3. Gel Strength

Gel strengths, 10-second and 10-minute, measured on the VG meter, indicate strength of attractive forces (gelation) in a drilling fluid under static conditions. **Excessive gelation is caused by high solids concentration leading to flocculation**. Signs of rheological trouble in a mud system often are reflected by a mud's gel strength development with time. When there is a wide range between the initial and 10-minute gel readings they are called "**progressive gels**". **This is not a desirable situation**. If initial and 10-minute gels are both high, with no appreciable difference in the two, these are "**high-flat gels**", also undesirable. The magnitude of gelation with time is a key factor in the performance of the drilling fluid. Gelation should not be allowed to become much higher than is necessary to perform the function of suspension of cuttings and weight material. For suspension "**low-flat gels**" are desired - as indicated in Figure (13).

Gel strength can be one of the following forms:

1. **Rapid – Soft (best one)**
2. Rapid – Hard
3. Slow – Soft
4. Slow – Hard

Gel strengths and yield point are both a measure of the attractive forces in a mud system. **A decrease in one usually results in a decrease in the other**; therefore, similar chemical treatments are used to modify them both. The 10-second gel reading more closely approximates the true yield stress in most drilling fluid systems. **Water dilution can be effective in lowering gel strengths, especially when solids are high in the mud**.

Excessive gel strengths can cause:

1. Swabbing, when pipe is pulled,
2. Surging, when pipe is lowered,
3. Difficulty in getting logging tools to bottom,
4. Retaining of entrapped air or gas in the mud, and
5. Retaining of sand and cuttings while drilling.

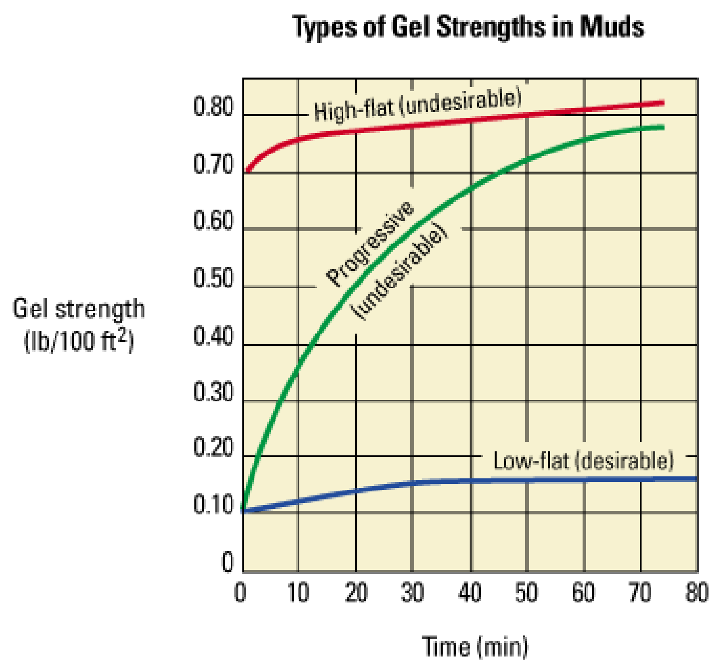


Fig. (13): Types of Gels

➢ Yield Point vs. Gel Strength

YP and GS are two different parameters, they should not be confused with each other:

- YP is a measurement of the attractive forces under flowing conditions;
- GS on the other hand is a measure of the attractive forces under static or non-flow conditions.

Since both YP and GS are a measure of the force of flocculation, they are related with each other:

- As YP **decreases** the GS will usually **decrease**.

➢ Thixotropy

Thixotropy is the ability to form a gelled structure (develop structural viscosity) over time when the circulation of the mud is stopped.

Thixotropy is measured as GS (10 s) and GS (10 min). The viscosity of a thixotropic fluid changes with time under constant shear rate until reaching equilibrium.

Most drilling muds exhibit thixotropy, which is necessary for fast drilling, efficient cuttings lifting and to support weighting agents when circulation stops.

➢ Importance of Measuring Rheological Properties

μ_p, μ_a, Y_b, gel, n, k, are very important because:-

1. Calculation of pressure losses due to fiction in circulating system which help in selecting the appropriate mud pump.
2. Evaluating of drillings mud's ability for cleaning and lifting cuttings rock from the well bottom to the surface (viscosity should be low at the bit and high in the annulus for optimum cleaning).
3. Evaluating the drilling mud ability for suspending cutting rock while stopping the circulation (gelation).
4. Calculating of hydrodynamic pressure while pulling or running in pipes in the well (surge and swab pressures).
5. Calculation of hydraulic parameters such as nozzles diameter, jet velocity and hydraulic power of mud pumps.

4) Filtration

A process of passing the liquid phase (filtrate) of drilling fluid into permeable formation, due to differential pressure between mud hydrostatic pressure and formation pressure. This process is combined by deposition of solids particles on surface, making mud cake. Filtration process depend on **formation characteristics (permeability)**, **drilling fluid characteristics (solid content, particle size**

distribution), and on differential pressure (Δp). There are two types of filtrations which are **static filtration** (occurs when drilling fluid is not circulating in the well bore and no pipe movement) and **Dynamic filtration** which occurs when mud is circulated. High filtrate rate caused some trouble such as: –

1. Inability to make accurate formation evaluation.
2. Formation damage (decreasing of pay zone productivity due to invasion of filtrate).
3. Well bore instability due to sloughing of shale.
4. Increased surge pressure when moving pipe due to decreased hole diameter.

- **Filtration control**

Filtration can be controlled by adding some additives called "filtration control additives" or "fluid loss reducers" such as CMC, starch, FCLS.

These additives:

1. Reduce the amount of the free liquid phase of the mud
2. Produce a thin, non-permeable mud cake

- **Laboratory measurement of filtration:**

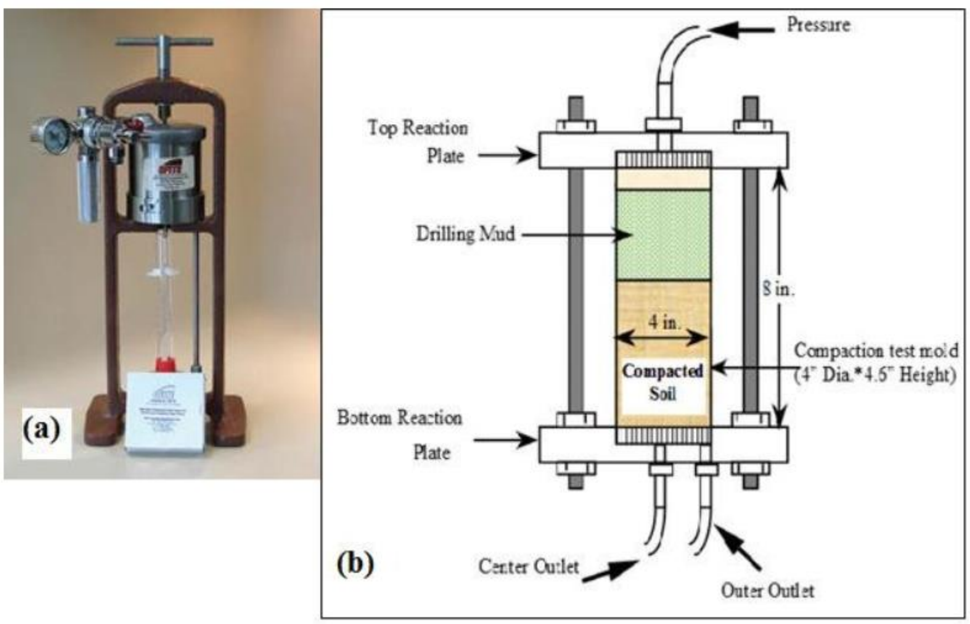
Filtration properties of a drilling fluid is evaluated by using **API Filter Press,** as shown Figure 14**.** Filtration properties includes:

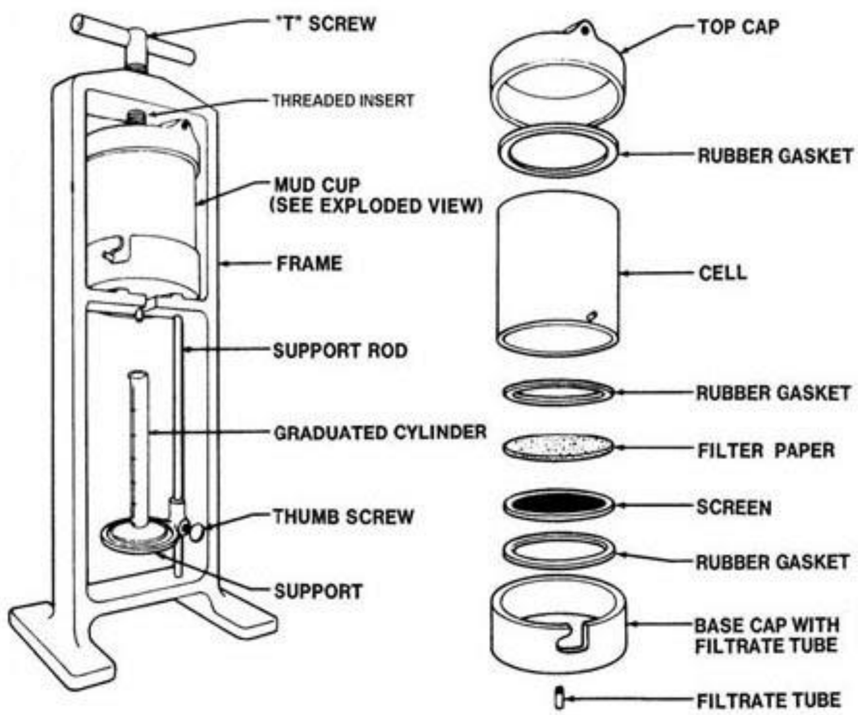
1. Amount of fluid loss into the drilled formation.
2. Ability of solids in mud to form a filter cake.

3. Magnitude of mud-cake permeability

API Filter Press:

1. Pressure source
2. Mud reservoir
3. Frame
4. Filtering paper
5. Graduated cylinder to collect and measure the filtrate discharged.





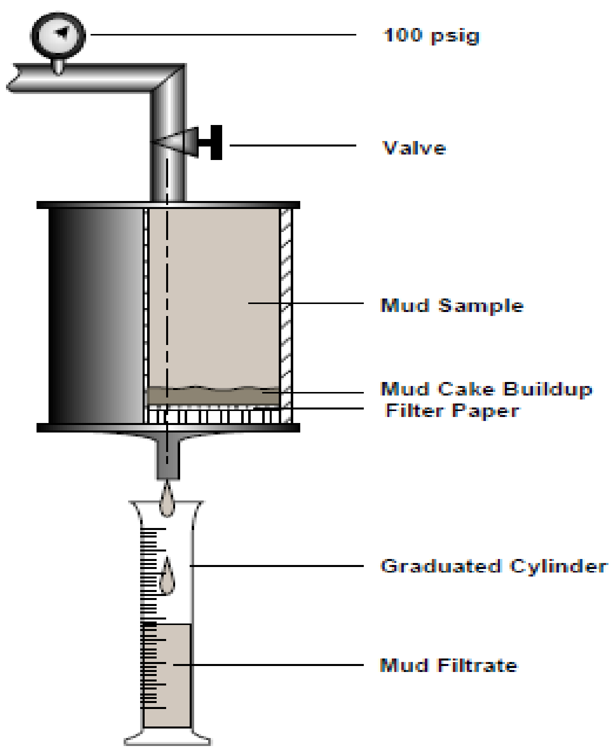
API Filter Press Test Procedures:

1. Assemble the filter press
2. Fill the mud cup cell with the required mud sample to approximately ¼", tight the T-screw to secure the unit.
3. Place a clean graduated cylinder below the filtrate outlet to collect and measure the discharge.
4. Apply a 100-psi pressure through the pressure inlet.
5. With a stop watch, start the test and as accurately as possible measure the volume collected in the graduated cylinder at 2, 5, 7.5, 10, 15 & 30 minutes.

6. At the end of the test (30 minutes), close the pressure source and open the safety relief valve and release pressure within the filter press apparatus.
7. Report the collected filtrate loss as indicated in Fig. below in (cm^3/30 min.)

API recommended test conditions

1. Time: 30 minutes
2. Pressure: 100 psi or 6.8 atmospheres
3. Filter Area: 45 cm^2



The relationship between filtrate volume and time

- The flow of mud filtrate through a mud cake under static condition follows Darcy's law:

$$\frac{dV_f}{dt} = \frac{kA\Delta p}{\mu h_{mc}}$$

V_f	= Volume of filtrate, cm^3
t	= time, seconds
k	= permeability of mud cake, darcy
A	= area of filter paper, cm^2
Δp	= pressure drop across mud cake, atm
m	= viscosity of the filtrate, cp
h_{mc}	= thickness of mud cake, cm

- The thickness of a mud cake depends on the concentration of solids in the mud and the amount of water retained in the cake. At any time (t), during a filtration process:

Volume of Solids Filtered from the Mud ≡ **Volume of Solids Deposited on Mud Cake**

- This relationship can be expressed as:

f_{sm}: Volume fraction of solids in the mud
V_m : Volume of mud
f_{sc} : Volume fraction of solids in the cake

$$f_{sm}V_m = f_{sc}h_{mc}A$$

$$f_{sm}(h_{mc}A + V_f) = f_{sc}h_{mc}A$$

$$h_{mc} = \frac{f_{sm}V_f}{A(f_{sc} - f_{sm})} = \frac{V_f}{A(\frac{f_{sc}}{f_{sm}} - 1)}$$

$$\frac{dV_f}{dt} = \frac{kA\Delta p}{\mu h_{mc}}$$

$$\frac{dV_f}{dt} = \frac{kA^2\Delta p}{\mu V_f}\left(\frac{f_{sc}}{f_{sm}} - 1\right)$$

Integrating:

$$V_f = \sqrt{\frac{2k\Delta p}{\mu} A^2 \left(\frac{f_{sc}}{f_{mc}} - 1\right)} \cdot \sqrt{t}$$

fundamental equation governing filtration under static conditions

- Rearrange

$$V_f = C \cdot \sqrt{t}$$

C is a constant given by $C = \sqrt{\frac{2k\Delta p}{\mu} A^2 \left(\frac{f_{sc}}{f_{mc}} - 1\right)}$

- Since the filtrate volume is proportional to the square root of time, the volume of filtrate @ 30 minutes can be estimated by the volume @ 7.5 minutes:

$$V_{30} = 2V_{7.5}$$

- Note that the total volume of filtrate should include spurt loss before the cake.

$$V_f = C \cdot \sqrt{t} + V_{sp}$$

V_{sp} : spurt loss

$$V_{30} = 2(V_{7.5} - V_{sp}) + V_{sp}$$

- The best method for determining spurt loss is to plot Vf vs $\sqrt{t}$ and extrapolate to zero time as shown in the plot: