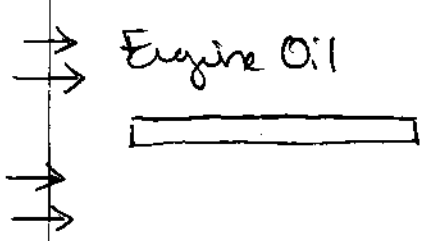
Problem 7.2 Engine Oil 100 °C



$V = 0.1$ m/s

$L = 1$ m

$T_s = 20°C$

$T_f = 60°C = 333K$

$\nu = 86.1 \times 10^{-6}$ m²/s

$\rho = 864$ kg/m³

$P_r = 1081.4$

$K_f = 0.140$

a) Find δ & δ_T at trailing edge

$\delta = 5x\, Re_x^{-1/2}$

$Re_x = \frac{VL}{\nu} = 1.16 \times 10^3$ $\boxed{\delta = 0.147 \text{ m}}$

$\frac{\delta}{\delta_T} = P_r^{1/3} \Rightarrow$ $\boxed{\delta_T = 0.0142 \text{ m}}$

b) Local Heat Flux & Shear Stress at trailing edge

$Re_L = 1160$ $Nu_x = 0.332\, Re_x^{1/2} P_r^{1/3}$

$Nu_x = 116.1 = \frac{h_x \cdot L}{K_f}$

$h_x = 16.25$ W/m²K

$q'' = h_x [T_s - T_\infty] = \boxed{-1300 \text{ W/m}^2}$

$C_{f,x} = 0.664\, Re_x^{-1/2} = 0.0195$

$\tau_s = C_{f,x} \cdot \rho \frac{V^2}{2} = \boxed{0.084 \text{ N/m}^2}$

c) Total Drag per unit width

$$\overline{C_{f_x}} = 1.328\, Re_x^{-1/2}$$

$$\overline{\tau_s} = 0.168 \ N/m^2$$

$$\boxed{D = 2L\overline{\tau_s} = 0.336 \ N/m}$$

$$\overline{Nu_x} = 0.664\, Re^{1/2}\, Pr^{1/3}$$

$$\overline{h} = 32.5 \ W/m^2K$$

$$q' = 2L\,\overline{h}\,[T_s - T_\infty]$$

$$\boxed{q' = -5200 \ W/m}$$

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nu = 86.1e-6
Pr = 1081
V = 0.1
kf = 0.14
rho = 864
{x= 1}

Rex = V*x/nu

delta = 5*x*Rex^(-1/2)
Pr^(1/3) = delta/delta_T

Nux = 0.332*Rex^(1/2)*Pr^(1/3)
Nux = hx*x/kf

qdp = hx*(80)

Cfx = 0.664*Rex^(-1/2)

tau_s = Cfx*rho*V^2/2
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SOLUTION
Unit Settings: [F]/[psia]/[lbm]/[degrees]
(Table 1, Run 25)

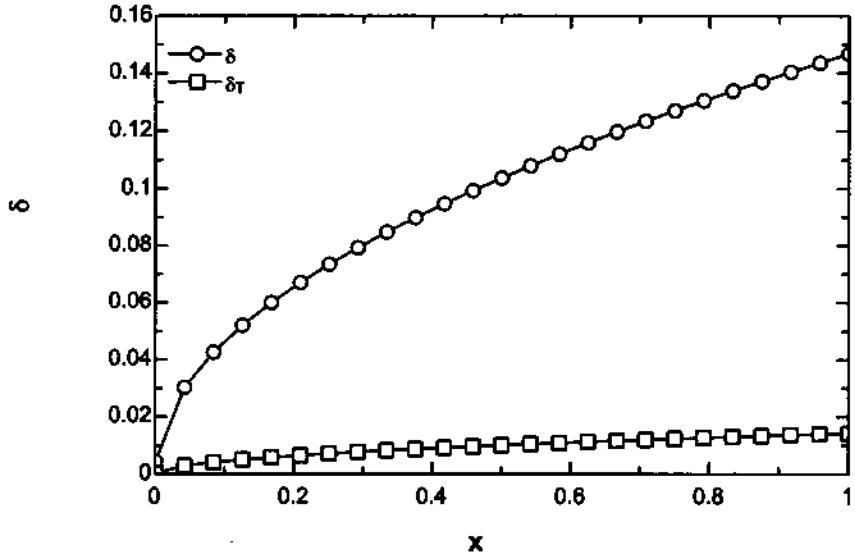
Cfx = 0.01948	δ = 0.1467	δ_T = 0.0143
hx = 16.26	kf = 0.14	ν = 0.0000861
Nux = 116.1	Pr = 1081	qdp = 1301
Rex = 1161	ρ = 864	τ_s = 0.08417
V = 0.1	x = 1	

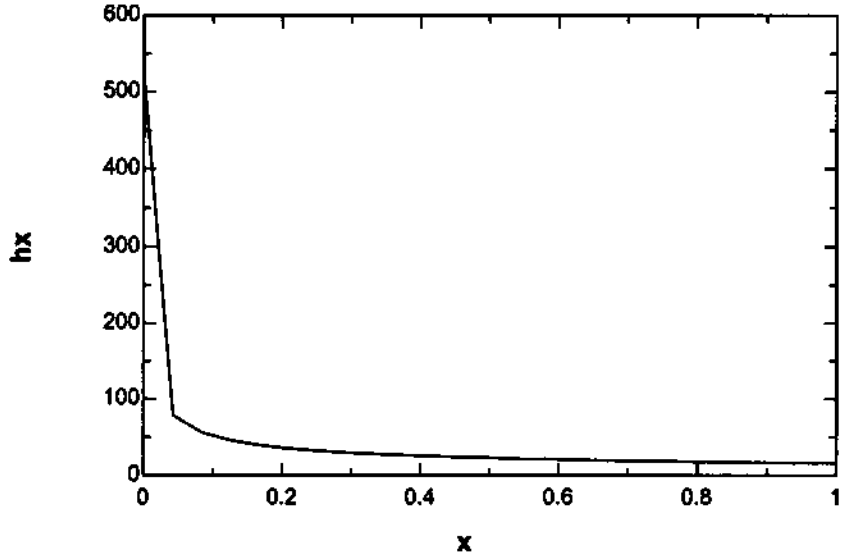
Parametric Table: Table 1

	x	δ	δ_T	hx	qdp	τ_s
Run 1	0.001	0.00464	0.0004521	514.1	41127	2.662
Run 2	0.04263	0.03029	0.002951	78.74	6299	0.4077
Run 3	0.08425	0.04258	0.004149	56.01	4481	0.29
Run 4	0.1259	0.05205	0.005072	45.82	3666	0.2372
Run 5	0.1675	0.06005	0.005851	39.72	3178	0.2057
Run 6	0.2091	0.06709	0.006537	35.55	2844	0.1841
Run 7	0.2508	0.07347	0.007158	32.47	2597	0.1681
Run 8	0.2924	0.07933	0.00773	30.07	2405	0.1557
Run 9	0.334	0.08479	0.008262	28.13	2250	0.1456
Run 10	0.3756	0.08992	0.008761	26.53	2122	0.1373
Run 11	0.4173	0.09477	0.009234	25.17	2013	0.1303
Run 12	0.4589	0.09938	0.009684	24	1920	0.1243
Run 13	0.5005	0.1038	0.01011	22.98	1838	0.119
Run 14	0.5421	0.108	0.01053	22.08	1766	0.1143
Run 15	0.5838	0.1121	0.01092	21.28	1702	0.1102
Run 16	0.6254	0.116	0.0113	20.56	1645	0.1064
Run 17	0.667	0.1198	0.01168	19.91	1592	0.1031
Run 18	0.7086	0.1235	0.01203	19.31	1545	0.09999
Run 19	0.7503	0.1271	0.01238	18.77	1502	0.09717
Run 20	0.7919	0.1306	0.01272	18.27	1462	0.09459
Run 21	0.8335	0.1339	0.01305	17.81	1425	0.09219

Parametric Table: Table 1

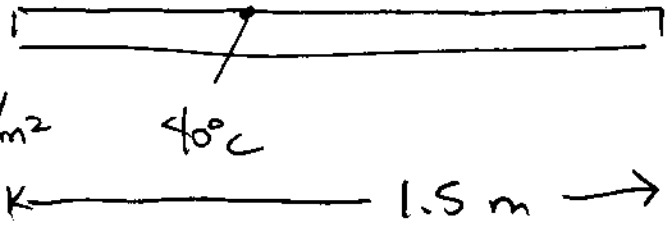
	x	δ	δ_T	hx	qdp	τ_w
Run 22	0.8751	0.1372	0.01337	17.38	1390	0.08997
Run 23	0.9168	0.1405	0.01369	16.98	1358	0.08791
Run 24	0.9584	0.1436	0.01399	16.61	1329	0.08598
Run 25	1	0.1467	0.0143	16.26	1301	0.08417





Problem 7.14

Water 40°C
$V = 0.6\ m/s$



$T_f = 295K$

$\rho = 998\ kg/m^3$

$\mu = 959 \times 10^{-6}\ Ns/m^2$

$K_f = 0.606\ W/mK$

$Pr = 6.62$

a) Calculate $Re = \rho \frac{VL}{\mu} = 936600$

$\therefore$ Turbulent (Mixed BL Condition)

$q' = L \cdot \bar{h}\,[T_s - T_\infty]$ Find $\bar{h}$

$\overline{Nu}_L = (0.037\, Re_L^{4/5} - 871)\, Pr^{1/3}$

$\overline{Nu}_L = 2524 = \frac{\bar{h} L}{K_f}$

$\bar{h} = 1019.7\ W/m^2K$

$q' = 55\ kW/m$

b) Repeat using $(T_f = T_\infty = 4°C)$

$Re_L = 576923$ - Turbulent Mixed BL

$\rho = 1000\ kg/m^3$

$\mu = 1560 \times 10^{-6}\ \frac{Ns}{m^2}$

$K_f = 0.577\ W/mK$

$Pr = 11.44$

$\overline{Nu}_L = 1425$

$\bar{h} = 548.1\ W/m^2K$

$q' = 29.6\ kW/m$

c) Repeat assuming Tripped BL Condition

$$\overline{Nu}_L = 0.037\, Re_L^{4/5}\, Pr^{1/3}$$

using Re_L from part (a)

$$\overline{Nu}_L = 4159$$

$T_f = 295\ K$

$$\bar{h} = \frac{\overline{Nu}_L \cdot k_f}{L} = 1680\ W/m^2K$$

$$q' = L \cdot \bar{h}\left[T_s - T_\infty\right] = 90.7\ kW/m$$

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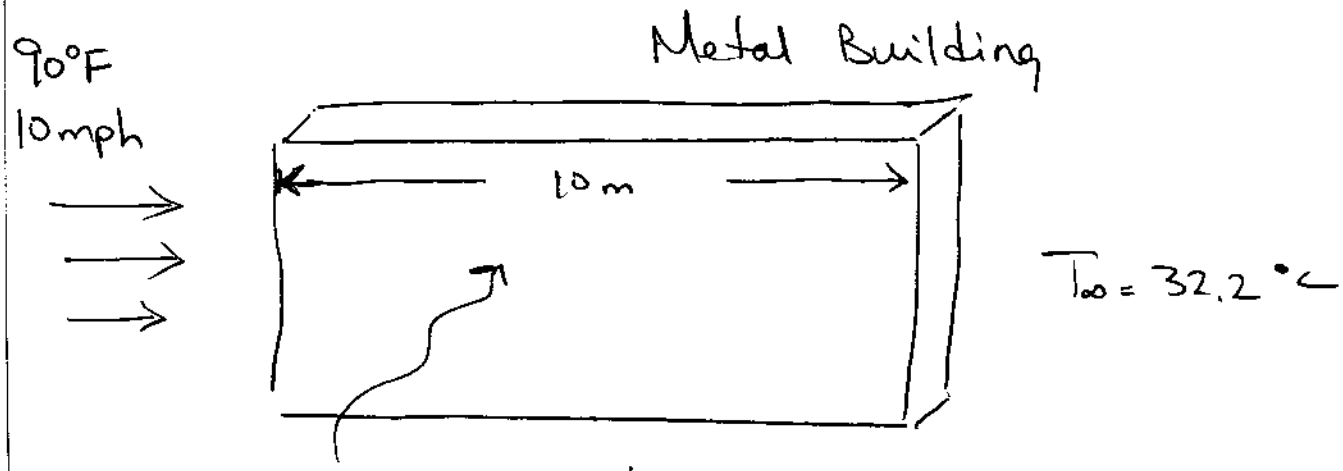
Problem 7.17



$q''_{solar} = 400\ W/m^2 = G_{abs}$

$\varepsilon = 0.93$

$V = 10\ mph = 4.47\ m/s$

assume $T_f = 300K$

$\rho = 1.1614\ kg/m^3$

$\nu = 15.89 \times 10^{-6}\ m^2/s$

$K_f = 0.0263\ W/mK$

$Pr = 0.707$

$Re_L = \frac{VL}{\nu} = 2.813 \times 10^6$

Turbulent

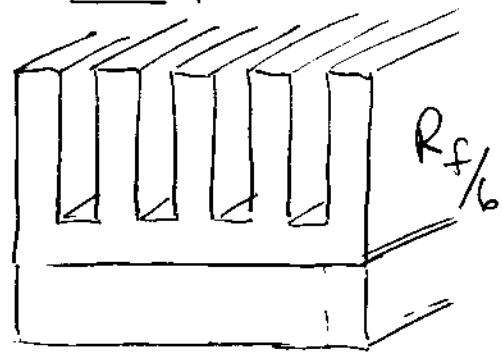
$\overline{Nu}_L = 0.037\, Re_L^{4/5}\, Pr^{1/3}$

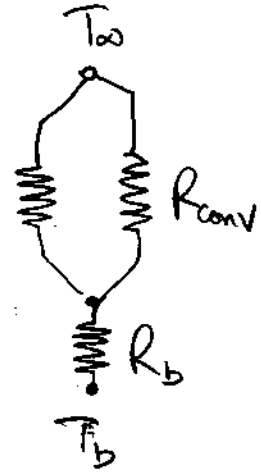
$\overline{Nu}_L = 4757 \qquad \bar{h} = \frac{\overline{Nu} \cdot K_f}{L} = 12.5\ W/m^2K$

$$\bar{h}\left[T_s - T_\infty\right] = \left[400\ W/m^2 - \varepsilon\sigma T_s^4\right]$$

$$\boxed{T_s = 302K}$$

Problem 7.30 Electronic Chips





$V = 3\ m/s$

$P = 1200\ W$

$T_\infty = 17°C$

$K_f = 0.62\ W/mK$

$\nu = 7.73 \times 10^{-7}\ m^2/s$

$Pr = 5.2$

$w_2 = 110\ mm$

$$Re_L = \frac{V \cdot w_2}{\nu} = 426908 \leftarrow \text{Laminar}$$

$$\overline{Nu_L} = 0.664\, Re^{1/2}\, Pr^{1/3} = 751.6$$

$$\bar{h} = \frac{\overline{Nu_L} \cdot K_f}{w_2} = 4236.2\ W/m^2K$$

Convection from tip

$$R_f = \frac{1}{\sqrt{hPKA_c}\ \underbrace{\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}}_{\approx 1}}$$

$$m = \sqrt{\frac{hP}{K_{AL} A_c}}$$

$P = 0.24\ m$

$A_c = 0.0011\ m$

$K_{AL} = 180\ W/m^2K$

$m = 71.67$

$mL = 7.88$

$R_f = 0.0705\ K/W$

$$R_{conv} = \frac{1}{hA} = \frac{1}{4236.2\ \frac{W}{m^2K} \cdot 50mm \cdot 110mm}$$

$R_{conv} = 0.0429\ K/W$

$$R_{TOT} = \left[1/R_{conv} + 6/R_f \right]^{-1} + R_b$$

$$R_b = \frac{L}{KA} = \frac{0.02\ m}{180\ W/mK \cdot (0.110m)^2}$$

$$R_b = 0.00918\ \frac{K}{W}$$

$$R_{TOT} = 0.0184\ K/W$$

$$q = \frac{T_b - T_\infty}{R_{TOT}} \Rightarrow \boxed{T_b = 49°C}$$

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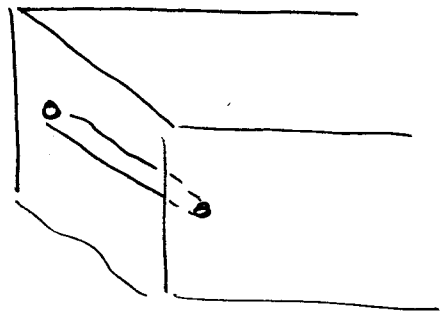
Problem 7.43 Heating Element in Duct

$T_\infty = 27°C$

$V = 10 m/s$



$D = 10 mm$

$K = 240 W/mK$

$\rho = 2700 kg/m^3$

$C_p = 900 J/kgK$

a) Find Surface Temp of Heater $q' = 1000 W/m$

$T_\infty = 300 K$ $\nu = 15.89 \times 10^{-6} m^2/s$

$k_f = 0.0263 W/mK$

$Pr = 0.707$ assume $Pr \cong Pr_s$

$$Re_D = \frac{V \cdot D}{\nu} = 6293$$

Table 7.2 $C = 1.93$ $m = 0.618$ $n = 0.37$

$$\overline{Nu}_D = C Re_D^m Pr^n$$

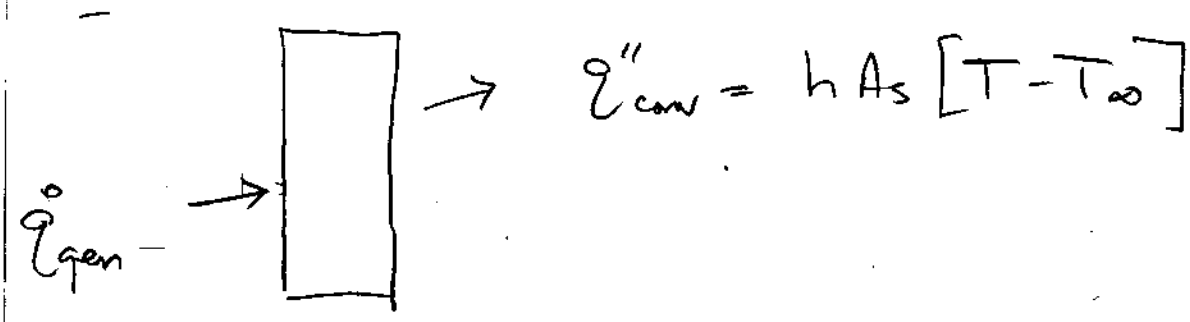
$$\overline{Nu}_D = 37.8 = \frac{\bar{h} \cdot D}{k_f} \Rightarrow \bar{h} = 99.4 W/m^2K$$

$$q' = \pi D \bar{h} [T_s - T_\infty]$$

$$T_s = \frac{q'}{\pi D \bar{h}} + T_\infty$$

$$T_s = 347.2°C$$

b) $Bi = \frac{h r_o}{2k} = 0.001$ ∴ Lumped Capacitance



$$\rho C_p V \frac{dT}{dt} = -hA[T - T_\infty] + \dot{q}V$$

$$\theta = T - T_\infty - \frac{\dot{q}V}{hA}$$

$$\rho C_p V \frac{d\theta}{dt} = -hA\,\theta \qquad T\big|_{t=0} = T_i - T_\infty - \frac{\dot{q}V}{hA}$$

$$\theta = Ce^{-hA_s/\rho C_p V\, t}$$

$$T_i - T_\infty - \frac{\dot{q}V}{hA_s} = C \qquad \dot{q} = \frac{q'}{\pi r^2} = 1.273\times10^7\ \frac{W}{m^3}$$

$$T = \left(T_i - T_\infty - \frac{\dot{q}r}{h2}\right)e^{-h2/\rho C_p r\, t} + T_\infty + \frac{\dot{q}r}{h2}$$

Solve for t when $T = 337.2°C$

$t \simeq 212$ seconds

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{ Problem 7.81 -  High-Temperature Gas Reator (HTGR) }

{Part (a) Find the rate of heat removal from a single pellet}
V =20 {m/s}
T_inf = 500 {K}
Do = 0.012 {m}
Di = 0.010 {m}
Tso = 1300 {K}
kg = 2 {graphite W/mK}
ku = 2 {uranium W/mK}
{q_dot = 1.5e8}

mu = viscosity(helium, T=T_inf, P=101.3)
rho = density(helium, T=T_inf, P=101.3)
{mu_s = viscosity(helium, T=1000, P=101.3)}
mu_s = 592e-7
Pr = prandtl(helium, T=T_inf,P=101.3)
kf = conductivity(helium, T=T_inf, P=101.3)

ReD = rho*Do*V/mu

NuD = 2 + (0.4*ReD^(1/2) + 0.06*ReD^(2/3))*(Pr^0.4)*(mu/mu_s)^(1/4)

NuD = h*Do/kf

q = h * pi*Do^2 * (Tso - T_inf)

{Part (b) Use the q_total to find the rate of volumetric heat generation}
q = q_dot * 4/3 *pi *(Di/2)^3

{Part (b) Calculate Tsi using the Conduction Resistance across the Graphite}
Rcond = 1/(4*pi*kg)*(2/Di - 2/Do)
q= (Tsi - Tso)/Rcond

{Part (c) Find an expression for T(r) - See Attached Sheet}

To = Tsi + q_dot/(6*ku)*(Di/2)^2

{Part (d) Determine Tsi, Tso and To as a function of Velocity and q_dot}
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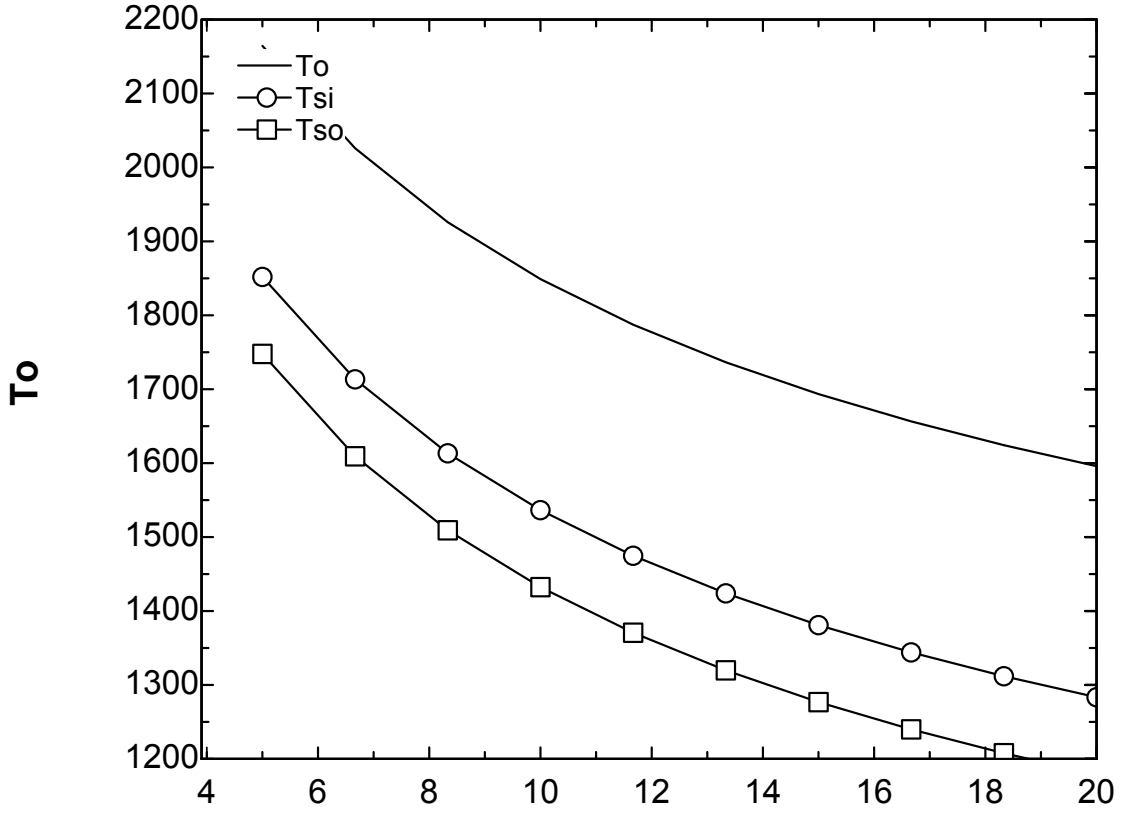
SOLUTION
Unit Settings: [kJ]/[K]/[kPa]/[kg]/[degrees]

Di	= 0.01	
Do	= 0.012	
h	= 255.6	
kf	= 0.2214	[W/m-K]
kg	= 2	
ku	= 2	
μ	= 0.00002844	[kg/m-s]
μ_s	= 0.0000592	
NuD	= 13.86	
Pr	= 0.6672	
q	= 92.5	
$\dot{q}$	= 1.767E+08	
Rcond	= 1.326	
ReD	= 822.8	

ρ = 0.09751 [kg/m^3]
To = 1791
Tsi = 1423
Tso = 1300
T_{inf} = 500
V = 20

Parametric Table: Table 1

	V	To	Tsi	Tso
Run 1	5	2164	1852	1748
Run 2	6.667	2026	1713	1609
Run 3	8.333	1926	1613	1509
Run 4	10	1849	1536	1432
Run 5	11.67	1787	1475	1371
Run 6	13.33	1736	1424	1320
Run 7	15	1693	1381	1277
Run 8	16.67	1657	1344	1240
Run 9	18.33	1624	1312	1208
Run 10	20	1596	1283	1179



Spherical Coordinates

$$\frac{1}{r^2}\frac{d}{dr}\left(k r^2 \frac{dT}{dr}\right) = -\dot{q}$$

$$\frac{d}{dr}\left(k r^2 \frac{dT}{dr}\right) = -\dot{q} r^2$$

$$k r^2 \frac{dT}{dr} = -\frac{\dot{q} r^3}{3} + C_1$$

$$\frac{dT}{dr} = -\frac{\dot{q} r}{3k} + \frac{C_1}{r^2}$$

$$T(r) = -\frac{\dot{q} r^2}{6k} + \frac{C_1}{r} + C_2$$

$$\left.\frac{dT}{dr}\right|_{r=0} = -\frac{\dot{q}(0)}{3k} + \frac{C_1}{(0)} = 0$$

$$\therefore C_1 = 0$$

$$T\big|_{r=r_i} = T_{si}$$

$$T(r_i) = -\frac{\dot{q} r_i^2}{6k} + C_2 = T_{si}$$

$$T(r) = -\frac{\dot{q}}{6k}\left(r^2 - r_i^2\right) + T_{si}$$