Final Exam (The Fracking Edition) **CBE 150A** **Spring 2014** **R.B. Eldridge**

Problem No. 1 (10 pts)

A static slurry of sand, chemicals, and water is located in a 8000 foot deep well bore. What is the static (non-flowing) pressure at the bottom of the well if the specific gravity of the slurry is 1.3?

Problem No.2 (10 pts)

The non-Newtonian (Power Law) slurry solution is being pumped 5 miles through 4 inch ID steel pipe at 250 GPM. It must arrive at the well head injection site, at the end of the line, at 3500 psig. What is the pump discharge pressure (psig)? The slurry specific gravity is 1.3, n = 0.4, and K = 0.60 (kg / m s $^{(2-n)}$). Ignore elevation changes and contraction / expansion losses.

Problem No.3 (10 pts)

What fluid horsepower is required to pump the slurry if the discharge pressure is 5000 psig and the pump efficiency is 65 percent ? The pump suction pressure is one atmosphere.

Problem No. 4 (10 pts)

Produced water from an oil / gas producing well is being treated for mercury contamination in a fixed bed column packed with adsorbent particles. What is the pressure drop (psi) in the column given the following data.

Water properties: ρ = 62.4 lb/ft^3, μ = = 0.9 cP
Adsorbent particles: sphericity – 0.9, diameter – 1/8 in, porosity – 0.45
Water flowrate: 1000 GPM
Packed column diameter – 2.0 ft., length – 10 ft.

Problem No. 5 (10 pts)

Natural gas produced from a well is being collected at a central processing facility. The natural gas (Mwt – 17.5 lb /lbmol, μ = 0.01 cP) flows through a 10 mile pipeline at 60 F. It arrives at a processing facility which has an inlet pressure of 50 psig. The flow line is 2 inch ID plastic pipe. What is the maximum flow rate of natural gas in the line in lb/hr ?

Problem No. 6 (10 pts)

What motor horsepower is required to compress 10 million SCFD of carbon dioxide from 150 psig and 60 F to 1000 psig using two stages of compression. γ for CO_2 = 1.3. Compressor efficiency – 80 percent.

Problem No. 7 (10 pts)

A fracking slurry flowing at 100,000 lb/hr is being cooled in a countercurrent exchanger with an outside tube area of 210 ft^2 with water entering at 60 F and leaving at 100 F. The incoming slurry is at 250 F. U_o = 200 BTU / hr ft^2 F. Cp slurry – 0.65 BTU / lb F. Cp water – 1.0 BTU / lb F. What is the required cooling water flow rate ?

Problem No. 8 (10 pts)

What is the temperature of the plastic cover over a pond containing produced water if the net radiant flux the pond surface is 225 BTU / hr ft^2, the pond cover emissivity is 0.90, the convective heat transfer coefficient is 1.0 BTU / hr ft^2 F, the ambient air temperature is 90 F, and the sky effective sink temperature is minus 95 F.

Problem No. 9 (10 pts)

How far down in a pond of fracking fluid will a 6000 pound log float ?

Data: log projected area – 150 ft^2, fracking fluid specific gravity– 1.2

Problem No. 10 (10 pts)

A 1.0 inch diameter cylindrical metal bar initially at 350 F is placed in stream of produced water flowing around the cylinder perpendicular to the axis at 60 F. How long will it take the center axis of the bar to reach a temperature of 140 F ?

Data:	h_o – 150 BTU / hr ft^2 F.
Cylinder properties:	k – 15 BTU / hr ft F
	Cp – 0.12 BTU / lb F
	ρ - 530 lb /ft^3

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1)

$$\Delta P = \frac{\rho g h}{g_c} = 1.3\left(\frac{62.4\ lbm}{ft^3}\right)\left(\frac{lbf}{lbm}\right)(8000\ ft)$$

$$\Delta P = 4507\ psig \quad (4521.3\ psiA)$$

2)

$$L = 5(5280\ ft) = 26{,}400\ ft$$

$$ID = \frac{4}{12}\ ft = 0.3333\ ft, \quad CSA = 0.0873\ ft^2$$

$$\bar{V} = \frac{250\ gal}{min}\left(\frac{1\ min}{60\ s}\right)\left(\frac{1\ ft^3}{7.48\ gal}\right)\left(\frac{1}{0.0873\ ft^2}\right)$$

$$\bar{V} = 6.381\ \frac{ft}{s}\left(\frac{1\ m}{3.281\ ft}\right) = 1.945\ \frac{m}{s}$$

$$D = 0.3333\ ft\left(\frac{1\ m}{3.281\ ft}\right) = 0.1016\ m$$

$$\rho = 1.3\left(1000\ \frac{kg}{m^3}\right) = 1300\ \frac{kg}{m^3}$$

$$Re_{PL} = 2^{(3-0.4)}\left(\frac{0.4}{3(0.4)+1}\right)^{0.4}\left(\frac{\left(1.945\ \frac{m}{s}\right)^{2-0.4}(0.1016\ m)^{0.4}\left(1300\ \frac{kg}{m^3}\right)}{0.6\ \frac{kg}{m\ s^{1.6}}}\right)$$

$$Re_{PL} = 6.063\ (0.5057)\ (2516.6)$$

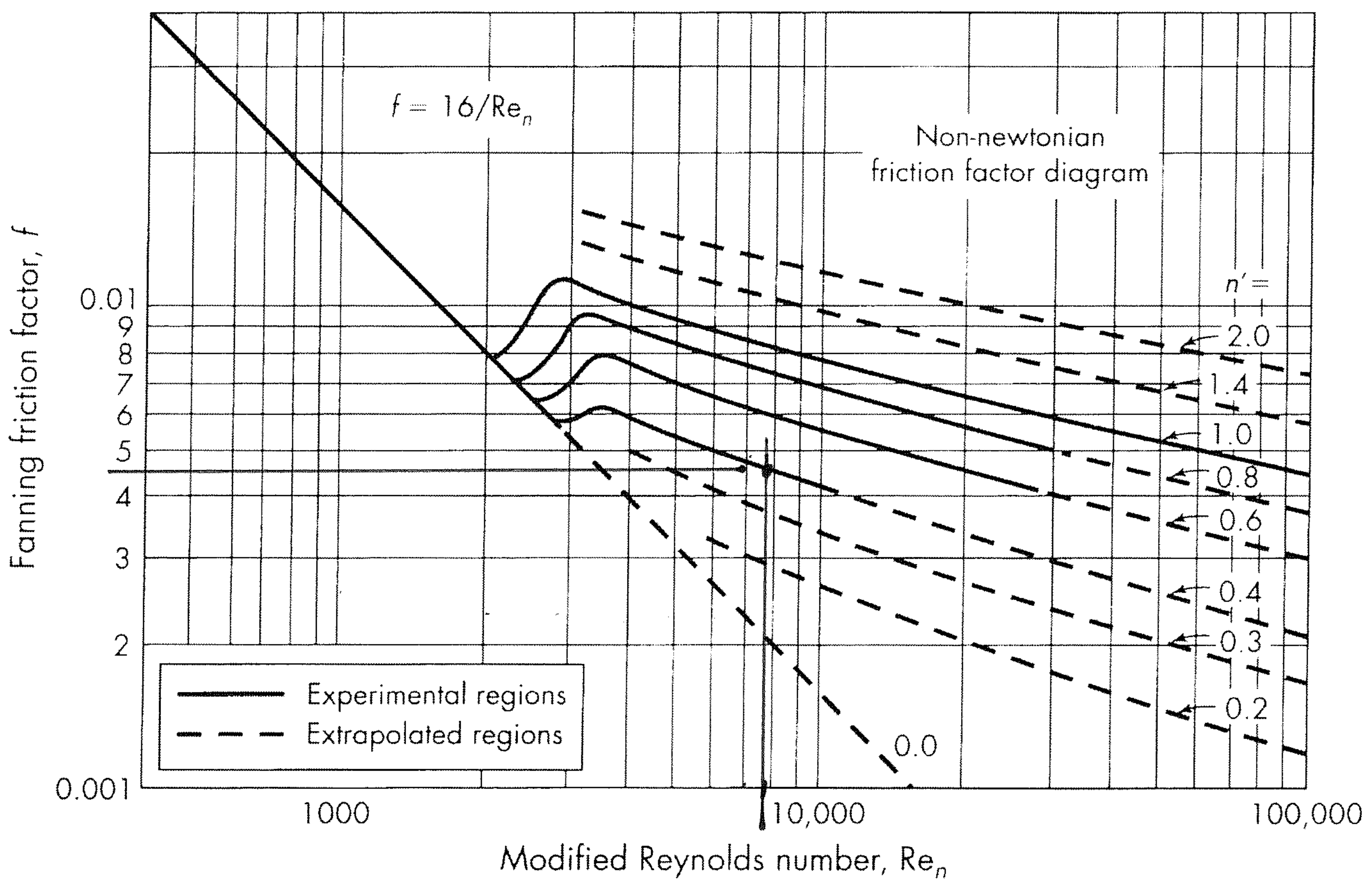
$$Re_{PL} = 7716, \quad n = 0.4, \quad f = 0.0045$$

$$\frac{\Delta P}{\rho} = 4 f \frac{L}{D}\frac{V^2}{2 g_c}$$

$$= 4(0.0045)\left(\frac{26{,}400\ ft}{0.3333\ ft}\right)\frac{\left(6.381\ \frac{ft}{s}\right)^2}{2\left(32.2\ \frac{ft\ lbm}{lbf\ s^2}\right)}$$

$$\frac{\Delta P}{\rho} = 901.4\ \frac{ft\ lbf}{lbm}$$

Turbulent Flow Friction Factor Power Law Fluid (Smooth Pipe)



1A/

$$\frac{\Delta P}{\rho} = 901.4 \ \frac{ft\ lb_f}{lb_m}$$

$$\Delta P = \frac{901.4 \ ft\ lb_f}{1\ lb_m}(1.3)\left(\frac{62.4\ lb_m}{ft^3}\right)\left(\frac{1\ ft^2}{144\ in^2}\right)$$

$$\Delta P = 507.8\ psi$$

$$P_D = 507.8 + 3500 = \underline{\underline{4008\ psig}}$$

3) $p = 1\,Atm\ (\phi\,psig)$ $\quad p = 5000\,psig$

Fluid $\varepsilon = \underline{100\%}$

$$\frac{\Delta P}{\rho} = \hat{W} = \frac{5000\ lb_f/in^2 \left(\frac{144\ in^2}{ft^2}\right)}{1.3\left(62.4\ \frac{lb_m}{ft^3}\right)}$$

$$\hat{W} = 8875.7\ \frac{ft\ lb_f}{lb_m}$$

$$\dot{m} = \frac{250\ gal}{min}(1.3)\left(\frac{8.333\ lb}{gal}\right)\left(\frac{1\ min}{60\ s}\right)$$

$$\dot{m} = 45.137\ \frac{lb_m}{s}$$

$$P_{fluid} = \frac{8875.7\ \frac{ft\ lb_f}{lb_m}\left(\frac{45.137\ lb_m}{s}\right)}{550\ Hp/ft\ lb_f/s}$$

$$P_{fluid} = \underline{\underline{728\ Hp}}$$

4) $$\Delta P = \frac{150\,\mu\, V_0 L (1-\varepsilon)^2}{\phi_s^2 D_p^2 \varepsilon^3} + \frac{1.75\,\rho V_0^2 L (1-\varepsilon)}{\phi_s D_p \varepsilon^3}$$

$$V_0 = \frac{1000\ \text{gal}}{\text{min}}\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\left(\frac{1\ \text{ft}^3}{7.48\ \text{gal}}\right)\left(\frac{1}{3.1416\ \text{ft}^2}\right)$$

$$CSA = \frac{\pi (2)^2}{4} = 3.1416\ \text{ft}^2$$

$$V_0 = 0.709\ \frac{\text{ft}}{\text{s}}, \quad \mu = 6.041 \times 10^{-4}\ \frac{\text{lb}}{\text{ft-s}}$$

Term 1

$$\frac{150\left(6.041 \times 10^{-4}\ \frac{\text{lbm}}{\text{ft-s}}\right)\left(0.709\ \frac{\text{ft}}{\text{s}}\right)(10\ \text{ft})(1-0.45)^2}{(0.9)^2 (0.0104\ \text{ft})^2 (0.45)^3}$$

$$= 24343\ \frac{\text{lbm}}{\text{s}^2\ \text{ft}}$$

Term 2

$$\frac{1.75\left(62.4\ \frac{\text{lb}}{\text{ft}^3}\right)\left(0.709\ \frac{\text{ft}}{\text{s}}\right)^2(10\ \text{ft})(1-0.45)}{(0.90)(0.0104\ \text{ft})(0.45)^3}$$

$$= 353968\ \frac{\text{lbm}}{\text{s}^2\ \text{ft}}$$

$$\Sigma \Delta P = \frac{(24343 + 353968)\ \frac{\text{lbm}}{\text{s}^2\ \text{ft}}\left(\frac{1\ \text{ft}^2}{144\ \text{in}^2}\right)}{32.2\ \frac{\text{ft lbm}}{\text{lbf s}^2}}$$

$$\Delta P = 81.6\ \frac{\text{lbf}}{\text{in}^2} \quad (81.6\ \text{psi})$$

5) $P_2 = 50\ psig = 64.7\ psiA$

$$\rho_2 = \frac{64.7\ psiA\left(17.5\ \frac{lb}{lbmol}\right)}{10.73\ \frac{psiA\ ft^3}{lbmol\ R}\left(520R\right)} = 0.203\ \frac{lbm}{ft^3}$$

$$G_{max} = \sqrt{0.203\ \frac{lbm}{ft^3}\left(\frac{64.7\ lbf}{in^2}\right)\left(\frac{144\ in^2}{ft^2}\right)\frac{32.2\ ft\ lbm}{lbf\ s^2}}$$

$G_{max} = 246.8\ \frac{lbm}{ft^2 s}$, $CSA = \frac{\pi(2/12)^2}{4}$

$\dot{m} = 246.8\ \frac{lbm}{ft^2 s}\left(0.0218\ ft^2\right)$ $CSA = 0.0218\ ft^2$

$\dot{m} = 5.384\ \frac{lb}{s}\left(\frac{3600\ s}{hr}\right) = \underline{\underline{19,384\ \frac{lb}{hr}}}$

6) $\sqrt{\frac{1014.7}{164.7}} = \sqrt{6.16} = \underline{2.482}$

$164.7 \xrightarrow{①} 408.8 \xrightarrow{②} 1014.7$

$$\hat{W}_{\Delta S=\phi} = \frac{(1.3)164.7\ \frac{lbf}{in^2}\left(\frac{144\ in^2}{ft^2}\right)}{1.30\ \frac{lbm}{ft^3}\left(1.3-1.0\right)}\left(\left(2.482\right)^{\frac{1.3-1}{1.3}}-1\right)$$

$\hat{W}_{\Delta S=\phi} = 18455\ \frac{ft\ lbf}{lbm}$

$$\rho_1 = \frac{164.7\ psiA\left(44.0\ \frac{lb}{lbmol}\right)}{10.73\ \frac{psiA\ ft^3}{lbmol\ R}\left(520\ R\right)} = 1.30\ \frac{lbm}{ft^3}$$

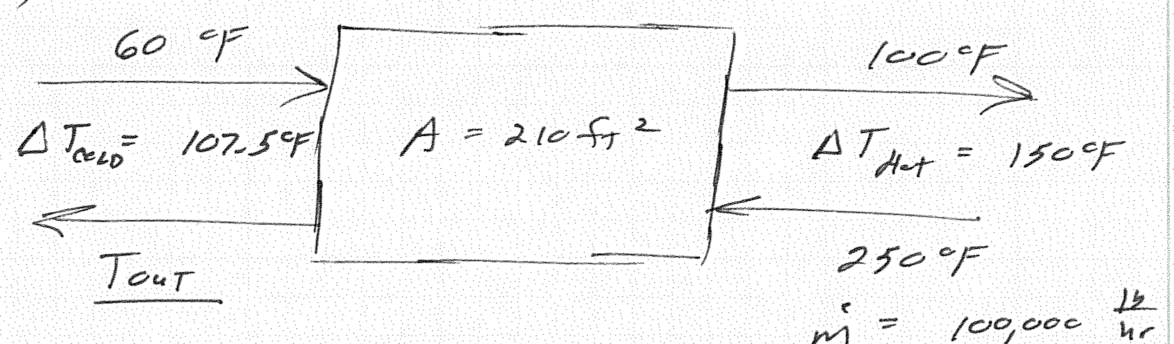
$$\dot{m} = 10 \times 10^6 \frac{ft^3}{Day}\left(\frac{1D}{24HR}\right)\left(\frac{1HR}{3600s}\right)\left(\frac{1lbmol}{379.5 ft^3}\right)\left(\frac{44 lb}{1lbmol}\right)$$

$$\dot{m} = 13.419 \frac{lb}{s}$$

$$P = \frac{18455 \frac{ft\,lbf}{lbm}\left(\frac{13.419\ lbm}{s}\right)}{550 \frac{ft\,lbf}{s}/Hp\ (0.80)}$$

$P = 562.8$ Hp per Stage   1125.7 Hp Total

7)



Assume $T_{OUT} = 167.5$ °F

$$\dot{Q} = 100{,}000 \frac{lb}{hr}\left(0.65 \frac{BTU}{lb°F}\right)(250 - 167.5)F$$

$$\dot{Q} = 5{,}362{,}500 \frac{BTU}{hr}$$

Check

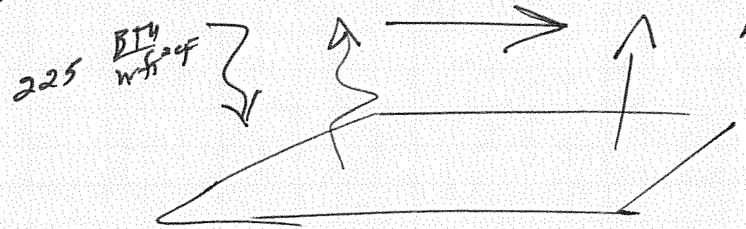
$$\dot{Q} = 200 \frac{BTU}{HR\,ft^2\,°F}\left(210\ ft^2\right)\left(\frac{150 - 107.5}{\ln\left(\frac{150}{107.5}\right)}\right)$$

$$\dot{Q} = 5{,}358{,}036 \frac{BTU}{HR}$$ ✓

$$\dot{m}_{H_2O} = \frac{5{,}362{,}500 \frac{BTU}{HR}}{1.0 \frac{BTU}{lb°F}(40F)} = 134{,}063 \frac{lb}{hr}$$

8)

$T_{SINK} = -95°F$



$h = 1.0 \frac{BTU}{hr\,ft^2\,F}$

$\varepsilon = 0.90$

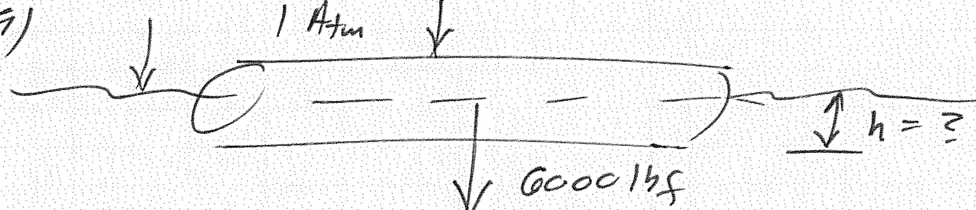
$T_{Air} = \underline{90°F}$

$$225 \frac{BTU}{hr\,ft^2} = 1.0 \frac{BTU}{hr\,ft^2\,F}\left(T_p - 90\right)$$

$$+0.1713 \times 0.90 \left[\left(\frac{T_p + 460}{100}\right)^4 - (3.64)^4\right]$$

$T_p = \underline{141\ °F}$

9)



$e = 1.2$

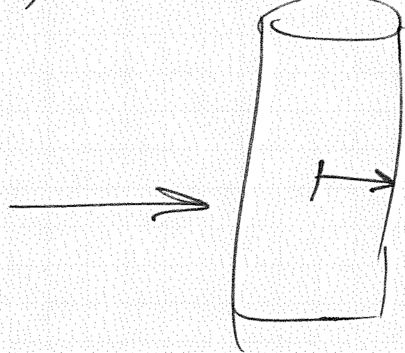
$Area = 150\ ft^2$

$$\frac{6000\ lbf}{150\ ft^2} = \frac{40\ lbf}{ft^2} = e\,\frac{g}{g_c}\,h$$

$$\frac{40\ lbf}{ft^2} = \frac{62.4\,(1.2)\ lbm}{ft^3}\left(\frac{lbf}{lbm}\right)\left(h\right)$$

$h = 0.53\ ft\ \ (6.4\ in)$

10)



Cylinder

Non-SS Problem

$r = 0.5$ in

$T_o = 350\,°F$

$h_o = 150 \dfrac{BTU}{hr\,ft^2\,°F}$ $T_w = 60\,°F$

T_f = center = 140 °F

$$B_i = \frac{150 \frac{BTU}{hr\,ft^2\,°F}\left(\frac{0.5\,in}{12\,in}\,ft\right)}{15 \frac{BTU}{hr\,ft\,F}} \cong 0.42$$

$$\theta_i^c = \frac{140 - 60}{350 - 60} \cong 0.28$$

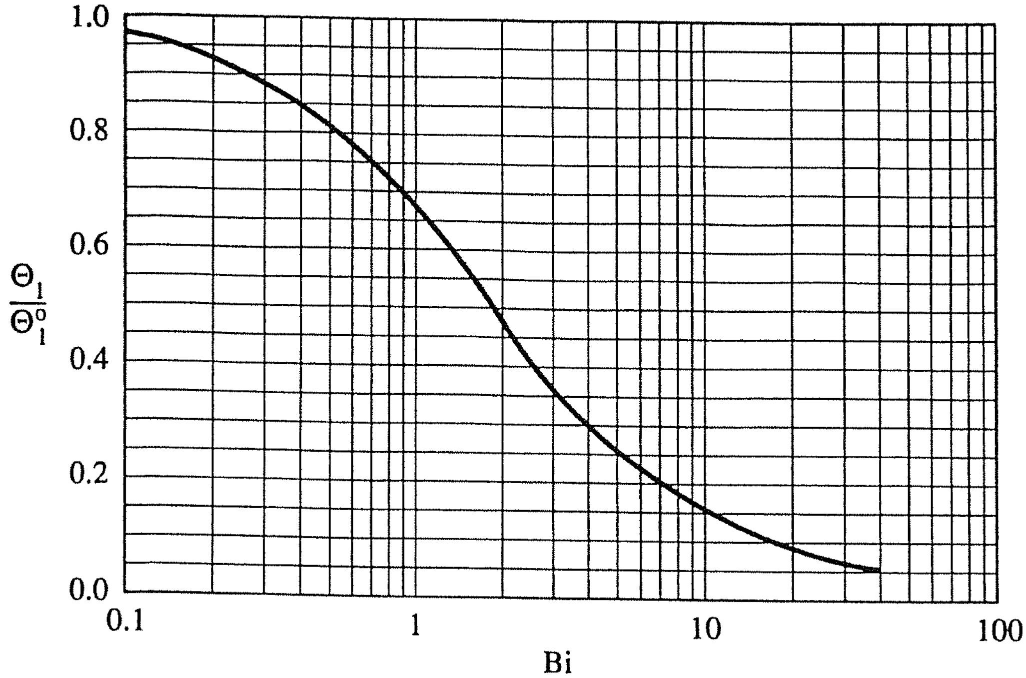
$$X_{Fo} = 2.2 = \frac{\alpha t}{\left(\frac{0.5}{12}ft\right)^2}$$

$$\alpha = \frac{k}{\rho C_p}_{\text{solid}} = \frac{15 \frac{BTU}{hr\,ft\,F}}{530 \frac{lb}{ft^3}\left(0.12 \frac{BTU}{lb\,F}\right)}$$

$$\alpha = 0.236 \frac{ft^2}{hr}$$

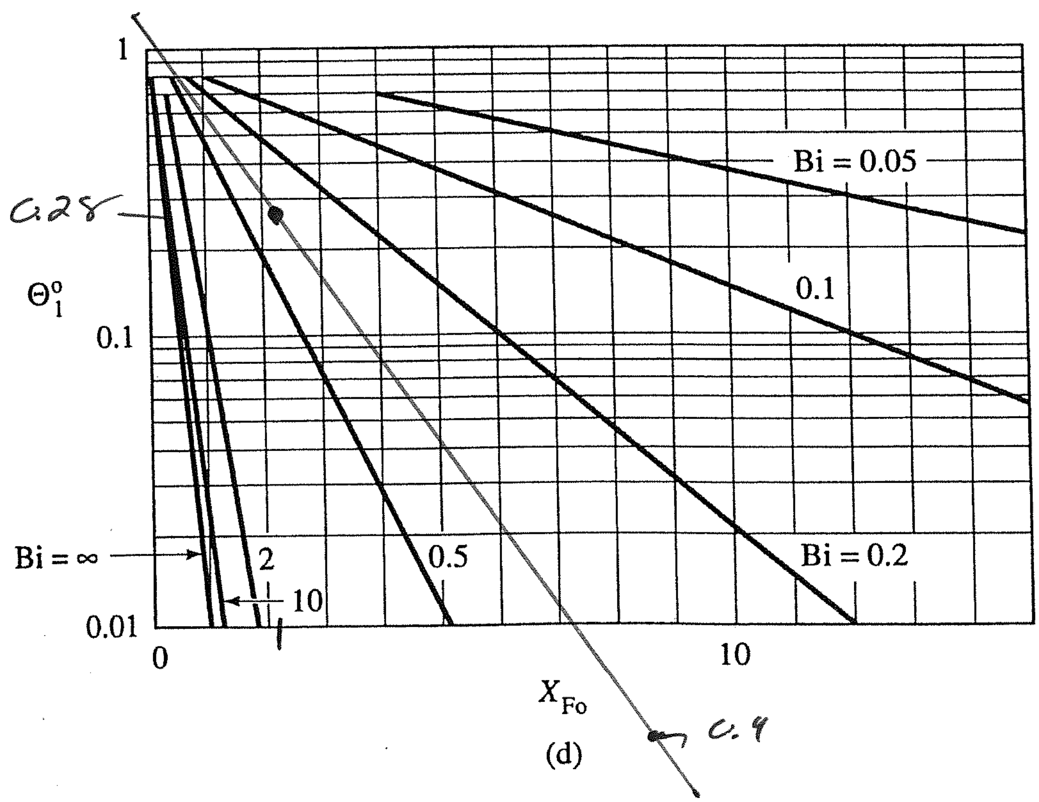
$$\frac{2.2\left(1.736 \times 10^{-3}\ ft^2\right)}{0.236 \frac{ft^2}{hr}} = t = 0.0162\ hr$$

58.3 seconds



(c)

c) Transient surface ($\varepsilon = 1$) temperature function for a slab (Eqn. 11.1.40c)



(d)

d) Transient axial temperature for a long cylinder as a function of Biot number.