Pressure Basics and Concepts
Learning Objectives

You will be familiarized with the following basic pressure concepts:

- Defining pressure
- Hydrostatic pressure
- Pressure gradient
- Bottomhole pressure
- Formation pressure
- Normal, abnormal, subnormal pressure
- Differential pressure

You will also learn and should be able to describe pressure losses throughout the circulating system will be able to calculate ECD.
Pressure Basics/Concepts

Overview

- A **fluid** is something that flows.
- Fluids have weight and exert a downward force.
- **Pressure** is the amount of force exerted on a specific area.
Overview

- Pressures that are dealt with day after day in the oil industry include: fluid, formation, friction, and mechanical pressure.
- It is important to get a tight grasp on these pressures and their relationships in order to understand well control.
- Don’t forget about human pressures!
Pressure Basics/Concepts

Overview

- If fluid force in wellbore is less than formation pressure, formation fluids may enter the wellbore.
- **Production** – wanted flow of hydrocarbon into the wellbore.
- **Kick** – unwanted formation flow of gas or fluids into the wellbore.
- A kick, if uncontrolled can turn into a blowout.
Pressure Basics/Concepts
Formations are sedimentary.

Spaces between rocks during this process are called pores, or pore spaces.

Deposits of more layers produce an overburden on both rock and pore spaces.

Compaction may occur.

This produces formation pressure.

If formation fluid can escape back to surface, normal pressure exists.
Geology – Pressure Origins
Geology – Pressure Origins
Geological Data

- Certain geological conditions may cause higher than normal formation pressures.
  - **Faults** - a shifting of formations, up or down may trap fluids and create higher or lower pressures than normal.
  - **Anticlines** – geological formations that are domed upward that may pierce shallower formations or create a bending upwards of deeper formations to shallower depths.
  - **Salts** – exhibit plastic flow ability under the pressure of the overburden, not allowing pore fluids to flow through it. As a result, formations under a salt layer are usually overpressured.
**Geology – Pressure Origins**

- **Shales** – Overpressured shales have had their normal depositional burial stopped and the water trapped by some cataclysmic event. It locks the water in place. With continued burial the result is under compaction and overpressure as the overburden weight is shifted onto water in the pore space.

- **Charged Zones** – usually shallow sands and formations that exhibit abnormal pressure. These zones can be man-made or naturally existing due to upward migration of fluids from a deeper zone.

- **Depleted Zones** – these zones are subnormal. Severe lost circulation may occur in these zones. If the fluid level decreases, hydrostatic pressure will all decrease, allowing another zone, or the depleted zone, to flow.
Geology – Pressure Origins

Salt Dome
Geology – Pressure Origins
Geology – Pressure Origins

Sand and Shale (normal pressure)

Massive Shale (impermeable zone)
Predicting Formation Pressure

- Three sources of data can assist in predicting well pressures:
  - Historical data
  - Seismic interpretations
  - Geological data
Historical Data

- Historical data from other wells in the area can provide indications of potential problems.
- Mud records and drilling reports can give a good sign of the drilling conditions.
- Pep log.
Seismic Interpretations

- Seismology involves creating sound waves that penetrate the subsurface rock layers.
  - When the sound waves are reflected back from each formation, they are recorded by instruments that measure their strength.
  - From these results, geologists are able to define the shape of subsurface formations.
- Exploration and drilling programs can use the data for predicting pressured zones.
Understanding Pressure

♦ Pressure – applied force on an area.

**Pressure = Force x Area**

- Typically, we use **Pounds per Square Inch**, or PSI to define pressure.

♦ Fluids exert pressure as a result of the density of the fluid and height of the fluid column.
Understanding Pressure

- Almost anything can change into a fluid if enough pressure or temperature is exerted on it.

- **Pressure Gradient** – the force exerted by a fluid column one foot in height on one square inch of area.

- **Hydrostatic Pressure** – the pressure exerted at the bottom (or specified depth) of a column of fluid.
Since density is measured in pounds per gallon (ppg), a “density conversion factor” is required to make it compatible with the pounds per square inch per foot (ft) measurement that pressure gradient requires.

The density conversion factor is used commonly in everyday oilfield pressure related calculations.

Density Conversion Factor = 0.052
Pressure Gradient

- **Pressure gradient** is the amount of pressure increase per unit of depth in feet or meters.
- Gradient is measured in psi/foot with each foot of TVD (true vertical depth).
- To calculate the pressure gradient of a fluid, multiply the density of the fluid (ppg) by 0.052 (conversion factor).

\[
\text{Pressure Gradient}_{\text{psi/ft}} = \text{Fluid Density}_{\text{ppg}} \times 0.052
\]
Hydrostatic Pressure and TVD vs. MD

- **Hydrostatic pressure** is the total pressure applied by the fluid’s weight and height of the static column of fluid.
- With the knowledge to calculate pressure gradient, we are now able to calculate the “hydrostatic pressure” at a given depth simply by multiplying the pressure gradient by the total number of feet to that vertical depth.
- However, you must first learn the distinction between measured depth (MD) and true vertical depth (TVD).
Hydrostatic Pressure and TVD vs. MD
True vertical depth (TVD) measures the total vertical depth of a well according to the path of gravity, which pulls straight down (as opposed to the actual curved path that a well may have). Always use true vertical depth in calculations dealing with pressure.

Measured depth (MD) is the total depth according to the actual path of the well.

To calculate hydrostatic pressure:

\[
\text{Hydrostatic Pressure} = \text{Pressure Gradient} \times \text{Depth}^{\text{TVD}}
\]
Hydrostatic Pressure and TVD vs. MD
A normal graduated arm and beam balance is the conventional way to measure density.

- However, sometimes the mud or cement being measured contains trapped air and the pressurized balance should be used for accurate measurement.
  - A pressurized mud balance should be used whenever the fluid contains gas or air.
It can be helpful to visualize the well as a U-tube, with one column of the tube being the annulus or wellbore and the other column representing the string in the well.

- Fluids create hydrostatic pressures in the U-tube.
- **U-tubing** is the tendency of liquids to find a balance point of pressure.
- The bottom of the U-tube can only be one value.
Formation Pressure

- **Formation pressure** is the amount of pressure within the pores of a formation rock. It fluctuates depending on the weight of the rock layers above it, which exert pressures on both the grains and pore fluids.

- **Grains** are solid portion.

- **Pores** are spaces in rocks.

- **Compaction** is the process in which pore fluids are able to escape, causing the grains to lose support and move closer together.
Formation Characteristics

- Two characteristics of reservoir rock are *porosity* and *permeability*.

- **Porosity** is the measurement of void space within a rock. It is the ratio of void space in a rock to solid volume and expressed as a percentage (%).

- **Permeability** is the ability for hydrocarbons to flow between connected pores of a rock. It is an essential characteristic because it allows hydrocarbons to flow into a well instead of being locked in the rock.

- If a formation can flow, production or kicks can occur.
Formation Characteristics

Yellow represents space between sand grains which dictates porosity.
Formation Characteristics

- Normally pressured formations exert a pressure equal to a vertical column of fluid from the formation to the surface.
  - Most of the overburden weight is supported by the grains that make up the rock.
  - The pressure gradient is between 0.433 up to 0.465 psi/ft.
  - Normalized pressures vary from basin to basin and area to area worldwide.
Formation Characteristics

- Abnormal pressured formations have pressure greater than 0.465 psi/ft.
- Subnormal pressured formations have pressure gradients lower than 0.433 psi/ft.
  - This occurs with depletion of pore fluid through evaporation and depletion of formation fluids.
Bottomhole Pressure

- **Bottomhole pressure** is the pressure exerted by a column of fluid at the base of the wellbore.
  - The hydrostatic of a fluid column creates most of the pressure on the walls of the hole.
  - Additional pressures that add to the bottomhole are: backpressure, pressure held on the choke and friction pressures from circulating.
Bottomhole Pressure

- Bottomhole pressure can be calculated as follows:
  - **Well Static** = Hydrostatic Pressure of fluid in wellbore
  - **Normal Circulation** = Hydrostatic Pressure + Circulating Friction Pressure in Annulus
  - **Rotating Head** = Hydrostatic Pressure + Circulating Friction Pressure in Annulus + Back Pressure held on Rotating Head
  - **Circulating a Kick Out** = Hydrostatic Pressure + Circulating Friction in Annulus + Back Pressure held on Choke
  - **Reverse circulation** = Hydrostatic Pressure + Circulating Friction Pressure inside Tubing or Drill Pipe
Differential Pressure

- **Differential pressure** is the difference between the formation pressure and bottomhole hydrostatic pressure.

  - In the well, differential pressure may be either:
    - **Overbalanced**: $HP > FP$
    - **Underbalanced**: $HP < FP$
    - **Balanced**: $HP = FP$

  - Most wells are drilled, completed and worked over in **overbalanced** conditions.
Surface Pressure

Pressure observed at surface falls into two categories:

- **Standpipe pressure** – this is often referred to as pump pressure, tubing pressure or drill pipe pressure.
  - Pressure generated from pumps.
  - Pressure from the formation.

- **Annulus pressure** – this is often referred to as casing pressure, however, in a well control situation it may be referred to as choke pressure.
  - Pressure from the formation.
Surface Pressure

- With the well shut in, pressure on either gauge (Annular or Standpipe) may indicate a kick.
- The pressure is exerted throughout the well in addition to the fluid’s hydrostatic.
- If pressure is too great in the annulus, formation breakdown may happen as well as downhole and surface equipment failure may occur!
Pressure-Losses/Circulating

- **Friction** is the resistance to movement and has to be overcome by force or pressure in order to perform tasks in the well such as moving fluid.

- The amount of force that is used to overcome friction is termed **frictional loss**.

- Most pressure loss will happen while circulating down the string and when encountering restrictions such as reduction in pipe ID, tubing ID, sliding sleeves and jet nozzles. Additionally, friction must be overcome in the annulus.
Pressure-Losses/Circulating

- Pump pressure is the amount of friction it takes to overcome the friction throughout the wellbore, at a given rate.

- While the well is being circulated, bottomhole pressure increases by the amount of friction necessary to overcome the fluid’s resistance to flow in the direction being circulated. (Either normal or reverse).

- Since friction adds pressure to the wellbore, it increases the effective weight of the fluid.
Trapped Pressure

- Pressure often becomes trapped:
  - Below a closed BOP
  - Below packers and plugs
  - Between valves
  - In the string
  - Between pump and string

- Trapped pressure is always a dangerous situation.

- Every precaution should be used to ensure that potential trapped pressure areas have been bleed off prior to opening.
Annular Pressure Loss (psi)

- Annular Pressure Loss is often termed “APL”.
- APL exists only while circulating – density, viscosity and other mud properties affect it. If mud properties change, so does the APL.
  - There are many calculations, from simple to complex multi-phase flow models to do so.
- It adds pressure to bottomhole pressure.
- Should be considered in well control events.
**Equivalent Circulating Density (ppg)**

- **Equivalent Circulating Density**, or **ECD** for short, is the added pressure from APL from a given point to surface, plus the existing fluid hydrostatic pressure, but expressed as a mud weight (ppg).

- ECD when drilling or working over a well should always be considered.

- Can be calculated as follows:

\[
ECD_{ppg} = MW_{ppg} + \left( \frac{APL_{psi}}{0.052} \div TVD_{ft} \right)
\]