cdot g\#}{\mu_{l,c} \cdot k_{l,c} \cdot (T_{sat,c} - T_{wc,in})} \cdot \left(h_{lv,c} + 0.68 \cdot cp_{l,c} \cdot (T_{sat,c} - T_{wc,in})\right)\right)^{0.25} \tag{43}$$

$$P_{sat,c} = \mathrm{P_{sat}}\left(Fluid\$,\ \mathrm{T} = T_{sat,c}\right) \tag{44}$$

$$k_{l,c} = \mathrm{k}\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 0\right) \tag{45}$$

$$h_{lv,c} = \mathrm{h}\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 1\right) - \mathrm{h}\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 0\right) \tag{46}$$

$$cp_{l,c} = \mathrm{c_p}\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 0\right) \tag{47}$$

$$\mu_{l,c} = \mu\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 0\right) \tag{48}$$

$$\mu_{v,c} = \mu\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 1\right) \tag{49}$$

$$\rho_{v,c} = \rho\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 1\right) \tag{50}$$

$$\rho_{l,c} = \rho\left(Fluid\$,\ \mathrm{P} = P_{sat,c},\ \mathrm{X} = 0\right) \tag{51}$$

$$h_c = 1.51 \cdot h_N \cdot \left(P_{sat,c}/\mathrm{P_{crit}}\right)^{0.15} \tag{52}$$

$$P_{crit} = \mathrm{P_{crit}}\left(Water\right) \tag{53}$$

3.3 ORC evaporateur

Cooper

$$h_{wf} = 55 \cdot MM_{wf}^{-0.5} \cdot q_c^{0.67} \cdot p_{r,wf}^{0.12} \cdot \left(-\log 10(p_{r,wf})\right)^{-0.55} \tag{54}$$

$$p_{r,wf} = \frac{P_{ev,wf}}{\mathrm{P_{crit}}\left(ORCFluid\$\right)} \tag{55}$$

$$MM_{wf} = \mathrm{MW}\left(ORCFluid\$\right) \tag{56}$$

$$P_{ev,wf} = \mathrm{P_{sat}}\left(ORCFluid\$,\ \mathrm{T} = T_{ev,wf}\right) \tag{57}$$

3.4 Global

$$\dot{Q}_c = \dot{Q}_e \tag{58}$$

$$\dot{Q}_c = 2 \cdot \pi \cdot L_c \cdot r_o \cdot h_{wf} \cdot (T_{wc,out} - T_{ev,wf}) \tag{59}$$

$$\dot{Q}_c = \frac{2 \cdot \pi \cdot L_c \cdot \lambda_c}{\ln (r_o / r_i)} \cdot (T_{wc,in} - T_{wc,out}) \tag{60}$$

$$\dot{Q}_c = 2 \cdot \pi \cdot L_c \cdot r_i \cdot h_c \cdot (T_{sat,c} - T_{wc,in}) \tag{61}$$

$$q_c = \frac{\dot{Q}_c}{2 \cdot \pi \cdot L_c \cdot r_i} \tag{62}$$

4 Limites de fonctionnement

4.1 Limite d'entrainement

Habituellement la plus contraignante dans le cas d'un thermosyphon diphasique

$$\dot{Q}_{limit,ent} = 3.2 \cdot h_{lv,e} \cdot A_v \cdot \left(\rho_{v,e}^{-0.25} + \rho_{l,e}^{-0.25}\right)^{-2} \cdot (\sigma_{eau} \cdot g\# \cdot (\rho_{l,e} - \rho_{v,e}))^{0.25} \tag{63}$$

$$\sigma_{eau} = \gamma \left(Water, \ \mathrm{T} = T_{sat,e}\right) \tag{64}$$

4.2 Limite d'ébullition

$$\dot{Q}_{limit,ebu} = (\pi \cdot d_v \cdot l_e) \cdot 0.149 \cdot \rho_{v,e} \cdot h_{lv,e} \cdot \left(\frac{\sigma_{eau} \cdot (\rho_{l,e} - \rho_{v,e}) \cdot g\#}{\rho_{v,e}^2}\right)^{0.25} \tag{65}$$

4.3 Limite sonique

$$\dot{Q}_{limit,son} = 0.474 \cdot A_v \cdot h_{lv,e} \cdot \left(\rho_{v,e} \cdot P_{sat,e} \cdot \left|100000 \ \frac{\mathrm{Pa}}{\mathrm{bar}}\right|\right)^{0.5} \tag{66}$$

$$\dot{Q}_{cal} = \dot{Q}_c \tag{67}$$

end (68)

1. Inputs et paramètres

1.1 Caractéristiques géométriques

$A_f = 11.56 \ \left[\mathrm{m}^2\right]$ Aire du conduit de fumée (69)

1.2 Matériau et fluide

$PipeMat\$ =$ 'Carbon_steel' (70)

$Fluid\$ =$ 'Water' (71)

1.3 Fluides secondaires

Point de fonctionnement du 11/09/2014 à 15:34:31

$$\rho_{f,N} = 1.242 \ \left[\mathrm{kg/m^3}\right] \tag{72}$$

$ORCFluid\$ =$ 'n-pentane' (73)

1.4 Constantes

$$P_{atm} = 1 \ [\mathrm{bar}] \tag{74}$$

1.5 Echangeur caloduc

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$Constant nbr_cal#=160
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$Constant nbr_rangee#=20
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$$nbr_{total,cal} = nbr_{cal\#} \tag{75}$$

$$nbr_{rangee,cal} = nbr_{rangee\#} \tag{76}$$

$$nbr_{ligne,cal} = nbr_{cal\#}/nbr_{rangee\#} \tag{77}$$

$$D_{ech} = 3.4 \text{ [m]} \tag{78}$$

1.6 ORC

2 Echange thermique caloduc

Coefficient de convection moyen

call $External_{Flow,Inline,Bank}$(‘Air’ , $T_{in,f}$, $T_{out,f}$, $T_{we,moy}$, 1, $u_{f,1}$, $nbr_{cal\#}/nbr_{rangee\#}$, D_o, S_T, S_L : $h_{f,c}$, Δp_f, $Nusselt_f$

Discrétisation spatiale

$$T_{f,1} = T_{in,f} \tag{80}$$

duplicate $i = 1,\ nbr_{cal\#}/nbr_{rangee\#}$ (81)

call $Caloduc\Big(PipeMat\$,\ Fluid\$,\ ORCFluid\$,\ d_i,\ d_o,\ L_e,\ L_c,\ L_a,\ u_{f,i},\ \dot{M}_f,\ \rho_{f,i},\ T_{f,i},\ P_f,\ P_{atm},\ T_{ev,wf},\ h_{f,c} : \dot{Q}_{cal,i},$

$$\rho_{f,i} = \rho_{f,N} \cdot \frac{273.15}{T_{f,i} + 273.15} \tag{83}$$

$$u_{f,i} = \frac{\dot{M}_f}{\rho_{f,i} \cdot A_f} \tag{84}$$

$$cp_{f,i} = 1300 \text{ [J/kg·K]} \tag{85}$$

$$T_{f,i+1} = T_{f,i} - \dot{Q}_{cal,i} \cdot \frac{nbr_{rangee\#}}{\dot{M}_f \cdot cp_{f,i}} \tag{86}$$

end (87)

Valeurs globales

$$T_{out,f} = T_{f,nbr,cal\#/nbr,rangee\#+1} \tag{88}$$

$$T_{we,moy} = \frac{\text{Sum}(T_{we,out,i} \cdot nbr_{rangee\#},\ i = 1,\ nbr_{cal\#}/nbr_{rangee\#})}{nbr_{cal\#}} \tag{89}$$

$$\dot{Q}_{total} = \text{Sum}\Big(\dot{Q}_{cal,i} \cdot nbr_{rangee\#},\ i = 1,\ nbr_{cal\#}/nbr_{rangee\#}\Big) \tag{90}$$

$$\dot{Q}_{total,limit,ent} = \text{Sum}\Big(\dot{Q}_{limit,ent,i} \cdot nbr_{rangee\#},\ i = 1,\ nbr_{cal\#}/nbr_{rangee\#}\Big) \tag{91}$$

$$\dot{Q}_{moy} = \dot{Q}_{total}/nbr_{cal\#} \tag{92}$$

$$\dot{Q}_{max} = \dot{Q}_{cal,1} \tag{93}$$

$$\dot{Q}_{min} = \dot{Q}_{cal,nbr,cal\#/nbr,rangee\#} \tag{94}$$

$$\dot{Q}_{limit,ent,max} = \dot{Q}_{limit,ent,1} \quad (95)$$

$$\dot{Q}_{limit,ent,min} = \dot{Q}_{limit,ent,nbr,cal\#/nbr,rangee\#} \quad (96)$$

$$\dot{Q}_{limit,ent,moy} = \dot{Q}_{total,limit,ent}/nbr_{cal\#} \quad (97)$$

3 Performance ORC

$$\dot{Q}_{ev} = \dot{Q}_{total} \quad (98)$$

$$P_{ev} = \mathrm{P_{sat}}\left(ORCFluid\$,\ \mathbf{T} = T_{ev,wf}\right) \quad (99)$$

$$P_{cd} = \mathrm{P_{sat}}\left(ORCFluid\$,\ \mathbf{T} = T_{cd}\right) \quad (100)$$

$$h_{in,tur} = \mathrm{h}\left(ORCFluid\$,\ \mathbf{P} = P_{ev},\ \mathbf{X} = 1\right) \quad (101)$$

$$s_{in,tur} = \mathrm{s}\left(ORCFluid\$,\ \mathbf{P} = P_{ev},\ \mathbf{X} = 1\right) \quad (102)$$

$$h_{out,s,tur} = \mathrm{h}\left(ORCFluid\$,\ \mathbf{s} = s_{in,tur},\ \mathbf{P} = P_{cd}\right) \quad (103)$$

$$w_{s,tur} = h_{in,tur} - h_{out,s,tur} \quad (104)$$

$$w_{tur} = w_{s,tur} \cdot \epsilon_{s,tur} \quad (105)$$

$$h_{out,tur} = h_{in,tur} - w_{tur} \quad (106)$$

$$T_{out,tur} = \mathrm{T}\left(ORCFluid\$,\ \mathbf{P} = P_{cd},\ \mathbf{h} = h_{out,tur}\right) \quad (107)$$

$$h_{out,cd} = \mathrm{h}\left(ORCFluid\$,\ \mathbf{P} = P_{cd},\ \mathbf{X} = 0\right) \quad (108)$$

$$s_{out,cd} = \mathrm{s}\left(ORCFluid\$,\ \mathbf{P} = P_{cd},\ \mathbf{X} = 0\right) \quad (109)$$

$$h_{out,s,pp} = \mathrm{h}\left(ORCFluid\$,\ \mathbf{P} = P_{ev},\ \mathbf{s} = s_{out,cd}\right) \quad (110)$$

$$w_{s,pp} = h_{out,s,pp} - h_{out,cd} \quad (111)$$

$$w_{pp} = w_{s,pp}/\epsilon_{s,pp} \quad (112)$$

$$h_{out,pp} = h_{out,cd} + w_{pp} \quad (113)$$

$$T_{out,pp} = \mathrm{T}\left(ORCFluid\$,\ \mathbf{P} = P_{ev},\ \mathbf{h} = h_{out,pp}\right) \quad (114)$$

$$cp_{out,tur} = \mathrm{c_p}\left(ORCFluid\$,\ \mathbf{P} = P_{cd},\ \mathbf{h} = h_{out,tur}\right) \quad (115)$$

$$cp_{out,pp} = \mathrm{c_p}\left(ORCFluid\$,\ \mathbf{P} = P_{ev},\ \mathbf{h} = h_{out,pp}\right) \quad (116)$$

$$\dot{C}_{min} = Min\left(\dot{M}_r \cdot cp_{out,tur},\ \dot{M}_r \cdot cp_{out,pp}\right) \quad (117)$$

$$\dot{Q}_{rec} = \dot{C}_{min} \cdot \epsilon_{rec} \cdot \left(T_{out,tur} - T_{out,pp}\right) \quad (118)$$

$$T_{out,rec,fr} = T_{out,pp} + \frac{\dot{Q}_{rec}}{\dot{M}_r \cdot cp_{out,pp}} \quad (119)$$

$$T_{out,rec,ch} = T_{out,tur} - \frac{\dot{Q}_{rec}}{\dot{M}_r \cdot cp_{out,tur}} \quad (120)$$

$$\dot{Q}_{total} + \dot{Q}_{rec} = \dot{M}_r \cdot \left(h_{in,tur} - h_{out,pp}\right) \quad (121)$$

$$\dot{W}_{pp} = \dot{M}_r \cdot (h_{out,pp} - h_{out,cd}) \tag{122}$$

$$\dot{W}_{tur} = \dot{M}_r \cdot (h_{in,tur} - h_{out,tur}) \tag{123}$$

$$\dot{W}_{net} = \dot{W}_{tur} - \dot{W}_{pp} \tag{124}$$

$$\eta_{gross,ORC} = \dot{W}_{tur} / \dot{Q}_{total} \tag{125}$$

$$\eta_{net,ORC} = \dot{W}_{net} / \dot{Q}_{total} \tag{126}$$

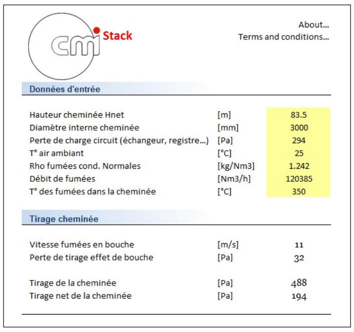
7 Pertes de charges conduit fumées

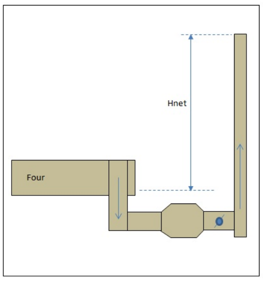
$$L_{ech} = (S_L + d_o) \cdot nbr_{cal\#} / nbr_{rangee\#} \quad \textbf{Encombrement dans le sens de l'écoulement} \tag{127}$$

$$S_T = \frac{D_{ech}}{nbr_{rangee\#} + 1} \tag{128}$$

$$\Delta P = 100000 \cdot \Delta P_f \tag{129}$$

Stack effect





Température fumées cheminée [°C]	Tirage cheminée [Pa]
100	202
150	297
200	354
250	408
300	452
350	488
400	519
450	545
500	567