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15 LENG 07/012

Question One.

Given data.

$$q_o = 500 \text{ bbl/day}$$

$$D = 2 \text{ inches}$$

$$\text{Temp} = 120^\circ \text{F} + 460 = 580^\circ \text{R}$$

$$\text{Pressure} = 1000 \text{ psia}$$

$$q_L = ?$$

$$\text{GOR} = 1000 \text{ scf/bbl}$$

$$\text{Area} = ?$$

Step 1 \rightarrow Calculate Area.

$$\text{Using } A = \frac{\pi D^2}{4} = \frac{3.143 \times \left(\frac{2}{12}\right)^2}{4} = 0.02182 \text{ ft}^2$$

Step 2 \rightarrow Calculate U_{sc} , U_{sg} , U_m .

$$\text{where } U_{sc} = \frac{q_L}{A}$$

$$U_{sc} = \frac{500 \times 5.614 \text{ ft}^3}{86400 \text{ sec}} = \frac{1.48 \text{ ft}^3/\text{s}}{0.02182}$$

$$U_{sg} = \frac{q_g}{A} = \frac{4}{\pi D^2} \left[\frac{q \times Z}{P_{sc}} \right] \times \left[\frac{P_{sc}}{P} \right]$$

to calculate flowrate of gas when GOR and flowrate of oil is given.

$$\text{GOR} = 1000 \text{ scf/bbl} = \frac{\text{ft}^3}{\text{bbl}} = 1000$$

$$\frac{\text{ft}^3}{\text{day}} = 1000$$

$$\frac{\text{bbl}}{\text{day}}$$

$$\frac{Ft^3}{day} \times \frac{day}{10^6} = 1000$$

$$\frac{Ft^3}{day} \times \frac{1}{\frac{10^6}{day}} = 1000$$

$$\frac{Ft^3}{day} \times \frac{1}{500} = 1000$$

$$\frac{Ft^3}{day} \times 0.002 = 1000$$

$$\frac{Ft^3}{day} = \frac{1000}{0.002} = \underline{\underline{500,000}} \text{ [Flowrate of gas]}$$

82 ft²

* Since Z was not given.

Use the Z -Factor Chart.

$$\frac{T}{T_{pc}} = \frac{580}{395} = 1.47, \quad \frac{P}{P_{pc}} = \frac{1000}{667} = \underline{\underline{1.5}}$$

From the Chart.

$$Z = \underline{\underline{0.85}}$$

Therefore.

$$U_{sg} = \frac{4}{\pi \times \left(\frac{7}{12}\right)^2 Ft^2} \times \left(\frac{500,000 \times 0.85}{86400} \right) \left(\frac{580}{520} \right) \left(\frac{14.7}{1000} \right)$$

$$U_{sg} = \frac{4}{0.08726} \times \left(\frac{425000}{86400} \right) \left(\frac{580}{520} \right) \left(\frac{14.7}{1000} \right)$$

$$U_{sg} = \frac{14,494,200,000}{3,920,417,280} = \underline{\underline{4.068}} \text{ ft/sec}$$

$$= \underline{\underline{3.697}} \text{ ft/sec}$$

$$U_m = U_{sc} + U_{sg} = 1.48 + 3.69 = 5.176 \text{ ft/s}$$

Step 3 \rightarrow To get the Baker Flow regime
to calculate density of oil & gas.

given that

$$\gamma_o (\text{s.g.}) = 32^\circ \text{API}$$

$$\gamma_g (\text{s.g.}) = 0.71$$

For oil (---)

$$\text{API} = \frac{141.5}{\text{s.g.}} - 131.5$$

$$32 = \frac{141.5}{\text{s.g.}} - 131.5$$

$$32 + 131.5 = \frac{141.5}{\text{s.g.}}$$

$$163.5 \times \text{s.g.} = 141.5$$

$$\text{s.g.} = \frac{141.5}{163.5} = \underline{\underline{0.865}}$$

$$\text{Therefore } \rho_o = 0.865 \times 62.4 = \underline{\underline{53.96 \text{ lbm/ft}^3}}$$

For Gas (---)

Use the formula: Given $\gamma_g = 0.71$

$$\rho_g = \frac{2.7 \times \gamma_g \times P}{Z \times T} = \frac{2.7 \times 0.71 \times 1000}{0.85 \times 580}$$

$$\rho_g = \underline{\underline{3.88 \text{ lbm/ft}^3}}$$

To get G_L and G_g :

$$G_L = U_{GL} P_L \quad \dots \textcircled{*}$$

$$G_g = U_{Gg} P_g \quad \dots \textcircled{*}$$

$$G_L = \left(\frac{1.487t}{s} \right) \left(\frac{53.96 \text{ km}}{ft^3} \right) \left(\frac{3600 \text{ sec}}{hr} \right)$$

$$G_L = \underline{\underline{287498.88 \text{ km/hr-ft}^2}}$$

$$G_g = \left(\frac{3.697t}{s} \right) \left(\frac{3.88 \text{ km}}{ft^3} \right) \left(\frac{3600 \text{ sec}}{hr} \right)$$

$$G_g = \underline{\underline{51,541.92 \text{ km/hr-ft}^2}}$$

To get λ and ϕ

$$\lambda = \left[\left(\frac{P_g}{0.075} \right) \left(\frac{P_L}{62.4} \right) \right]^{\frac{1}{2}} \quad \dots \textcircled{*}$$

$$\phi = \frac{73}{20} \left[\mu_1 \left(\frac{62.4}{P_L} \right)^2 \right]^{\frac{1}{3}} \quad \dots \textcircled{*}$$

$$\lambda = \left[\left(\frac{3.88}{0.075} \right) \left(\frac{53.96}{62.4} \right) \right]^{\frac{1}{2}}$$

$$\lambda = \sqrt{(44.7360)} = \underline{\underline{6.688}}$$

$$\phi = \frac{73}{20} \left[2 \left(\frac{62.4}{53.96} \right)^2 \right]^{\frac{1}{3}}$$

$$\phi = \frac{73}{20} (2.67457)^{\frac{1}{3}} = \underline{\underline{5.1}}$$

The coordinates for the baker map are

$$\frac{G_g}{\lambda} = \frac{51541.92}{6.688} = \underline{\underline{7706.63}}$$

$$\frac{G_c \lambda \phi}{G_g} = \frac{287498.88 \times 6.688 \times 51}{51541.92} = \underline{\underline{190.26}}$$

* Reading from the Baker map, the flow regime is predicted to be slug flow

* Reading from the Mandhane map using $U_{sc} = 1.487 \text{ ft/s}$, $U_{sg} = 3.67 \text{ ft/sec}$ is predicted to be slug flow.

* Reading from the Beggs and Brill map using the formulae

$$N_{FR} = \frac{U_m^2}{gD}, \quad \lambda_c = \frac{U_{sc}}{U_m}$$

$$N_{FR} = \frac{(5.176)^2}{32.17 \times \left(\frac{2}{12}\right)}$$

where g is constant 32.17 .

$$N_{FR} = \frac{26.79076}{5.3616} = \underline{\underline{4.99}}$$

$$\lambda_L = \frac{U_{sl}}{U_{ms}} = \frac{1.48}{5.176} = \underline{\underline{0.286}}$$

Beggs and Brill's map is predicted to be intermittent

Question TWO.

Given data

$$q_o = 4000 \text{ bbl/day}$$

$$q_g = ?$$

$$D = 3 \text{ inches}$$

$$\sigma = 20 \text{ dynes/cm}$$

$$\text{Temp} = 150^\circ\text{F} + 460 = 610^\circ\text{R}$$

$$\text{Pressure} = 200 \text{ psia}$$

$$\text{GOR} = 500 \text{ scf/bbl}$$

Step 1 → Calculate the Area.

$$\text{Using } A = \frac{\pi d^2}{4} = \frac{\pi \times (3/12)^2}{4} = \underline{\underline{0.049 \text{ ft}^2}}$$

Step 2 → Calculate U_{sl} , U_{sg} , U_m

$$U_{sl} = \frac{q_o}{A} = \frac{4000 \times 5.614 \text{ ft}^3}{86400 \text{ sec} \times 0.049} = \underline{\underline{5.30 \text{ ft/sec}}}$$

$$U_{sg} = \frac{q_g}{A} = \frac{4}{100} \left[\frac{9.2}{100} \right] \left[\frac{1}{100} \right] \left[\frac{100}{1} \right]$$

To calculate the gas flowrate.

$$GOR = 500 \text{ scf/bbl}$$

Ft^3

$$\frac{\text{day}}{\text{day}} = 500$$

$\frac{\text{bbl}}{\text{day}}$

$$\frac{Ft^3}{\text{day}} \times \frac{1}{\frac{\text{bbl}}{\text{day}}} = 500$$

$$\frac{Ft^3}{\text{day}} \times \frac{1}{4000} = 500$$

$$Ft^3/\text{day} \times 0.00025 = 500$$

$$\frac{Ft^3}{\text{day}} = \frac{500}{0.00025} = 2000,000$$

To get Z-Factor

$$\frac{T}{T_{pc}} = \frac{610}{395} = 1.54 \quad \frac{P}{P_{pc}} = \frac{200}{667} = 0.30$$

From the chart $Z = 0.96$

$$U_{sg} = \frac{4}{\pi d^2} \left[9.2 \left[\frac{T}{T_{sc}} \right] \left[\frac{P_{sc}}{P} \right] \right]$$

$$U_{sg} = \frac{4}{\pi \left(\frac{3}{12}\right)^2} \times \left[\frac{2 \times 10^6 \times 0.96}{86400} \right] \left[\frac{610}{520} \right] \left[\frac{14.7}{200} \right]$$

$$U_{sg} = \frac{68,866,560,000}{1,764,318,434.25603} = \underline{39.038 \text{ ft/sec}}$$

$$U_{tm} = U_{sg} + U_{sl} = 39.03 + 5.30 = \underline{44.33 \text{ ft/sec}}$$

So therefore, from the holdup constants table

$$a = 1.065, \quad b = 0.5824, \quad c = 0.0609.$$

$$Y_{Lo} = \frac{a \lambda_L^b}{N_{Re}^c} = \frac{1.065 \times (0.12)^{0.5824}}{(244.34)^{0.0609}}$$

$$Y_{Lo} = \frac{0.30978812}{1.39775} = \underline{\underline{0.22163}}$$

Step 4 \rightarrow Calculate the no-slip friction factor based on the mixture Reynolds number

$$\rho_m = \rho_L \lambda_L + \rho_g \lambda_g.$$

$$\lambda_L = 0.12, \quad \lambda_g = \frac{U_{sg}}{U_{tm}} = \frac{39.033}{44.33} = \underline{\underline{0.8805}}$$

$$\rho_L = 53.96 \text{ lbm/ft}^3$$

$$\rho_g = \frac{2.7 \times \rho_g \times P}{Z \times T} = \frac{2.7 \times 0.71 \times 200}{0.96 \times 610}$$

$$\rho_g = 0.654 \text{ lbm/ft}^3$$

$$\rho_m = 53.96 \times 0.12 + 0.654 \times 0.8805$$

$$\rho_m = 6.475 + 0.5758 = \underline{\underline{7.050847 \text{ (lbm/ft}^3)}}}$$

* Calculate Reynolds number using.

$$N_{Re} = \frac{164878}{2.21}$$

$$\mu_m = \mu_L \lambda_L + \mu_g \lambda_g$$

$$\mu_m = 2 \times 0.12 + 0.0131 \times 0.8805$$

$$\mu_m = 0.24 + 0.011534 = \underline{\underline{0.252}}$$

From Fig 10.6

$$F \left(\frac{m}{\text{min}} \right)^{0.1} = 0.02$$

$$F = 0.02 \left(\frac{14.03}{15.283} \right)^{0.1} = \underline{\underline{0.0201}}$$

$$\left(\frac{dP}{dx} \right) = \frac{F \rho_m U_m^2}{2g_c D} \quad \left[\text{Pressure gradient} \right]$$

$$= \frac{0.0201 \times 7.050 \times (44.33)^2}{2 \times 32.17 \times 0.25}$$

$$= \frac{17.0167 \text{ lbf/ft}^2}{144} \times \frac{17 \text{ ft}^2}{144 \text{ in}^2}$$

$$= \underline{\underline{0.12 \text{ psi/ft}}}$$

For Dukler Correlation.

Step 1 \rightarrow Assume $\gamma_L = \lambda$, $\rho = \rho_m$

$N_{Re} = N_{Re}$

$$\gamma_L = \lambda = 0.15$$

$$\rho_L = \rho_m =$$

$$\rho_L = \frac{\rho_L \lambda^2}{\gamma_L} + \frac{\rho_g \lambda_g^2}{\gamma_g}$$

$$\gamma_g = 1 - \gamma_L$$

Question 8

$$\frac{1}{f_n} = 1 - \frac{\ln(0.12)}{0.2665 + 1.9780} = 0.8959 + 0.16931$$

$$\frac{F}{f_n} = - \frac{2.12}{1.51836}$$

$$\frac{F}{f_n} = 1 - \left(\frac{2.12}{1.51836} \right)$$

$$F = - \frac{2.12 \times 0.00630}{1.51836}$$

$$\frac{F}{f_n} = \frac{1 + \frac{2.12}{1.51836}}{1}$$

$$\frac{F}{f_n} = \frac{1.51836 + 2.12}{1.51836}$$

$$1.51836 F = (1.51836 + 2.12) 0.00630$$

$$F = \underline{\underline{0.023}}$$

Pressure gradient

$$\left(\frac{dP}{dx} \right)_F = \frac{F \rho_K U_m^2}{2g_c D} = \frac{0.023 \times 5.77 \times 44.33}{2 \times 32.17 \times 0.25}$$

$$\left(\frac{dP}{dx} \right)_F = 16.2155 \underline{\underline{0.113 \text{ PSI/ft}}}$$

$$Y_L = 0.15$$

$$\lambda_g = \frac{U_{gs}}{U_{ms}} =$$

$$P_{15} = \frac{58.93 \times 0.12^2}{0.15} + \frac{0.654 \times 0.8805}{(1 - 0.15)}$$

$$P_{15} = 5.1773 + 0.5965 = \underline{5.77416 \text{ m}^2/\text{h}}$$

Next calculate NR_{ek} .

$$NR_{ek} = \frac{P_k U_m D}{\mu_m} = \frac{5.774 \times 44.33 \times 0.25}{0.0250}$$

$$NR_{ek} = \frac{NR_{em} U_m}{\mu_m}$$

$$46483.1437 \times \frac{44.33}{0.0250}$$

$$NR_{ek} = \underline{818213250.4088}$$

Next calculate F_n .

$$F_n = 0.0056 + 0.5(NR_{ek})^{-0.32}$$

$$= 0.0056 + 0.5(818213250.4088)^{-0.32}$$

$$F_n = \underline{0.00630}$$

$$\frac{F}{F_n} = \frac{\ln(\lambda_L)}{1.281 + 0.478 \ln(\lambda_L) + 0.44 [\ln(\lambda_L)]^2 + 0.094 \ln(\lambda_L)^3 + 0.00843 [\ln(\lambda_L)]^4}$$

$$N_{Rem} = \frac{\rho_m U_m D}{\mu_m} = \frac{7.05084 \times 44.33 \times \frac{3}{12}}{0.252 \times 6.72 \times 10^{-4}}$$

$$N_{Rem} = 461,433.14377$$

Then calculate for α , S , F_{EP}

$$\alpha = \frac{\lambda_L}{\gamma_{L0}^2} = \frac{0.12}{(0.221)^2} = \underline{\underline{2.5}}$$

$$S = \ln(\alpha)$$

$$\sqrt{-0.0523 + 3.182 \ln(\alpha) - 0.8725 [\ln(\alpha)]^2 + 0.01853 [\ln(\alpha)]^4}$$

$$S = 0.92$$

$$[-0.0523 + 3.182(0.92) - 0.8725(0.92)^2 + 0.01853(0.92)^4]$$

$$S = 0.4279$$

$$F_{EP} = \mu_m e^S = 0.006 \times e^{0.4279} = \underline{\underline{0.009176}}$$

Step 5 \rightarrow calculate $(\frac{dp}{dz})_z$

$$\frac{dp}{dz} = \frac{2 F_{EP} \rho_m U_m^2}{g_c D}$$

$$\frac{dp}{dz} = \frac{2 \times 0.009176 \times 7.05084 \times (44.33)^2}{32.17 \times (\frac{3}{12})}$$

$$\frac{dp}{dz} = 32.0116 \text{ ft}^3 = \frac{32.0116}{\text{ft}^3} \times \frac{1 \text{ ft}^3}{144 \text{ in}^2} =$$

$$\frac{dp}{dz} = 0.22982 \text{ ft}$$

To get Beggs Brill Reading, Use the Formula

$$NFR = \frac{U_m^2}{g \cdot D}, \quad \lambda_1 = \frac{U_{sc}}{U_m}$$

$$NFR = \frac{(44.33)^2}{32.17 \times (\frac{3}{12})} = \frac{1965.1489}{8.0425} = 244.34$$

$$\lambda_1 = \frac{U_{sc}}{U_m} = \frac{5.20}{44.33} = 0.12$$

Therefore the Reading is

~~to report~~

Step 3 → Calculate the holdup for horizontal flow. Using the Formula
Recall that.

$$\text{Segr } L_1 = 316 \lambda_1^{0.302}$$

$$L_2 = 0.0009252 \lambda_1^{-2.4684}$$

$$L_3 = 0.10 \lambda_1^{-1.4516}$$

$$L_4 = 0.5 \lambda_1^{-6.738}$$

$$L_1 = 316 (0.12)^{0.302} = 166.57$$

$$L_2 = 0.0009252 \times (0.12)^{-2.4684} = 0.17345$$

$$L_3 = 0.10 \times (0.12)^{-1.4516} = 2.171$$

$$L_4 = 0.5 \times (0.12)^{-6.738} = 800,657.48$$

The flow regime transition is Segr
distributed flow because

$$\lambda_1 < 0.4 \text{ and } NFR \geq L_1$$

Question One.

* Horizontal multi-Phase Flow Regimes

Multiphase flow in horizontal pipes different from that in vertical pipes.

Due to the Potential Energy constant in horizontal flow, the flow regime has no significant effect and pressure drop on horizontal flow. However certain correlations

Consider flow regime -

Flow regime can be classified into Segregated flow (two phases are for the most part separate). Intermittent flow (gas & liquid are alternating). Distributed flow in which one phase is dispersed in the other phase.

Segregated is further divided into stratified smooth, stratified wavy (ripple flow) or annular, stratified smoother flow consists of liquid flow along the bottom of the gas.

* Intermittent is divided into Slug: High liquid slugs and high velocity gas bubbles plug.

* Distributed flow bubble, most dispersed bubble flow

* Flow regime are predicted.

Fig - Baker (1953) modified to Scott (1961) [Page and 670]

Mandhane et al (1979)

Beggs and Brill's Correlation.

Froude number against liquid fraction - Taitel and Dukler (1976): A theoretical model used to generate flow regime maps for particular fluid & pipe size.

(4) Restricted Flow refers to flow of fluid under a choke used to control flow due to many factors such as prevention of the causes of sand production.

Fluid flowing through a restriction may be accelerated to reach some velocity in the throat of the choke. This is the critical condition. As downstream pressure of choke do affect the flow rate.

For single phase liquid flow through choke. It is rare for this case, the flowing pressure is below bubble point.

But in case it happens.

Flow rate is related to pressure drop across choke by

$$q = CA \sqrt{2g_c \Delta P}$$

C = Co-efficient of the choke

$$A = C \cdot d, \quad q = 22000 C (d_c)^2 \sqrt{\frac{\Delta P}{\rho}}$$

d_c in choke is diameter in inches.

Question 4

297.6032

Choke Performance Curves ^{188.706}

Assume GLR to be 500scf/661

Choke sizes 8/64, 12/64, 16/64

$$\text{Using } P_L = \frac{A q_L (GLR)^B}{D_{64}^C}$$

$$A = 10, B = 0.546, C = 1.89$$

Using the Gilbert Correlation.

$$P_L = \frac{A q_L (GLR)^B}{D_{64}^C}$$

For 8/64 Choke size.

$$P_L = \frac{10 \times q_L (500)^{0.546}}{(8)^{1.89}} = \frac{297.6032 q_L}{50.914}$$

$$P_L = 5.849 q_L$$

For 16/64 Choke size.

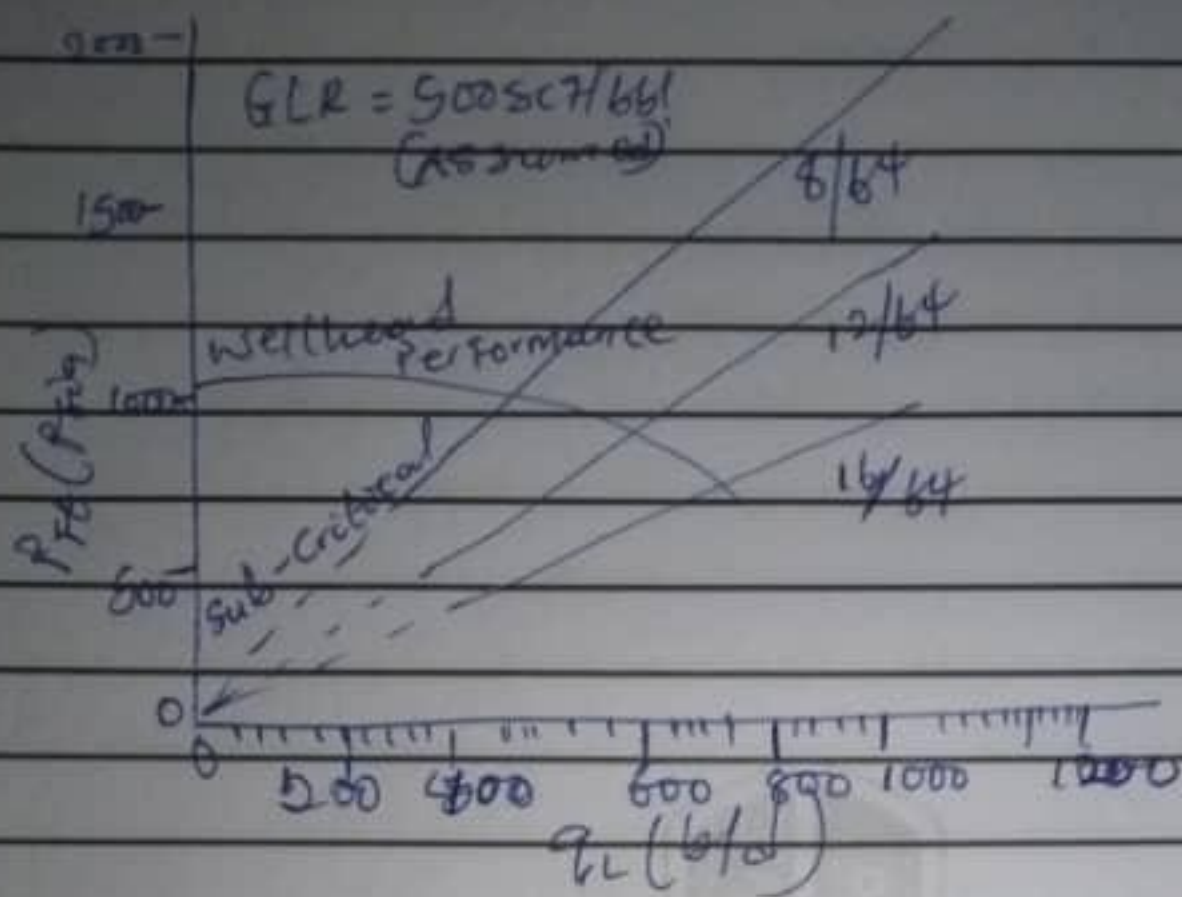
$$P_L = \frac{10 \times q_L \times (500)^{0.546}}{(16)^{1.89}} = \frac{297.6032 q_L}{188.706}$$

$$P_L = 1.577 q_L$$

For 12/64 Choke size

$$P_L = \frac{10 \times q_L \times (500)^{0.546}}{(12)^{1.89}} = \frac{297.6032 q_L}{109.56}$$

$$P_L = 2.7163 q_L$$



For calculate flowrate.

For 8/64.

$$P_i = 4350 \text{ psi}$$

$$P_L = 5.84 q_L$$

$$\frac{(4350 - 14.7) = q_L}{5.84}$$

$$q_L = 742.34$$

$$P_2 = 3000 \text{ psi}$$

$$\frac{(3000 - 14.7) = q_L}{5.84}$$

$$= 511.181$$

$$P_3 = 2000 \text{ psi}$$

$$\frac{(2000 - 14.7) = q_L}{5.84}$$

$$= 339.94$$

$$P_4 = 1000 \text{ psi}$$

$$\frac{1000 - 14.7 = q_L}{5.84}$$

$$q_L = 168.71$$

For 12/64

$$P_i = 4350 \text{ psi}$$

$$P_L = 2.7163 q_L$$

$$\frac{4350 - 14.7 = q_L}{2.7163}$$

$$q_L = 1596.03$$

$$P_2 = 3000$$

$$\frac{3000 - 14.7 = q_L}{2.7163}$$

$$q_L = 1099.03$$

$$P_3 = 2000$$

$$\frac{2000 - 14.7 = q_L}{2.7163}$$

$$q_L = 730.88$$

$$P_4 = 1000$$

$$\frac{1000 - 14.7 = q_L}{2.7163}$$

$$q_L = 362.74$$

For 14/64

$$P_i = 4350$$

$$P_L = 1.577 q_L$$

$$\frac{4350 - 14.7 = q_L}{1.577}$$

$$q_L = 2749.08$$

$$P_2 = 3000$$

$$\frac{3000 - 14.7 = q_L}{1.577}$$

$$q_L = 1893$$

$$P_3 = 2000$$

$$\frac{2000 - 14.7 = q_L}{1.577}$$

$$q_L = 1258.90$$

$$P_4 = 1000$$

$$\frac{1000 - 14.7 = q_L}{1.577}$$

$$q_L = 624.8$$