Lecture #4 PeE 3321

Hydrostatic pressures in the wellbore and the subsurface

Covered in Lecture 3

Concepts

- Difference between fluid pressure and density
- Know the difference between pressure and stress
- Understand the concept of equivalent density

Calculations

- Volumes in the wellbore and displacements (Cont'd)
- The hydrostatic pressure in a liquid filled wellbore
- Pressures in mixed density columns
- Hydrostatic pressure in a deviated and horizontal well

OUTLINE

- Volumes in the wellbore and displacements
- Pressure and stress
- Hydrostatic pressure in a liquid filled wellbore
- Fluid pressure and density
- Mixed density columns
- Equivalent density
- Hydrostatic pressure in deviated and horizontal wells

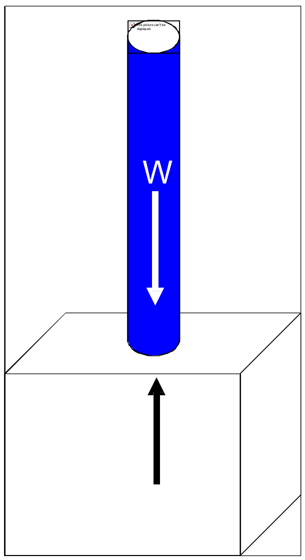
Volumes Calculations Example # 4

- Example : a) Calculate number of barrels of drilling fluid in a 5000 ft open well bore with diameter of 8 ½". When a 7x6 inch (OD-ID) casing is run in the hole how many bbl will it displace?

$$\text{OH Vol.} = \frac{8.5^2}{1029.4} \times 5000 = 351 \text{ bbls}$$

$$\text{CSG will displace} = \frac{7^2 - 6^2}{1029.4} \times 5000 = 63.14 \text{ bbls}$$

Definition of pressure and stress



Pressure is the weight of the column of fluid above a unit area.

For example, the fluid pressure at a bottom of a well is the weight of the column of drilling mud

Pressure = Force per Unit Area

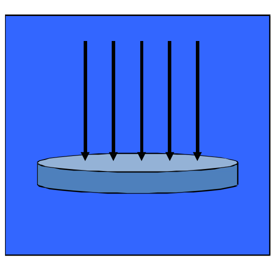
P = (Weight of column)/(Area)

*F=pA (Force = pressure *Area)*

Fluid Statics

Basic Principles:

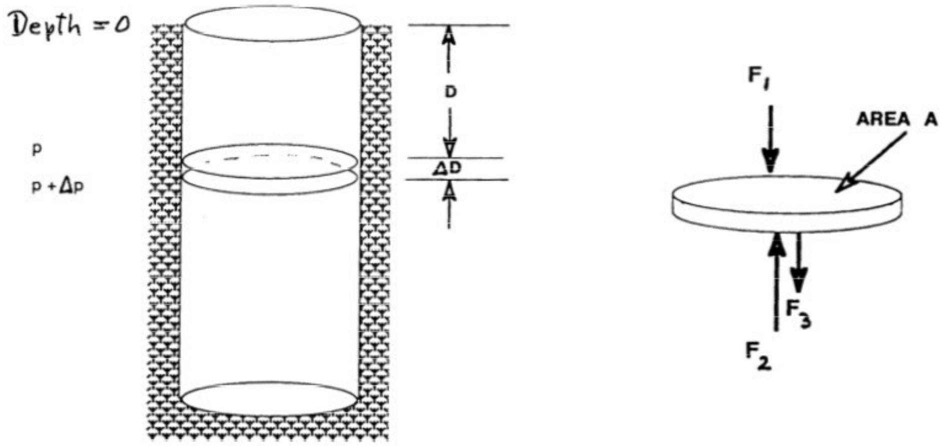
- When fluid is at rest pressure is the only force acting



What are the forces acting on the block?

- Air pressure on the surface - neglect
- Weight of the water above the block
- **<u>Pressure only a function of depth</u>**

Forces Acting on a Fluid Element



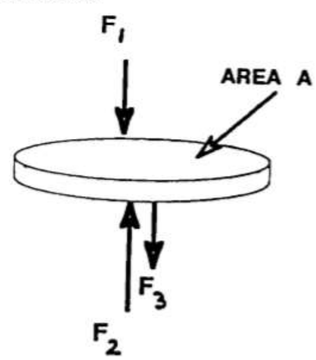
Free-body diagram for the vertical forces acting on an element of fluid at depth D in a hole of cross-sectional area A.

Forces Acting on a Fluid Element

$F_1 = pA$

$F_2 = pA + \frac{dp}{dD}\Delta DA$

$F_3 = F_{wv} A \Delta D$

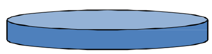


Where:
F_1 = The downward force on the fluid element exerted by the fluid above
F_2 = The upward force on the element exerted by the fluid below
F_3 = The weight of the fluid element
F_{WV} = Weight of the fluid

Pressures in a fluid column

- Since the fluid is at rest, no shear forces exist and the three forces must be in equilibrium

$$\Sigma F = 0$$



$$0 = F_1 + F_2 + F_3$$

$$\sum F = 0 = pA - pA + \frac{dp}{dD}\Delta D A + F_{wv} A \Delta D$$

$$\therefore dp = F_{wv} dD$$

Incompressible Fluids

When dealing with liquids such as drilling mud, fluid compressibility can be neglected

$$dp = F_{wv} dD$$

Integrating, $$p = F_{wv} D + p_0$$

Where p_0, the constant of integration, is equal to the surface pressure, i.e. when D = 0

$$[\, p = p_0 \text{ when } D = 0 \,]$$

$$p = F_{wv} D$$

Where:
F_{WV} = the specific weight in psi/ft

Calculating density

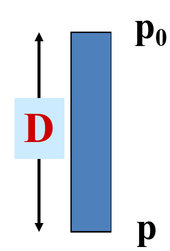
$$p = F_{wv} D$$

- P = pressure measured in pounds per square inch = lb/in^2 = psi
- D = Depth in feet
- F_{wv} Weight in psi/ft
- psi/ft = lb/(in^2 * ft)

Incompressible fluids

Since, $F_{wv} = 0.052\, q$ **(in field units)**

$$\therefore \quad p = 0.052 \rho D + p_0$$



If $p_0 = 0$ (The case except during well control or cementing procedures)
then,

$$p = 0.052\, \rho\, D \qquad \{\text{psig, lbm/gal, ft}\}$$

$$\rho = \frac{p}{0.052\, D}$$

Drilling field units

$$F_{wv} = \frac{lb/in^2}{ft} = \frac{lb}{in^2 * ft}$$

$$= \frac{lb}{in^2 * ft} * \frac{1\,ft}{12in}$$

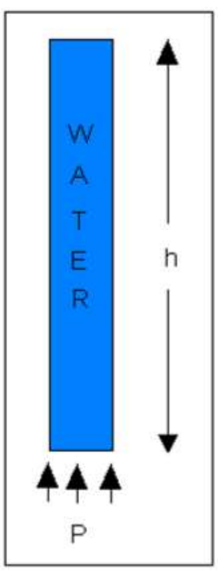
$$1gal = 231in^3$$

$$= \frac{lb}{12in^3 \frac{1gal}{231in^3}}$$

$$7.48\ gal = 1ft^3$$

$$= 0.052 lb/gal$$

What is the pressure at 10,000 ft?

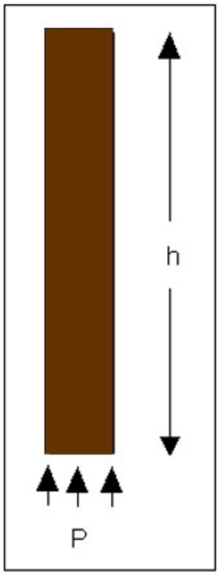


1 10,000 ft depth, density 8.34 lb/gal
Sol:

2 10,000 ft well, density 0.4337 psi/ft
Sol:

3 10,000 ft well, mudweight 62.38 lb/ft^3
Sol:

What is the pressure at the bottom of a 10,000 ft well with mud density of?



1. 10,000 ft well, mudweight 12 lb/gal

   = psi

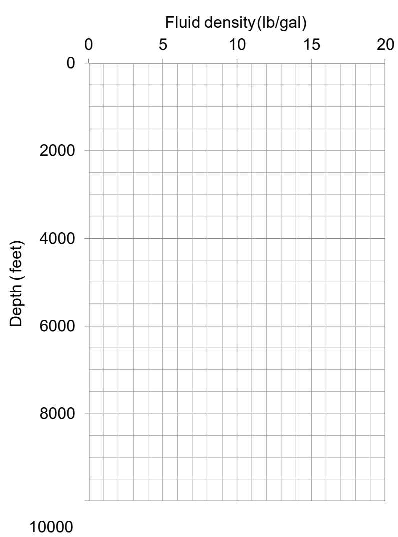
2. 10,000 ft well, mudweight 0.624 psi/ft

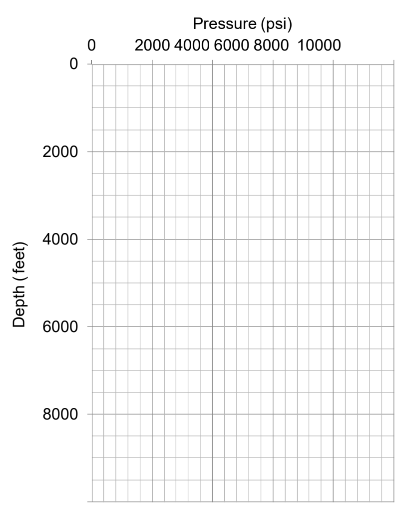
   = psi

3. 10,000 ft well, mudweight 89.85 lb/ft^3

   = psi

Fluid pressure and equivalent density plot





Example: In the density plot water at 8.33 lb/gal and a drilling fluid of 12 lb gal for each 1000 ft.
Plot the drilling fluid pressure in the pressure plot.

Calculate pressure in mixed column

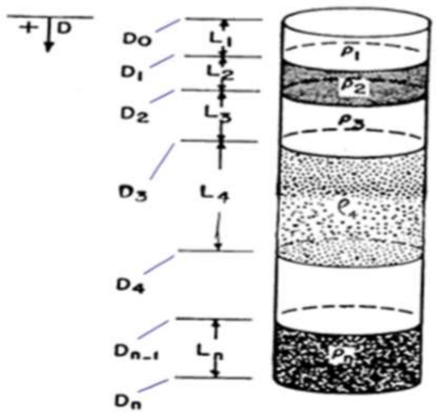


Fig. 4-3. A Complex Liquid Column

$$p = 0.052\rho\ D + p_0$$

$$\Delta p = 0.052\rho\ \Delta D$$

$$p = p_0 + 0.052\sum_{i=1}^{n}\rho_i(D_i - D_{i-1})$$

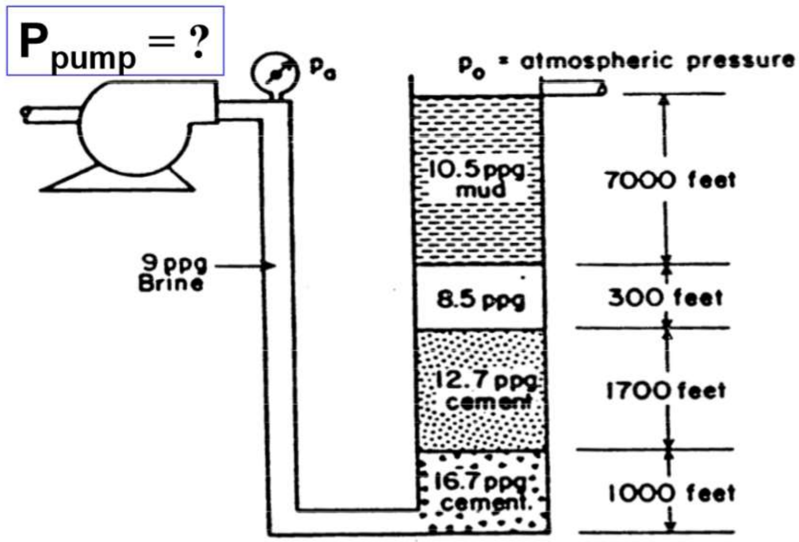
Example # 1 Mixed density Column

- An intermediate casing is to be cemented at 10,000 ft. The well contains 10.5 ppg when the casing is placed on bottom. The cementing operation is designed so that the 10.5 ppg will be displaced by:
  (1) 300 ft of 8.5 ppg mud flush,
  (2) 1700 ft of 12.7 ppg filler cement ,and
  (3) 1000 ft of 16.7 ppg high strength cement.

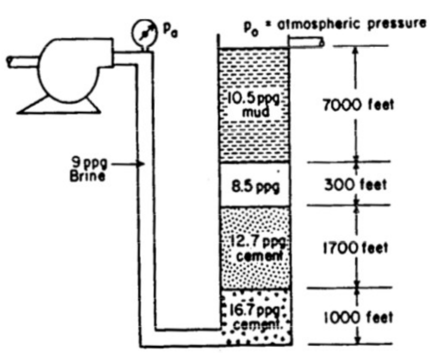
The high strength cement will be displaced from the casing with 9 ppg brine.

Calculate the pump pressure required to completely displace the cement from the casing

Viewing the Well as a U-Tube



$$p_{pump} = p_0 + 0.052\{10.5(7,000) + 8.5(300) + 12.7(1,700) + 16.7(1,000) - 9.0(10,000)\}$$

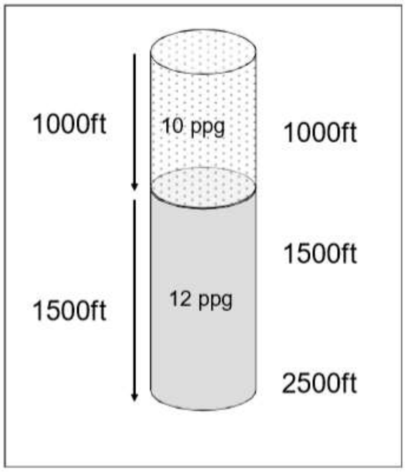


$$p_0 = 0 \text{ psi}$$

$$\therefore\ p_{pump} = 1,266 \text{ psi}$$

Equivalent Density

Density in a wellbore with multiple density column



Equivalent density always refers to a specific depth

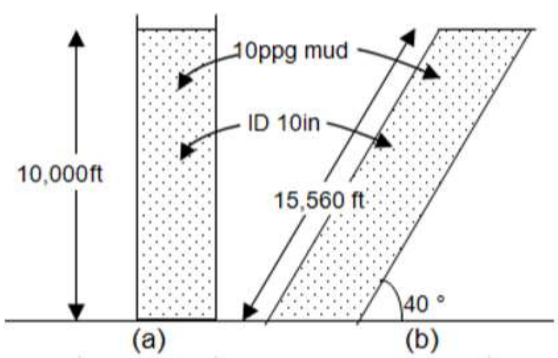
$$\rho_e = \frac{p}{D \times 0.052}$$

$$\rho_{e-1000} = \frac{520}{1000 \times 0.052} = 10\,ppg$$

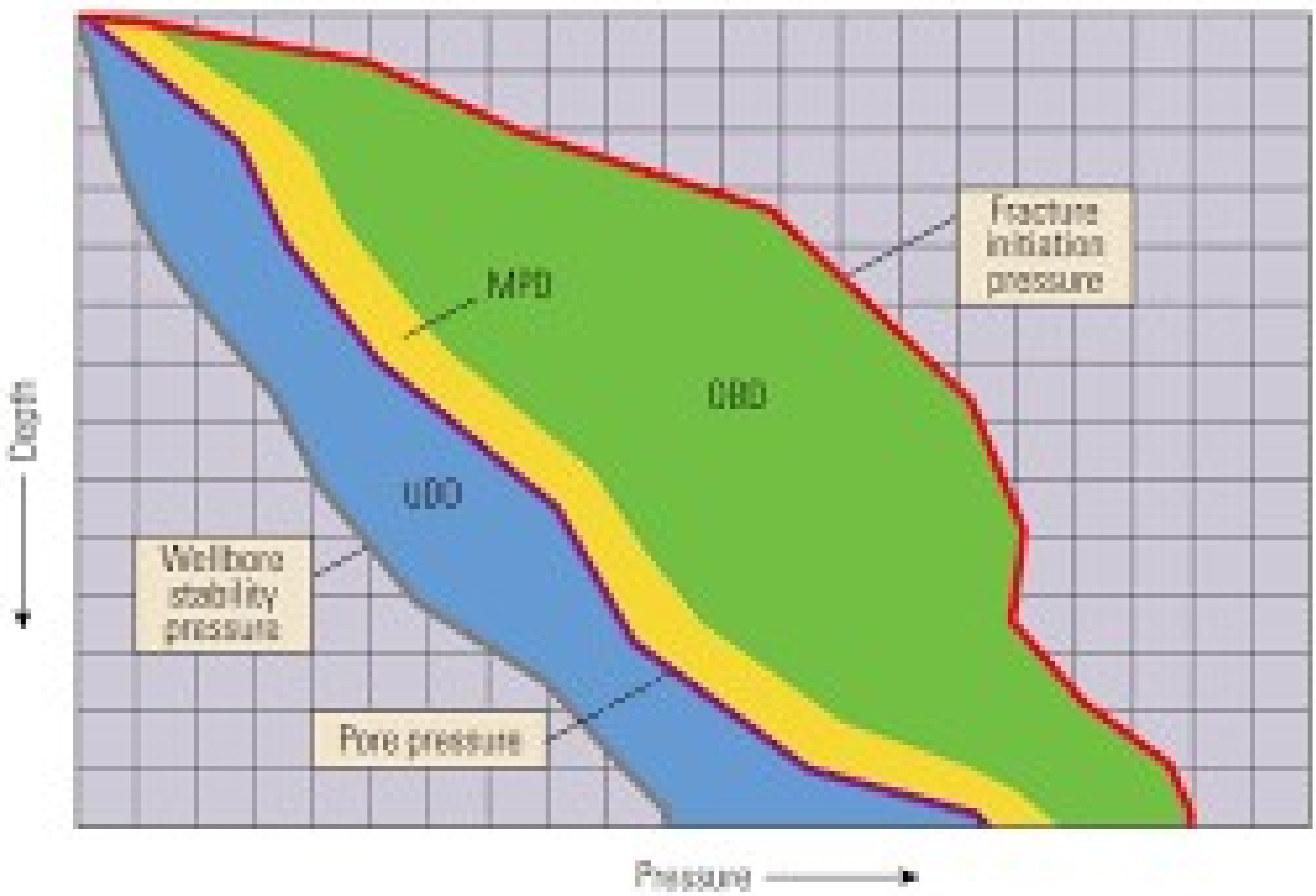
$$\rho_{e-1500} = \frac{832}{1500 \times 0.052} = 10.7\,ppg$$

$$\rho_{e-2500} = \frac{1456}{2500 \times 0.052} = 11.2\,ppg$$

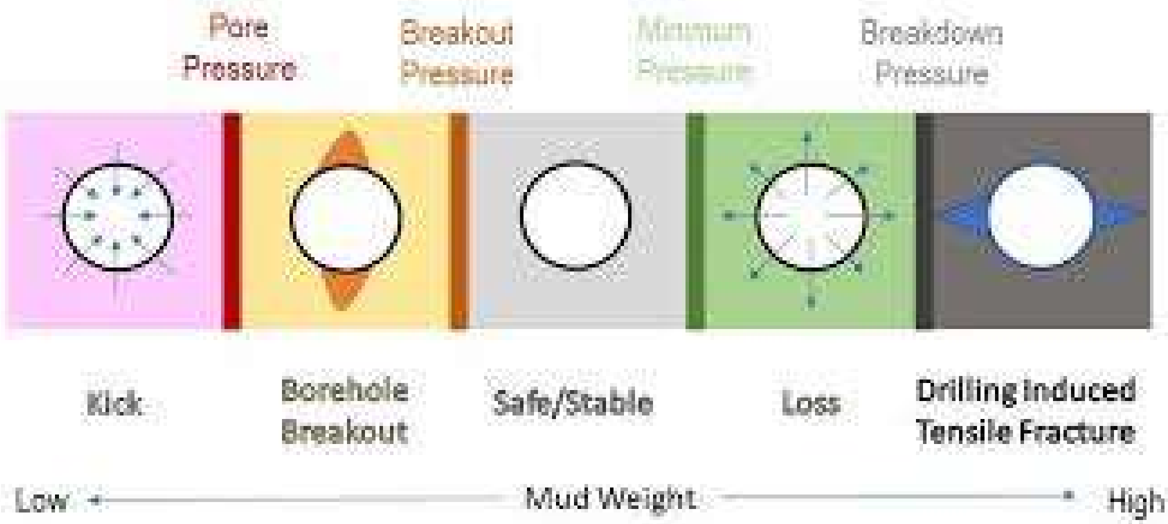
Hydrostatic pressure in deviated wells



Overbalanced drilling, Managed Pressure Drilling, and Underbalanced Drilling



Mud weight and Drilling Problems

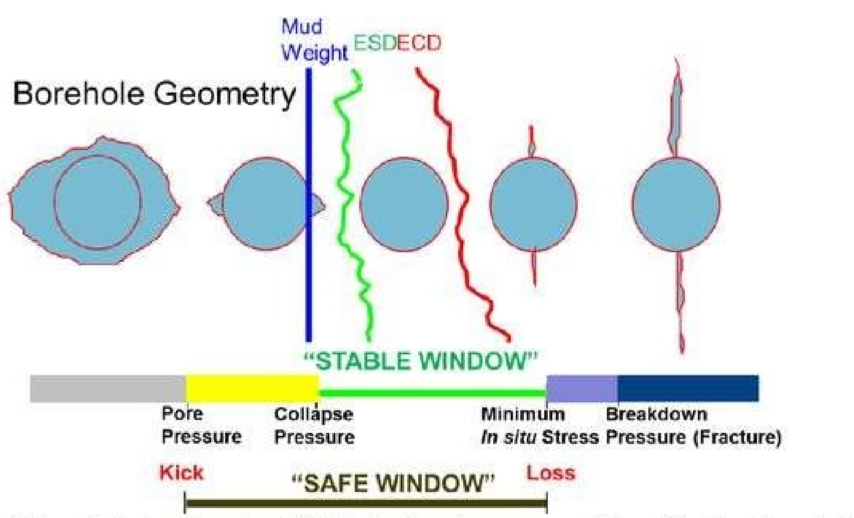


Importance of Geomechanics

Factors determining wellbore stability

- Pore pressure
- **Mud Weight and casing policy***
- Stress magnitudes
- Stress Anisotropy direction
- Rock Mechanical Properties
- **Wellbore trajectory***

*Factor under human control



It is important to keep the mud weight **higher** than the collapse pressure but **lower** than the minimum *in situ* stress to maintain hole stability.