The University of Calgary
Department of Chemical & Petroleum Engineering

ENCH 501: Transport Processes Quiz #6 **November 18, 2003**

Time Allowed: 40 mins. **Name:**

Mud or a suspension of bentonite in water (plus additives) is used in drilling for bringing "cuttings" of soil and rock produced by drill bits to the surface, to stabilize the hole, and to prevent blowouts when a pocket in a formation containing petroleum fluids under high pressure is breached. It is because of the function of regulation of pressure that the use of mud is termed "over-balanced" drilling. At the bottom of the well, the pressure (P_2) is determined, in part, by the pressure applied at the surface (P_1) to push the mud through the "string" of pipes and the hydrostatic pressure of the column of mud. The latter can be adjusted by changing the composition of the mud and thereby its density.

For a well drilled to a depth of 1 km, you are required to estimate the minimum gauge pressure (P_1) required to maintain the flow of mud through both the pipe and the annular space between the pipe and the casing which lines the well. Assume the fluid is Newtonian. The pipe is 6-inch schedule 80 steel and the inside diameter of the casing is 9.6 inches. (1 inch = 2.54 cm.) The density (ρ) of the mud is 1350 kg/m^3 and the effective viscosity (μ) is 520 mPa s. The mud flow is steady and the discharge from the well is into the atmosphere (P_3). The flow rate of mud through the pipe is 166 m^3 per hour. At the bottom of the well, reservoir liquids leak into and mix with the mud at a rate of 32 m^3 per hour. The properties of the mud is changed by the dilution. The density decreased to 1278 kg/m^3 and the viscosity becomes 380 mPa s. Perform the evaluation, explaining all important steps and check your assumptions.

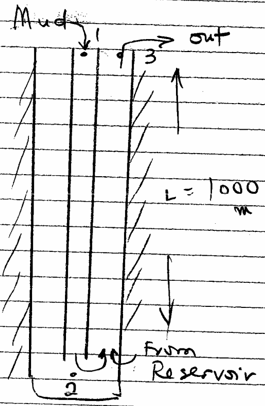
(Table of data on standard steel pipes attached.)

DIMENSIONS, CAPACITIES, AND WEIGHTS OF STANDARD STEEL PIPE

Nominal pipe size, in.	Outside diameter, in.	Schedule no.	Wall thickness, in.	Inside diameter, in.	Cross-sectional area of metal, in.^{2}	Inside sectional area, ft^2	Circumference, ft or surface, ft^2/ft of length		Capacity at 1 ft/s velocity		Pipe weight lb/ft
							Outside	Inside	U.S. gal/min	Water, lb/h	
2	2.375	40	0.154	2.067	1.075	0.02330	0.622	0.541	10.45	5,225	3.65
		80	0.218	1.939	1.477	0.02050	0.622	0.508	9.20	4,600	5.02
2½	2.875	40	0.203	2,469	1.704	0.03322	0.753	0.647	14.92	7,460	5.79
		80	0.276	2.323	2.254	0.02942	0.753	0.608	13.20	6,600	7.66
3	3.500	40	0.216	3.068	2.228	0.05130	0.916	0.803	23.00	11,500	7.58
		80	0.300	2.900	3.016	0.04587	0.916	0.759	20.55	10,275	10.25
3½	4.000	40	0.226	3.548	2.680	0.06870	1.047	0.929	30.80	15,400	9.11
		80	0.318	3.364	3.678	0.06170	1.047	0.881	27.70	13,850	12.51
4	4.500	40	0.237	4.026	3.17	0.08840	1.178	1.054	39.6	19,800	10.79
		80	0.337	3.826	4.41	0.07986	1.178	1.002	35.8	17,900	14.98
5	5.563	40	0.258	5.047	4.30	0.1390	1.456	1.321	62.3	31,150	14.62
		80	0.375	4.813	6.11	0.1263	1.456	1.260	57.7	28,850	20.78
6	6.625	40	0.280	6.065	5.58	0.2006	1.734	1.588	90.0	45,000	18.97
		80	0.432	5.761	8.40	0.1810	1.734	1.508	81.1	40,550	28.57
8	8.625	40	0.322	7.981	8.396	0.3474	2.258	2.089	155.7	77,850	28.55
		80	0.500	7.625	12.76	0.3171	2.258	1.996	142.3	71,150	43.39
10	10.75	40	0.365	10.020	11.91	0.5475	2.814	2.620	246.0	123,000	40.48
		80	0.594	9.562	18.95	0.4987	2.814	2.503	223.4	111,700	64.40
12	12.75	40	0.406	11.938	15.74	0.7773	3.338	3.13	349.0	174,500	53.56
		80	0.688	11.374	26.07	0.7056	3.338	2.98	316.7	158,350	88.57

† Based on ANSI B36.10-1959 by permission of ASME.

ENCH 501 Solution Quiz 6 Nov. 18, 2003



Locate 3 points —

1 at inlet of mud
2 bottom of well
3 exit

Pipe — 6" sch. 80 ⇒

i.d. = 5.761" or 14.633 cm

wall thickness = 0.432"

☑ Inside the pipe

$Q = 166\ m^3/hr$ or $0.04611\ m^3/s$

The area of pipe (inside)

$$= \frac{\pi D^2}{4} = \frac{\pi (0.14633)^2}{4} = 0.01682\ m^2$$

$$\therefore \bar{u} = \frac{Q}{A} = 2.7419\ m/s$$

Assume flow is laminar ~~(and fluid Newtonian)~~

$$Re = \frac{D\bar{u}\rho}{\mu} = \frac{(0.14633)(2.7419)(1350)}{0.52}$$

$$= 1041.6 \quad \therefore \text{Flow is laminar.}$$

In this case, the Hagen-Poiseuille eq. is valid if one neglects flow effects ~~at the~~ ends ~~of the~~ pipe.

That is $Q = \dfrac{\pi X_i R_i^4}{8\mu L}$ where $X_i = P_1 - P_2 + \rho g L$

(Note that $\rho g L$ is added because $\sin\beta$ (in Notes) $= \sin(-\frac{\pi}{2})$ or -1.)

substitute numbers in the Hagen - Poiseuille eq.

$$\tau_i = \frac{Q \cdot 8\mu L}{\pi R_i^4} = \frac{61.050954}{\left(\frac{0.14633}{2}\right)^4} = 2{,}130{,}487.3 \text{ Pa}$$

$$\therefore \quad P_1 - P_2 = \tau_i - L\rho g = -11{,}113{,}012.7 \text{ Pa}$$

(i.e. $P_2 = P_1 + 109.68$ atm)

☑ The annular space

from Notes, eq. 6.38 and 6.39, p. 144

$$Q_o = \pi R_o^2 (1-K^2) \frac{\tau_o R_o^2}{8\mu L}\left[\frac{1-K^4}{1-K^2} - \frac{1-K^2}{\ln(1/K)}\right]$$

where $K = \frac{5.761'' + 2(0.432'')}{9.6''} = 0.6901$

But $Q_o = 166 + 32 = 198 \text{ m}^3/\text{hr}$ or $0.055 \text{ m}^3/\text{s}$

Substitute

$$0.055 = \pi (1-K^2) \frac{\tau_o R_o^4}{8\mu L} f(K) \quad ; \quad f(K) = 0.064161$$

where

$$\tau_o = P_2 - P_3 - \rho g L \qquad (P_3 = 0 \text{ gauge})$$

using $\rho = 1278 \text{ kg/m}^3$ and $\mu = 380$ mPa.s

$$\tau_o = \frac{0.055 \cdot 8\mu L}{\pi (1-K^2) f(K) R^4} = P_2 - \rho g L$$

$$R_o = 9.6''/2 = 4.8'' \text{ or } 12.192 \text{ cm}$$

$\therefore \quad P_2 = 7,167,727.4 + 1278(9.81)(1000)$

$= 19,704,907.4 \text{ Pa}$

$(P_2 = 194.47 \text{ atm.})$

substitute for P_2 in above eq.

$194.47 = P_1 + 109.68 \text{ atm}$

$\therefore \quad P_1 = 84.79 \text{ atm}$

Injection pressure ⟶