EES models for heat transfer external flow

Equations

procedure $EF_{unit,check}(dv : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (1)

If(Unitsystem('SI') = 1) then $ENG = 0$ else $ENG = 1$ (2)

If(Unitsystem('K') = 1) then $UT\$$ = 'K' else (3)

If(Unitsystem('C') = 1) then $UT\$$ = 'C' else (4)

If(Unitsystem('R') = 1) then $UT\$$ = 'R' else $UT\$$ = 'F' check for temperature units (5)

endif (6)

endif (7)

If($ENG = 0$) then check whether in english or SI units to determine units for length, heat transfer coefficient, and to conv

$Uh\$$ = 'W/m$\hat{2}$-K' (9)

$UL\$$ = 'm' (10)

$UV\$$ = 'm/s' (11)

else (12)

$Uh\$$ = 'Btu/hr-ft$\hat{2}$-R' (13)

$UL\$$ = 'ft' (14)

$UV\$$ = 'ft/min' (15)

endif (16)

$UP\$$ = Unitsystem('Pressure') (17)

end (18)

procedure $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (19)

$UPorC\$$ = Unitsystem('Pressure') (20)

If(Uppercase\$($Fluid\$$) = 'AIRH2O') then (21)

$Fluid\$$ = 'Air' (22)

call Warning('AirH2O is considered to have the same properties as dry air in the Heat Transfer library.') (23)

endif (24)

$Ind = (fluid\$)$ (25)

If($ind = -2$) then (26)

$UPorC\$$ = '%' (27)

$C = P$ (28)

$\rho = \rho\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{C} = C)$ (29)

$\mu = \mu\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{C} = C)$ (30)

$k = \mathrm{k}\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{C} = C)$ (31)

$c = \mathrm{c_p}\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{C} = C)$ (32)

$Pr = c \cdot \mu / k$ (33)

If(Unitsystem('SI') $= 1) and$ (Unitsystem('kJ') $= 1$) then $Pr = Pr \cdot 1000$ (34)

$return$ (35)

endif (36)

If($Ind = -1$) then (37)

$\rho = \rho\,(Fluid\$,\ \mathrm{T} = T_{film})$ (38)

$\mu = \mu\,(Fluid\$,\ \mathrm{T} = T_{film})$ (39)

$k = k\,(Fluid\$,\ \mathrm{T} = T_{film})$ (40)

$c = c\,(Fluid\$,\ \mathrm{T} = T_{film})$ (41)

$Pr = c \cdot \mu / k$ (42)

If(Unitsystem('SI') $= 1) and$ (Unitsystem('kJ') $= 1$) then $Pr = Pr \cdot 1000$ (43)

else (44)

$\rho = \rho\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{P} = P)$ (45)

If($Ind = 1$) then (46)

$Pr = \mathrm{P_r}\,(Fluid\$,\ \mathrm{T} = T_{film})$ (47)

$\mu = \mu\,(Fluid\$,\ \mathrm{T} = T_{film})$ (48)

$k = \mathrm{k}\,(Fluid\$,\ \mathrm{T} = T_{film})$ (49)

else (50)

$Pr = \mathrm{P_r}\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{P} = P)$ (51)

$\mu = \mu\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{P} = P)$ (52)

$k = \mathrm{k}\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{P} = P)$ (53)

endif (54)

endif (55)

end (56)

procedure $External_{Flow,Plate,ND}(Re,\ Pr : Nusselt,\ C_f)$ (57)

$Re_c = 5 \times 10^5$ (58)

If($Re_{c>Re}$) then (59)

Laminar Flow

$Pe = Re \cdot Pr$ (60)

If($Pe < 100$) then call Warning('The value of the Peclet number in ExternalFlow_Plate should be greater than about 100. The v

$\nu_x = 0.3387 \cdot Re^{1/2} \cdot \frac{Pr^{1/3}}{\left(1 + (0.0468/Pr)^{2/3}\right)^{1/4}}$ Churchill and Ozoe, valid Pe> 100 (62)

$Nusselt = 2 \cdot \nu_x$ (63)

$C_f = 1.328 \cdot Re^{-1/2}$ (64)

else (65)

If($Re > 1e8$) then call Warning('Re=XXXF, for the function ExternalFlow_Plate, Re should be less than 1e8.' , Re)(66)

Mixed

If($0.5 > Pr$)or ($Pr > 60$) then call Warning('The range of acceptable Prandtl numbers in ExternalFlow_Plate is 0.5¡Pr¡60. Th

$Nusselt = 0.6774 \cdot Pr^{1/3} \cdot \frac{Re_c^{1/2}}{\left(1 + (0.0468/Pr)^{2/3}\right)^{1/4}} + 0.037 \cdot Pr^{1/3} \cdot \left(Re^{0.8} - Re_c^{0.8}\right)$ crit Re= 5*10^5, valid for Prandtl 0.5<Pr<

$C_f = (1/Re) \cdot \left(1.328 \cdot Re_c^{0.5} + 0.074 \cdot \left(Re^{0.8} - Re_c^{0.8}\right)\right)$ crit. Re= 5*10^5, valid from 5e5<Re<1e8 (69)

endif (70)

end (71)

procedure $External_{Flow,Plate}(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ L : \tau,\ h,\ C_f,\ Nusselt,\ Re)$ (72)

```
$RequiredOutputs 2
```

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (73)

If $ENG = 1$ then (74)

$V = V \cdot \left| 60 \ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (75)

$USS\$ =$ 'psi' (76)

else (77)

$V = V$ (78)

$USS\$ =$ 'Pa' (79)

endif (80)

$$T_{film} = \frac{T_s + T_{inf}}{2} \tag{81}$$

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (82)

$$Re_c = 5 \times 10^5 \tag{83}$$

$$x_c = Re_c \cdot \frac{\mu}{V \cdot \rho} \tag{84}$$

$$Re = V \cdot L \cdot \rho / \mu \tag{85}$$

call $External_{Flow,Plate,ND}(Re,\ Pr : Nusselt,\ C_f)$ (86)

$$h = Nusselt \cdot k / L \tag{87}$$

$$\tau = C_f \cdot 1/2 \cdot \rho \cdot V^2 \tag{88}$$

If$(ENG = 1)$ then $\tau = \tau \cdot \left| 2.1584 \times 10^{-4}\ \frac{\psi}{\mathrm{lb_m/ft \cdot s^2}} \right|$ (89)

end (90)

procedure $External_{Flow,Sphere,ND}(Re,\ Pr : Nusselt,\ C_d)$ (91)

If$(Re \leq 0)$ then $Re = 1 \times 10^{-5}$ (92)

$$Nusselt = 2 + \left(0.4 \cdot Re^{0.5} + 0.06 \cdot Re^{2/3}\right) \cdot Pr^{0.4} \tag{93}$$

If$(Re > 2E5)$ then call Warning('Re is out of range for External_Flow_Sphere The maximum values is 2E5 and the value is XXX

If$(Pr < 0.5) or\ (Pr > 380)$ then call Warning('The range of Prandtl number in External_Flow_Sphere should be between 0.5 and

$$C_d = 24/Re + \frac{6}{1 + \sqrt{Re}} + 0.4 \tag{96}$$

end (97)

procedure $External_{Flow,Sphere}(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ D : F_d,\ h,\ C_d,\ Nusselt,\ Re)$ (98)

```
$RequiredOutputs 2
```

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (99)

If$(ENG = 1)$ then (100)

$$V = V \cdot \left| 60\ \frac{\mathrm{ft/hr}}{\mathrm{ft/min}} \right| \tag{101}$$

$UF\$ =$ 'lb_f' (102)

else (103)

$V = V$ (104)

$UF\$ =$ 'N' (105)

endif (106)

$$T_{film} = \frac{T_{inf} + T_s}{2} \tag{107}$$

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (108)

$$Re = V \cdot D \cdot \rho / \mu \tag{109}$$

call $External_{Flow,Sphere,ND}(Re,\ Pr : Nusselt,\ C_d)$ (110)

$$h = Nusselt \cdot k / D \tag{111}$$

$$F_d = C_d \cdot \pi \cdot (D/2)^2 \cdot (1/2) \cdot \rho \cdot V^2 \tag{112}$$

If$(ENG = 1)$ then $F_d = F_d \cdot \left| 2.39822 \times 10^{\cdot 9}\ \frac{\mathrm{lb_f}}{\mathrm{lb_m \cdot ft/hr^2}} \right|$ (113)

end (114)

procedure $External_{Flow,Cuboid}(Fluid\$,\ T_{inf},\ T_s,\ P,\ u_{inf},\ a,\ b,\ c : F_d,\ h)$ (115)

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (116)

If $ENG = 1$ then (117)

$$u_{inf} = u_{inf} \cdot \left| 60\ \frac{\mathrm{ft/hr}}{\mathrm{ft/min}} \right| \tag{118}$$

$UF\$ =$ 'lb_f' (119)

$UA\$ =$ 'ft$\hat{2}$' (120)

$UVol\$ =$ 'ft$\hat{3}$' (121)

else (122)

$$u_{inf} = u_{inf} \tag{123}$$

$UF\$ =$ 'N' (124)

$UA\$ =$ 'm$\hat{2}$' (125)

$UVol\$ =$ 'm$\hat{3}$' (126)

endif (127)

$$T_{film} = \frac{T_s + T_{inf}}{2} \tag{128}$$

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (129)

$A_s = 2 \cdot a \cdot b + 2 \cdot b \cdot c + 2 \cdot a \cdot c$ surface area (130)

$per = 2 \cdot a + 2 \cdot b$ perimeter perpendicular to flow (131)

$$Re = u_{inf} \cdot \sqrt{A_s} \cdot \rho / \mu \tag{132}$$

$$Nusselt = 2 \cdot \sqrt{\pi} + \left(0.15 \cdot \sqrt{\left(\frac{per}{\sqrt{(A_s)}} \right)} \cdot \sqrt{(Re)} + 0.35 \cdot Re^{0.566} \right) \cdot Pr^{1/3} \tag{133}$$

$$h = Nusselt \cdot \frac{k}{\sqrt{A_s}} \tag{134}$$

$$Vol = a \cdot b \cdot c \tag{135}$$

$$D_{sph} = (6 \cdot Vol/\pi)^{1/3} \tag{136}$$

$$Re = u_{inf} \cdot D_{sph} \cdot \rho/\mu \tag{137}$$

$$\phi = 4 \cdot \pi \cdot \frac{(D_{sph}/2)^2}{A_s} \tag{138}$$

$$Ac = \exp\left(2.3288 - 6.4581 \cdot \phi + 2.4486 \cdot \phi^2\right) \tag{139}$$

$$Bc = 0.0964 + 0.5565 \cdot \phi \tag{140}$$

$$Cc = \exp\left(4.905 - 13.8944 \cdot \phi + 18.4222 \cdot \phi^2 - 10.2599 \cdot \phi^3\right) \tag{141}$$

$$Dc = \exp\left(1.4681 + 12.2584 \cdot \phi - 20.7322 \cdot \phi^2 + 15.8855 \cdot \phi^3\right) \tag{142}$$

$$C_d = 24 \cdot \frac{1 + Ac \cdot Re^{Bc}}{Re} + \frac{Cc}{1 + Dc/Re} \tag{143}$$

$$F_d = C_d \cdot \rho \cdot u_{inf}^2 \cdot a \cdot b/2 \tag{144}$$

$$\text{If}(ENG = 1)\ \text{then}\ F_d = F_d \cdot \left|2.39822 \times 10^{-9}\ \frac{\text{lb}_\text{f}}{\text{lb}_\text{m} \cdot \text{ft/hr}^2}\right| \tag{145}$$

end (146)

procedure $External_{Flow,Cylinder,ND}(Re,\ Pr : Nusselt,\ C_d)$ (147)

$$\text{If}(Re \le 0)\ \text{then}\ Re = 1 \times 10^{-5} \tag{148}$$

$$Nusselt = 0.3 + \frac{0.62 \cdot Re^{1/2} \cdot Pr^{1/3}}{\left(1 + (0.4/Pr)^{2/3}\right)^{1/4}} \cdot \left(1 + (Re/282000)^{5/8}\right)^{4/5}$$ Churchill and Bernstein- valid for all Re tested experimentally

$$\text{If}(Re > 1e7)\ \text{then}$$ call Warning('Re is out of range for External_Flow_Cylinder. The maximum value is 1E7 and the value is XXX

$$\text{If}(Re < 100)\ \text{then}$$ call Warning('Re is out of range for External_Flow_Cylinder. The minimum value is 100 and the value is XXX

$$Pe = Pr \cdot Re \tag{152}$$

$$\text{If}(Pe \le 0.2)\ \text{then}$$ call Warning('The Peclet number (Pr*Re) in External_Flow_Cylinder should be greater than 0.2. The value is X

$$C_d = \frac{10}{Re^{2/3}} + 1.0 \tag{154}$$

end (155)

procedure $External_{Flow,Cylinder}\left(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ D : F_{d/L},\ h,\ C_d,\ Nusselt,\ Re\right)$ (156)

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$RequiredOutputs 2
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call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (157)

If $ENG = 1$ then (158)

$V = V \cdot \left| 60\ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (159)

$UF\$ =$ 'lb_f/ft' (160)

else (161)

$V = V$ (162)

$UF\$ =$ 'N/m' (163)

endif (164)

$T_{film} = \frac{T_s + T_{inf}}{2}$ (165)

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (166)

$Re = V \cdot D \cdot \rho / \mu$ (167)

call $External_{Flow,Cylinder,ND}(Re,\ Pr : Nusselt,\ C_d)$ (168)

$h = Nusselt \cdot k / D$ (169)

$F_{d/L} = 1/2 \cdot \rho \cdot V^2 \cdot C_d \cdot D$ (170)

If$(Eng = 1)$ then $F_{d/L} = F_{dL} \cdot \left| 2.39822 \times 10^{-9}\ \frac{\text{lb}_\text{f}/\text{ft}}{\text{lb}_\text{m}/\text{hr}^2} \right|$ (171)

end (172)

procedure $External_{Flow,Inline,Bank}(Fluid\$,\ T_{in},\ T_{out},\ T_s,\ P,\ V,\ N_L,\ D,\ S_T,\ S_L : h,\ \Delta p,\ Nusselt,\ Re)$ (173)

```
$RequiredOutputs 1
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call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (174)

If $ENG = 1$ then (175)

$V = V \cdot \left| 60\ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (176)

else (177)

$V = V$ (178)

endif (179)

$a = S_T / D$ (180)

$b = S_L / D$ pitch to diameter ratios (181)

$T_m = \frac{T_{in} + T_{out}}{2}$ mean temperature of fluid, used to calculate fluid properties (182)

call $GetProps(Fluid\$,\ T_m,\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (183)

call $GetProps(Fluid\$,\ T_s,\ P : \rho_s,\ \mu_s,\ k_s,\ Pr_s,\ UPorC\$)$ (184)

$$V_{max} = \frac{S_T}{S_T - D} \cdot V \tag{185}$$

$$Re = \rho \cdot V_{max} \cdot D/\mu \tag{186}$$

If$(Re > 2E6)$ then call Warning('Re is out of range for ExternalFlow_Inline_Bank. The maximum value is 2E6 while the value su

If$(Re < 30)$ then call Warning('Re is out of range for ExternalFlow_Inline_Bank. The minimum value is 30 while the value supplie

If$(Pr < 0.5)$ then call Warning('The range of Prandtl number in ExternalFlow_Inline_Bank should be greater than 0.5. The value i

If$(Pr > 500)$ then call Warning('The range of Prandtl number in ExternalFlow_Inline_Bank should be less than 500. The value is

If$(b < 1.25)$ then call Warning('The longitudinal pitch, S_L/D is out of range for ExternalFlow_Inline_Bank. The minimum value i

If$(b > 2.5)$ then call Warning('The longitudinal pitch, S_L/D is out of range for ExternalFlow_Inline_Bank. The maximum value is

If$(10 < Re) and\,(Re < 100)$ then (193)

$C = 0.80$ (194)

$m = 0.40$ (195)

endif (196)

If$(100 < Re) and\,(Re < 1000)$ then (197)

$T_{inf} = T_{in}$ (198)

call $External_{Flow,Cylinder,ND}(Re,\ Pr_s : Nusselt,\ C_d)$ at Reynolds numbers between 100 and 1000, the Nusselt number can

endif (200)

If$(1000 < Re) and\,(Re < 2e5)$ then (201)

If$(S_T/S_{L>0.7})$ then (202)

$C = 0.27$ (203)

$m = 0.63$ (204)

else (205)

call Warning('S_T/S_L¡0.7. For values of S_T/S_L¡ 0.7, experimental results show that heat transfer is inefficient and aligned tu

endif (207)

endif (208)

If$\big(2 \times 10^5 < Re\big) and\,(Re < 2e6)$ then (209)

$C = 0.021$ (210)

$m = 0.84$ (211)

endif (212)

If$(N_{L<20}) and\,((Re < 1e2)\,or\,(Re > 1e3))$ then question here-to apply the correction factor for rows of tubes less than 20 for sm

$C_2 = \text{Interpolate}(\text{'Tube\_Bank\_Corr'}\ ,\ \text{'N\_L'}\ ,\ \text{'Aligned'}\ ,\ N_L = N_L)$ Credit of Zukauskas from p. 484, Heat Transfer handbook

$$Nusselt = C_2 \cdot C \cdot Re^m \cdot Pr^{0.36} \cdot (Pr/Pr_s)^{1/4} \tag{215}$$

endif (216)

If$(N_L \geq 20) and\, ((Re < 1e2)\, or\, (Re > 1e3))$ then (217)

$$Nusselt = C \cdot Re^m \cdot Pr^{0.36} \cdot (Pr/Pr_s)^{1/4} \tag{218}$$

endif (219)

pressure drop

$$var = \frac{a-1}{b-1} \tag{220}$$

$Eu = \text{Interpolate2dm}(\text{'inline\_friction'}\ ,\ b,\ Re)$ (221)

$\xi = \text{Interpolate2dm}(\text{'inline\_xi'}\ ,\ Re,\ var)$ (222)

$\Delta p_{row} = (1/2) \cdot Eu \cdot \rho \cdot V_{max}^2 \cdot xi$ average pressure drop across 1 row (223)

$\Delta p = \Delta p_{row} \cdot N_L \cdot |\text{UP\$ \$}|$ (224)

$h = Nusselt \cdot k/D$ (225)

end (226)

procedure $External_{Flow,Staggered,Bank}(Fluid\$,\ T_{in},\ T_{out},\ T_s,\ P,\ V,\ N_L,\ D,\ S_T,\ S_L : h,\ \delta p,\ Nusselt,\ Re)$ (227)

```
$RequiredOutputs 1
```

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (228)

If $ENG = 1$ then (229)

$$V = V \cdot \left| 60\ \frac{\text{ft/hr}}{\text{ft/min}} \right| \tag{230}$$

else (231)

$V = V$ (232)

endif (233)

$a = S_T/D$ (234)

$b = S_L/D$ pitch to diameter ratios (235)

$$T_m = \frac{T_{in} + T_{out}}{2}$$ mean temperature of fluid, used to calculate fluid properties (236)

call $GetProps(Fluid\$,\ T_m,\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (237)

call $GetProps(Fluid\$,\ T_s,\ P : \rho_s,\ \mu_s,\ k_s,\ Pr_s,\ UPorC\$)$ (238)

$$S_D = \left(S_L^2 + (S_T/2)^2 \right)^{1/2} \tag{239}$$

If$\left(\frac{S_{D<}\,(S_T+D)}{2}\right)$ then (240)

$V_{max}=\frac{S_T}{2\cdot(S_D-D)}\cdot V$ (241)

else (242)

$V_{max}=\frac{S_T}{S_T-D}\cdot V$ (243)

endif (244)

$Re=\rho\cdot V_{max}\cdot D/\mu$ (245)

If$(Re>2E6)$ then call Warning('Re is out of range for ExternalFlow_Staggered_Bank. The maximum value is 2E6 while the valu

If$(Re<30)$ then call Warning('Re is out of range for ExternalFlow_Staggered_Bank. The minimum value is 30 while the value su

If$(Pr<0.5)$ then call Warning('The range of Prandtl number in ExternalFlow_Staggered_Bank should be greater than 0.5. The va

If$(Pr>500)$ then call Warning('The range of Prandtl number in ExternalFlow_Staggered_Bank should be less than 500. The valu

If$(a<1.25)$ then call Warning('The transverse pitch, S_T/D is out of range for ExternalFlow_Staggered_Bank. The minimum valu

If$(a>2.5)$ then call Warning('The transverse pitch, S_T/D is out of range for ExternalFlow_Staggered_Bank. The maximum value

If$(10<Re)and\,(Re<100)$ then (252)

$C=0.90$ (253)

$m=0.40$ (254)

$Nusselt=C\cdot(Re^m)\cdot\left(Pr^{0.36}\right)$ (255)

endif (256)

If$(100<Re)and\,(Re<1000)$ then (257)

$T_{inf}=T_{in}$ (258)

call $External_{Flow,Cylinder,ND}(Re,\ Pr_s:Nusselt,\ C_d)$ at Reynolds numbers between 100 and 1000, the Nusselt number can

endif (260)

If$(1000<Re)and\,(Re<2e5)$ then (261)

If$(S_T/S_{L<2})$ then (262)

$C=0.35\cdot(S_T/S_L)^{1/5}$ (263)

$m=0.60$ (264)

else (265)

$C=0.40$ (266)

$m=0.60$ (267)

endif (268)

$Nusselt = C \cdot (Re^m) \cdot \left(Pr^{0.36}\right)$ (269)

endif (270)

If$\left(2 \times 10^5 < Re\right) and \, (Re < 2e6)$ then (271)

If$(Pr > 0.69) and \, (Pr < 0.71)$ then (272)

$C = 0.027 \cdot (S_T/S_L)^{0.2}$ (273)

$m = 0.8$ (274)

$Nusselt = C \cdot (Re^m) \cdot \left(Pr^{0.36}\right)$ (275)

endif (276)

If$(Pr \geq 0.70)$ then (277)

$C = 0.031 \cdot (S_T/S_L)^{0.20}$ (278)

$m = 0.80$ (279)

$Nusselt = C \cdot (Re^m) \cdot \left(Pr^{0.36}\right)$ (280)

endif (281)

endif (282)

If$(N_{L<20}) and \, (Re > 1e3)$ then (283)

$C_2 =$ Interpolate('Tube_Bank_Corr' , 'N_L' , 'Staggered_High' , $N_L = N_L$) Credit of Zukauskas from p. 484, Heat Transfer ha

$Nusselt = C_2 \cdot C \cdot Re^m \cdot Pr^{0.36} \cdot (Pr/Pr_s)^{1/4}$ (285)

endif (286)

If$(N_L \geq 20) and \, ((Re < 1e2) \, or \, (Re > 1e3))$ then (287)

$Nusselt = C \cdot Re^m \cdot Pr^{0.36} \cdot (Pr/Pr_s)^{1/4}$ (288)

endif (289)

pressure drop

$var = a/b$ (290)

$Eu =$ Interpolate2dm('staggered_friction' , a, Re) (291)

$\xi =$ Interpolate2dm('staggered_xi' , Re, var) (292)

$\delta p_{row} = (1/2) \cdot Eu \cdot \rho \cdot V_{max}^2 \cdot xi$ average pressure drop across 1 row (293)

$\delta p = \delta p_{row} \cdot N_L \cdot |\text{UP\$ \$}|$ (294)

$h = Nusselt \cdot k/D$ (295)

end (296)

procedure $External_{Flow,Diamond,ND}(Re,\ Pr : Nusselt,\ C_d)$ (297)

If$(Re < 5E3)$ then call Warning('Re is out of range for External_Flow_Diamond. The minimum value is 5E3 and the value is XXX

If$(Re > 1E5)$ then call Warning('Re is out of range for ExternalFlow_Diamond The maximum value is 1E5 and the value is XXX

$Nusselt = 0.246 \cdot Re^{0.588} \cdot Pr^{1/3}$ (300)

$C_d = 1.6$ (301)

end (302)

procedure $External_{Flow,Diamond}\big(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ W : F_{d/L},\ h,\ C_d,\ Nusselt,\ Re\big)$ (303)

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$RequiredOutputs 2
```

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (304)

If $ENG = 1$ then (305)

$V = V \cdot \left| 60\ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (306)

$UF\$ =$ 'lb_f/ft' (307)

else (308)

$V = V$ (309)

$UF\$ =$ 'N/m' (310)

endif (311)

$T_{film} = \frac{T_s + T_{inf}}{2}$ (312)

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (313)

$Re = V \cdot W \cdot \rho / \mu$ (314)

call $External_{Flow,Diamond,ND}(Re,\ Pr : Nusselt,\ C_d)$ (315)

$h = Nusselt \cdot k / W$ (316)

$F_{d/L} = 1/2 \cdot \rho \cdot V^2 \cdot C_d \cdot W$ (317)

If$(Eng = 1)$ then $F_{d/L} = F_{dL} \cdot \left| 2.39822 \times 10^{-9}\ \frac{\text{lb}_\text{f}/\text{ft}}{\text{lb}_\text{m}/\text{hr}^2} \right|$ (318)

end (319)

procedure $External_{Flow,Square,ND}(Re,\ Pr : Nusselt,\ C_d)$ (320)

If$(Re < 5E3)$ then call Warning('Re is out of range for External_Flow_Square. The minimum value is 5E3 and the value is XXXA

If$(Re > 1E5)$ then call Warning('Re is out of range for External_Flow_Square. The maximum value is 1E5 and the value is XXXA

$Nusselt = 0.102 \cdot Re^{0.675} \cdot Pr^{1/3}$ (323)

$C_d = 2.1$ (324)

end (325)

procedure $External_{Flow,Square}\big(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ W : F_{d/L},\ h,\ C_d,\ Nusselt,\ Re\big)$ (326)

$RequiredOutputs 2

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (327)

If $ENG = 1$ then (328)

$V = V \cdot \left| 60 \ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (329)

$UF\$ =$ 'lb_f/ft' (330)

else (331)

$V = V$ (332)

$UF\$ =$ 'N/m' (333)

endif (334)

$T_{film} = \frac{T_s + T_{inf}}{2}$ (335)

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (336)

$Re = V \cdot W \cdot \rho / \mu$ (337)

call $External_{Flow,Square,ND}(Re,\ Pr : Nusselt,\ C_d)$ (338)

$h = Nusselt \cdot k / W$ (339)

$F_{d/L} = 1/2 \cdot \rho \cdot V^2 \cdot C_d \cdot W$ (340)

If$(Eng = 1)$ then $F_{d/L} = F_{dL} \cdot \left| 2.39822 \times 10^{\cdot 9} \ \frac{\text{lb}_\text{f}/\text{ft}}{\text{lb}_\text{m}/\text{hr}^2} \right|$ (341)

end (342)

procedure $External_{Flow,Hexagon1,ND}(Re,\ Pr : Nusselt,\ C_d)$ (343)

If$(Re < 5E3)$ then call Warning('Re is out of range for External_Flow_Hexagon1. The minimum value is 5E3 and the value is XX

If$(Re > 1E5)$ then call Warning('Re is out of range for External_Flow_Hexagon1. The maximum value is 1E5 and the value is XX

$C = 0.160$ (346)

$n = 0.668$ (347)

If$(Re > 1.95E4)$ then (348)

$C = 0.0385$ (349)

$n = 0.782$ (350)

endif (351)

$Nusselt = c \cdot Re^n \cdot Pr^{1/3}$ (352)

$C_d = 0.7$ (353)

end (354)

procedure $External_{Flow,Hexagon1}\big(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ W : F_{d/L},\ h,\ C_d,\ Nusselt,\ Re\big)$ (355)

$RequiredOutputs 2

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (356)

If $ENG = 1$ then (357)

$V = V \cdot \left| 60\ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (358)

$UF\$ =$ 'lb_f/ft' (359)

else (360)

$V = V$ (361)

$UF\$ =$ 'N/m' (362)

endif (363)

$T_{film} = \frac{T_s + T_{inf}}{2}$ (364)

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (365)

$Re = V \cdot W \cdot \rho/\mu$ (366)

call $External_{Flow,Hexagon1,ND}(Re,\ Pr : Nusselt,\ C_d)$ (367)

$h = Nusselt \cdot k/W$ (368)

$F_{d/L} = 1/2 \cdot \rho \cdot V^2 \cdot C_d \cdot W$ (369)

If$(Eng = 1)$ then $F_{d/L} = F_{dL} \cdot \left| 2.39822 \times 10^{-9}\ \frac{\text{lb}_\text{f}/\text{ft}}{\text{lb}_\text{m}/\text{hr}^2} \right|$ (370)

end (371)

procedure $External_{Flow,Hexagon2,ND}(Re,\ Pr : Nusselt,\ C_d)$ (372)

If$(Re < 5E3)$ then call Warning('Re is out of range for External_Flow_Hexagon2. The minimum value is 5E3 and the value is XX

If$(Re > 1E5)$ then call Warning('Re is out of range for External_Flow_Hexagon2. The maximum value is 1E5 and the value is XX

$Nusselt = 0.153 \cdot Re^{0.638} \cdot Pr^{1/3}$ (375)

$C_d = 1.0$ (376)

end (377)

procedure $External_{Flow,Hexagon2}\big(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ W : F_{d/L},\ h,\ C_d,\ Nusselt,\ Re\big)$ (378)

$RequiredOutputs 2

call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (379)

If $ENG = 1$ then (380)

$V = V \cdot \left| 60 \ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (381)

$UF\$ =$ 'lb_f/ft' (382)

else (383)

$V = V$ (384)

$UF\$ =$ 'N/m' (385)

endif (386)

$T_{film} = \frac{T_s + T_{inf}}{2}$ (387)

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (388)

$Re = V \cdot W \cdot \rho / \mu$ (389)

call $External_{Flow,Hexagon2,ND}(Re,\ Pr : Nusselt,\ C_d)$ (390)

$h = Nusselt \cdot k / W$ (391)

$F_{d/L} = 1/2 \cdot \rho \cdot V^2 \cdot C_d \cdot W$ (392)

If$(Eng = 1)$ then $F_{d/L} = F_{dL} \cdot \left| 2.39822 \times 10^{\cdot 9} \ \frac{\text{lb}_\text{f}/\text{ft}}{\text{lb}_\text{m}/\text{hr}^2} \right|$ (393)

end (394)

procedure $External_{Flow,VerticalPlate,ND}(Re,\ Pr : Nusselt,\ C_d)$ (395)

If$(Re < 4E3)$ then call Warning('Re is out of range for External_Flow_VerticalPlate. The minimum value is 4E3 and the value is X

If$(Re > 1.5E4)$ then call Warning('Re is out of range for External_Flow_VerticalPlate. The maximum value is 1.5E4 and the value

$Nusselt = 0.228 \cdot Re^{0.731} \cdot Pr^{1/3}$ (398)

$C_d = 2.0$ (399)

end (400)

procedure $External_{Flow,VerticalPlate}\big(Fluid\$,\ T_{inf},\ T_s,\ P,\ V,\ W : F_{d/L},\ h,\ C_d,\ Nusselt,\ Re\big)$ (401)

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$RequiredOutputs 2
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call $EF_{unit,check}(1 : ENG,\ Uh\$,\ UL\$,\ UP\$,\ UT\$,\ UV\$)$ (402)

If $ENG = 1$ then (403)

$V = V \cdot \left| 60\ \frac{\text{ft/hr}}{\text{ft/min}} \right|$ (404)

$UF\$ =$ 'lb_f/ft' (405)

else (406)

$V = V$ (407)

$UF\$ =$ 'N/m' (408)

endif (409)

$T_{film} = \frac{T_s + T_{inf}}{2}$ (410)

$\rho = \rho\,(Fluid\$,\ \mathrm{T} = T_{film},\ \mathrm{P} = P)$ (411)

call $GetProps(Fluid\$,\ T_{film},\ P : \rho,\ \mu,\ k,\ Pr,\ UPorC\$)$ (412)

$Re = V \cdot W \cdot \rho/\mu$ (413)

call $External_{Flow,VerticalPlate,ND}(Re,\ Pr : Nusselt,\ C_d)$ (414)

$h = Nusselt \cdot k/W$ (415)

$F_{d/L} = 1/2 \cdot \rho \cdot V^2 \cdot C_d \cdot W$ (416)

If$(Eng = 1)$ then $F_{d/L} = F_{dL} \cdot \left| 2.39822 \times 10^{-9}\ \frac{\text{lb}_\text{f}/\text{ft}}{\text{lb}_\text{m}/\text{hr}^2} \right|$ (417)

end (418)

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