15 – 18 November 2021

SPE-207399-MS

Determining hole size and washout by running a fluid caliper, for cementing purposes

Jason Ellison and Charles Ellison III, Ellison Fluid Calipers; Mike Davis, Davis Fluid Calipers; Carl Bird, Concho Resources (retired); Ryan J. Broglie, P. E., Engineered Well Consulting; James Hattenbach and Jesse Ulate, West Texas Cementers; and Lee Smith, Alaskan Energy Resources

This paper was prepared for presentation at the 2021 Abu Dhabi International Petroleum Exhibition & Conference

Abstract

This paper describes the procedure to perform a fluid caliper and how by using fluid dynamics concepts, average hole size can accurately be determined, helping to derive the amount of hole washout and the appropriate amount of cement needed to circulate or achieve desired cement height.

This process has been successfully performed on over 40,000 Permian Basin wells in West Texas and Eastern New Mexico, as well as numerous other basins in the United States. This includes vertical, directional, and horizontal wells of varying hole sizes and depths, from surface to production hole. This paper will provide real world examples, discussion of geological formations encountered, drilling fluids used, and the ultimate benefit a fluid caliper provided each operator through the accurate estimation of cement volume for the reduction of waste and satisfaction of well design and regulatory requirements.

This paper will demonstrate that fluid calipers add to the operational efficiency of most drilling operations and should be considered a "Best Practice" for most drilling programs as their use can greatly limit the need to remediate a cement job necessitating additional downhole tool runs, wasting additional valuable rig time. Also, to be addressed are the limitations of fluid calipers including lost circulation, turbulent flow, and human error.

Cementing is an integral part of the process to ensure wellbore longevity, requiring increased attention. Field practice of pumping nut plug, dye, or other markers to estimate required volumes is outdated and inaccurate. This paper will clearly identify the reasons why the modern fluid caliper is aligned with today's heightened focus on ESG. Environmentally, fluid calipers determine the proper amount of cement to prevent waste. Regarding safety, fluid calipers help ensure the operator pumps accurate cement volumes to cover corrosive and/or productive zones to prevent unwanted annular influx, and referring to governance, fluid calipers help the operator pump adequate cement volumes to satisfy well construction regulations.

Introduction

According to multiple industry studies, over 10% of all wellbores constructed today will develop casing integrity issues. The likelihood of these leaks is significantly elevated when cement is nonexistent across a large portion of the wellbore length. In one such study of active wells with leakage, it was found that 44.8% of the leaks were attributed to production casing failures, only one of which had proper annulus cement integrity. The remainder of the issues were associated with poor or nonexistent cement. In 34.5%

of these cases, the leaks were tied to uncemented intervals in the intermediate casing section and 6.9% of leaks were found to occur from above the surface casing shoe. In all, approximately 80% of the leaks were attributed to non-existent or poor cement. The same study also examined leaks within abandoned wells and in 57% of these wells' leaks were determined to originate from uncemented intervals below the surface casing (Wisen 2019).

In today's world of increased scrutiny of water usage (and subsequent conservation) and greenhouse gas reduction, operators are focusing more than ever on avoidance of these potential leaks. One such tactic to ensure annular cement coverage is to exceed regulation minimums and circulate cement to surface, thereby eliminating any doubt that the annulus has been completely filled with cement. To accomplish this without the use of multi-arm caliper tools and the time and cost of a dedicated run, an accurate and cost-effective understanding of the actual hole volume is of the utmost importance.

Accurate prediction of the annular volume requirements to circulate cement to surface is important for two main reasons. First, it ensures that the operator plans for the proper amount of cement to circulate, eliminating the need for a costly remediation. Second, it ensures that the operator does not order an excessive volume of cement, leading to waste. This reduces not only product cost but also subsequent haul off costs of the excess and the added carbon footprint associated with this waste.

There are various ways to determine hole size using traditional electronic logging tools. While these logging tools offer various other benefits, it may not be necessary for an operator to make use of a logging tool in every hole section. If an operator has no need to perform a logging run other than to understand hole volume, it is clearly more cost effective to make use of a fluid caliper.

Performing a fluid caliper provides the operator with an accurate estimation of the annular volume of cement needed to fill the annular space with cement, it provides the average hole size as well as the percent washout over true (gauged) hole cased annular volume, and subsequent open hole annular volume. The calculated volume provided by a fluid caliper allows the operator a much higher degree of accuracy when ordering the appropriate amount of cement for cementing operations.

Common shortcuts taken by operators include choosing to forego the use of electronic logging tools, not performing a fluid caliper, relying on previous data from offset wells, or guesswork. Other practices include attempts to perform basic or rudimentary fluid calipers by pumping dye, paint, nut plug, or glitter. These approaches may provide adequate results at times; however, these practices will eventually lead to excess waste, issues with insufficient volumes leading to an immediate remediation job, or future wellbore issues. These shortcuts prove to be very costly to an operator and add unnecessary risk to the wellbore construction process.

Statement of Theory and Definitions

Definitions

Hagen-Poiseuille's Law – The Hagen–Poiseuille Equation (or Poiseuille equation) is a fluidic law to calculate flow pressure drop in a long cylindrical pipe and it was derived separately by Poiseuille and Hagen in 1838 and 1839, respectively. Consider a steady flow of an incompressible Newtonian fluid in a long rigid pipe. Using conservation equations and boundary conditions for cylindrical coordinates, the laminar flow has a parabolic profile from zero at the wall to a maximum velocity at the centerline **(Fig. 1)** (Ostadfar 2016).

Flow Curve – A graphical representation of how the shear viscosity of a sample changes when it is subjected to different shear rates or shear stresses (Fig. 1) (Ostadfar 2016).

Bingham Plastic Model – The Bingham plastic model is the most common rheological model used in the drilling industry. This model is a two-parameter model that includes yield stress and plastic viscosity of the fluid. The fluid initially resists flowing until the shear stress exceeds a certain value. After the fluid stars to flow there is a linear relationship between shear stress and shear rate **(Fig. 2)** (Rehm 2012).

Newtonian Fluid – a fluid whose viscosity does not change with rate of flow (Merriam-Webster 2021).

Non-Newtonian Fluid - has properties of a liquid and of a solid. Under certain conditions, a non-Newtonian fluid flows as a liquid and under other conditions, it exhibits elasticity, plasticity, and strength similar to a solid. In addition, unlike Newtonian fluids, the viscosity of many non-Newtonian fluids varies with shear rate (Schlumberger 2021).

Laminar Flow – the flow of a viscous fluid in which particles of the fluid move in parallel layers, each of which has a constant velocity but is in motion relative to its neighboring layers **(Fig. 3)** (Dictionary.com 2021).

Turbulent Flow - type of fluid flow in which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers (Fig. 3) (Britannica 2021).

Fluid Caliper - A survey in which the annular volume of the wellbore is mathematically calculated with a flowmeter and a marker. The drilling fluid in the hole is used as an analog to determine the amount of cement needed to circulate back to surface. It is performed by pumping the marker down the drill string, circulating it back up the annulus, and catching it where it exits the flow line. Using the circulation time, pump volume, hole size, fluid viscosity, and several other factors, the annular volume of cement is calculated. It can be utilized on any string to any depth with partial circulation loss, but not with total lost returns (Schlumberger 2021).

Turbine Flow Meter – A device that fluid flows through to help calculate a flow rate. A turbine spins as fluid flows through the meter. Every rotation of the turbine is picked up by a magnetic pickup and the signal is sent to an Electronic Totalizer **(Fig. 4)**.

Electronic Totalizer – A device that takes the signal from each revolution of the turbine in a flow meter and puts out an instant flow rate of the fluid passing through the flow meter, as well as gives you a total of the fluid passing through the flow meter over time.

Marker – Items introduced into the fluid system so that they can be seen, or “caught”. Examples are nutplug, glitter, cotton seed hulls, oats, etc.

Theory

Fluid caliper calculations are based on the laws of fluid dynamics **(Fig. 5)**. Newtonian Fluids can reasonably be described by Hagen-Poiseuille’s Law assuming that they are in laminar flow. Hagen-Poiseuille’s Law is based on these fluids flowing through a known medium, usually a long cylindrical pipe or blood vessel, where shear rates are generally known and constant. Drilling fluids however are generally non-Newtonian fluids due to additives and cuttings in the drilling fluid (Rehm 2012).

When considering the Bingham Plastic Model, it is generally thought that flow will not begin until the shear stress attains a minimal value, the yield stress. Once flow begins in the wellbore, it behaves similarly to that of a Newtonian fluid because the viscosity is constant and does not vary with shear rate (Yin 2001). Because of this, Hagen-Poiseuille's Law is still relevant to the calculations.

In a wellbore situation shear rates can vary depending on parameters such as wall roughness, amount and type of cuttings, washout, and string vibration, in addition to the usual effects of velocity and viscosity of the fluid, hole size, etc. Accounting for all these factors is impractical due to the enormous complexity of the calculations, and in some cases the information is unavailable (Podryabinkin 2013). However, accounting for the velocity and viscosity of the fluid, hole size, and a few other factors, as well as making some reasonable assumptions on the rest, can allow for accurate results consistent to within a small margin of error in most cases.

Limitations

Understanding the limitations of a fluid caliper are key to understanding the correct applications for their use. The most obvious limitation is lost circulation. If at least partial circulation on the hole cannot be achieved, the marker cannot be circulated around, negating the ability to perform a fluid caliper.

Another factor that limits the accuracy of a fluid caliper is turbulent flow. This can occur in certain areas of the wellbore, for example around the bit, but if the fluid is in laminar flow most of the time the effect is going to be immaterial. The largest contributor to turbulent flow relates to velocity of the fluid versus the hole size. When fluid enters turbulent flow, it creates eddies and chaotic motion that are unpredictable and therefore can contribute to inaccurate circulation times, which will in turn cause the results of a fluid caliper calculations to be inaccurate. Understanding the limitations of flow rates regimes in different hole sizes to keep the fluid in laminar flow as much as possible is a key to ensuring the accuracy of a properly executed fluid caliper.

A third limitation of the fluid caliper is human error. While mostly controllable with various redundancies, checks, and reviews it is still possible for human error to occur. This is evident in the form of miscommunication, incorrect data provided, miscalculation, and poor operational execution such as valves being opened/closed. A properly executed fluid caliper requires proper technician training, with job supervision performed by experienced personnel that can identify the above-mentioned errors. To ensure an even higher degree of accuracy, in some instances it may be necessary to perform a second fluid caliper depending on the error identified by the properly trained supervisor.

Description of Application of Equipment and Processes

A colored, neutrally buoyant organic material (marker) is introduced to the flow stream, circulated downhole, out of the bit, and to surface through the annulus. The marker can be introduced into the drilling fluid system at various points; however, the most common points of entry for this marker into the circulating system are at the flow meter or at the top of the open drill string on the drilling rig floor. If a marker is not placed into the open drill string, volume corrections are made accounting for the volume for the marker to travel to the rig floor.

While many markers have been tried such as cotton seed hulls, glitter, nut plug, dye, paint, and carbide, it is important that a neutrally buoyant organic material is utilized. Whole oats have proven to be the best marker as they absorb any drilling fluid and subsequently become suspended in the fluid **(Fig. 6)**. Other markers such as cotton seed hulls float and therefore travel up the annulus inherently outpacing the fluid flow, while conversely, denser markers can take longer to circulate. Obtaining a true circulation time is critical to the accuracy of fluid caliper calculations.

A flow meter with an electronic volume totalizer is installed at the discharge end of the mud pump to determine exact pump output **(Fig. 7)**. A turbine flow meter is most commonly used for accuracy although other types may be utilized. It is important to understand the limitations of the specific flow meter used to ensure its accuracy. Flow rates that are outside of a flow meter's operating parameters, or flow meters that are not installed in the correct configuration will produce inaccurate readings. Certain types of flow meters are fluid- or viscosity-specific and may need to be calibrated as such.

The manual counting of strokes and comparison of calculated flow rates with flow meter readings helps to determine flow meter reading accuracy. If anomalies arise, an investigation is immediately performed. Common causes of these anomalies are attributed to a torn pump liner, trash stuck in the flow meter, incorrect pump size factor used while performing manual calculations, debris in the mud such as the packing off of LCM on the turbine blades, incorrect meter installation, and flow rates outside the operating parameters of the flow meter.

Once the marker has circulated throughout the annulus, it is retrieved using a strainer located in a safe and convenient location. Commonly, this location is at the shakers or where the fluid exits the flow line into the mud tanks. Adjustments are made to account for the volume from the bell nipple to the location the marker was collected.

It is extremely important while performing the fluid caliper that all fluid pumped is going down hole. As obvious as this may seem, if a surface valve is open diverting a percentage of fluid, this will significantly impact the calculations. It is also extremely important to ensure that any gain or loss is quantified as accurately as possible. Performing the procedure in a closed-loop environment in addition to marking the pits is generally the best way to accomplish this, although other methods can be used. If gain or loss is present, it is critical to understand the approximate depth of the gain or loss. The gain or loss only effects the marker after it travels past said depth, so depth-based adjustments must then be made.

Viscosity is another important factor that can significantly affect the calculations. It is important to obtain an accurate viscosity of the fluid "coming out" of the hole as opposed to the fluid "going in" the hole. Obtaining the viscosity measurement from a fluid sample that is close to the marker return time is important as viscosities can vary. Funnel Viscosity is generally used due to the simplicity of performing this test in the field, however if a viscometer is available, the reading in Centipoise can be used as well.

As previously discussed, the initial marker travels at the apex of the flow curve through the annulus **(Fig. 8)**. The calculations correct for the volume that is outside of this flow curve. Once all inputs are obtained and verified, the calculations are performed, and the results provided to the operator. Results include annular casing volume from shoe to surface, average hole size, and washout over true (gauged) hole cased annular volume **(Fig. 9)**.

Presentation of Data and Results

Case Study #1 – 1 SWD well (Fig. 9)

A saltwater disposal (SWD) was drilled in Martin County, Texas in the Permian Basin. This well was a 2-string design with 9-5/8 in 36 lb/ft surface casing set at 449 ft. The production interval was drilled to 3,872 ft with a bit size of 8-¾ in and 7 in 23 lb/ft casing was run in the hole.

This interval was drilled through a known salt zone **(Fig. 10)** with an initial mud weight of 9.5 ppg. While the fluid caliper was performed, the mud weight coming out had increased to 10.2 ppg with chlorides of 176,000 ppm and a funnel viscosity of 30.

A flow meter was installed to the 6 in x 16 in duplex pump. The PASON (electronic data measurements) measurements indicated a pump output of 60 spm, which was also manually confirmed at 60 spm. The flow meter read an average of 53.1 ft^3/min during the caliper, equating to a pump efficiency of 92.5%.

The fluid caliper was performed at a depth of 3,794 ft, and drilling resumed. The marker returned at a depth of 3,814 ft after 34 minutes. After the completion of the fluid caliper, it was determined that the annular volume of cement needed to circulate behind the 7 in casing to be run was 1,314 ft^3, or 234.0 bbl. This equated to an average hole size of 10-¾ in and a washout of 141% over true (gauged) hole cased annular volume (open hole only).

The original cement procedure called for pumping 100% excess cement over true (gauged) hole cased annular volume. This would have equated to 1,105 ft^3, or 196.8 bbl. Using the results from the fluid caliper, the operator ordered additional cement based on the fluid caliper-calculated volume plus 35% additional to ensure proper circulation. After cementing was completed the cement report showed that 210 sacks or cement or 88 bbl were circulated to surface. The difference between the amount of cement pumped and the amount of cement circulated determined that the actual hole volume was 1,302 ft^3 or 281.9 bbl **(Table 1)**.

Post-run analysis proved that the fluid caliper was within 12 ft^3, or 2.1 bbl of actual hole size, a 1.0% difference, quite remarkably within any practical margin of error. Based on the operator's original plan to pump 100% excess over true (gauged) hole cased annular volume, without performing a fluid caliper and adjusting the volumes, they would not have circulated cement to surface. As this was an SWD well, generally under higher regulatory scrutiny than that of a producing oil or gas well, regulations require cement to be circulated to surface, therefore an expensive remediation job would have been required.

The incorporation of a fluid caliper on this project saved the operator approximately USD 50 thousand in rig time and remediation cost.

Case Study #2 – 2-well package **(Fig. 11)**

An operator drilled a two well package in the Permian Basin, one in Midland County and one in Howard County, performing a fluid caliper on both surface hole sections. Both surface intervals were drilled with a 17-½ in bit using a fresh water-based fluid with a mud weight of 8.4 ppg and a funnel viscosity of 29. A 13-3/8 in 54.5 lb/ft casing job was planned. Well #1 surface hole was drilled to a depth of 1,170 ft and Well #2 was drilled to 1,850 ft.

Flow meters were installed on both rigs, and it was determined that on well #1 the pumps were operating at 85% efficiency, while well #2 the pumps were 93% efficient. This difference illustrates the importance of the use of a flow meter for the determination of the exact pump output. If calculated pump efficiency differs from assumed pump efficiency, a large margin of error will occur, and the final calculations will be inaccurate.

Washouts in surface hole sections in the Permian Basin are common and vary across the basin. This, coupled with the regulations to circulate cement to surface make it critical to accurately estimate the actual hole volume for cementing. In this case, the operator planned to pump 200% excess over true (gauged) hole cased annular volume on both wells (Fig. 11). The fluid calipers determined that the washout on well

#1 was only 54% and well #2 had a washout of 71% over true (gauged) hole cased annular volume.

The fluid caliper volumes were over by 15 ft^3 (2.7 bbl) of actual hole volume on Well #1 **(Table 2)** and under by 62 ft^3 (11.0 bbl) of actual hole volume on Well #2 **(Table 3)**. This represented a difference of +1.3% and -2.6% difference between actual hole volume and the fluid caliper volume, also well within any practical margin of error.

Based on the fluid caliper information the operator was able to adjust their cement volumes down a combined 1,595 ft^3, or 284.1 bbl **(Table 4)** saving them over USD 20 thousand in cement cost alone.

Conclusions

Applying the laws of fluid dynamics to real world drilling situations allows the operator to estimate the correct volume of cement to be circulated reasonably and accurately. This practice has been incorporated successfully on over 40,000 wells in the Permian and other basins in the United States.

When performed correctly with highly trained personnel, fluid calipers can be an invaluable part of most drilling programs. With the shifting mindset in today’s oilfield toward an increased focus on ESG issues, operators’ goals include more than just saving money. Heightened focus is placed upon creating less waste, reducing the carbon footprint, and being a better steward to the environment. With this mindset, operators are now desiring to find better ways to construct higher quality wellbores that will ultimately last longer and manifest fewer future problems. As discussed, an integral part of that is circulating cement to surface on all strings.

Circulating cement to surface without creating excessive waste is achieved through the careful application of fluid calipers. While other solutions do exist, fluid calipers are a more efficient and cost-effective alternative that can be utilized while drilling to provide a high-quality cement integrity solution. Operators who incorporate them regularly into their drilling programs significantly reduce the chance of out-of-compliance issues with regulatory agencies and subsequent expensive remediation jobs, increase productivity, and enjoy cost savings and improved safety over the life cycles of their wells.

Acknowledgements

The authors would like to thank Ellison Fluid Calipers, Davis Fluid Calipers, West Texas Cementers, Big E Services, Alaskan Energy Services, Engineered Well Consulting, and Electronic Data Devices for their support with this project. A special thanks goes to Janie Snelson, Cary Billingsly, Hal Hulett, and Kevin Swikert for their additional help and support. Acknowledgement also goes out all the technicians and onsite personnel for their help and continued support.

Nomenclature

bbl – barrel
ft^3 - cubic feet
ft^3/min – cubic feet per minute
% - percent
SWD – saltwater disposal well
ft – foot
in – inch
lb/ft – pounds per foot (weight per foot) of casing

lb – pound (weight)
gal – gallon
ppg – pounds per gallon (density) of drilling fluid
ppm – parts per million
min - minute
spm – strokes per minute
PASON - electronic data measurements

References

Britannica, T. Editors of Encyclopedia. Turbulent flow. In *Encyclopedia Britannica*. Retrieved September 1, 2021 https://www.britannica.com/science/turbulent-flow

Dictionary.com Unabridged. Laminar flow. In *Dictionary.com dictionary*. Retrieved September 1, 2021, from https://www.dictionary.com/browse/laminar-flow

Merriam-Webster. (n.d.). Newtonian fluid. In *Merriam-Webster.com dictionary*. Retrieved September 1, 2021, from https://www.merriam-webster.com/dictionary/Newtonian%20fluid

Ostadfar, A. 2016. Fluid Mechanics and Biofluids Principles. In 'Biofluid Mechanics – Principles and Applications.' Chap. 1, pp. 1-60. (Elsevier Inc.: Amsterdam) DOI: https://doi.org/10.1016/C2014-0-01583-3

Podryabinkin, E., Rudyak, V., Gavrilov, A. et al 2013. Detailed Modeling of Drilling Fluid Flow in a Wellbore Annulus While Drilling. Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE. 6. 10.1115/OMAE2013-11031. https://www.researchgate.net/publication/267607468_Detailed_Modeling_of_Drilling_Fluid_Flow_in_a_Wellbore_Annulus_While_Drilling

Rehm, B., Haghshenas, A., Schubert, J. et al 2012. Flow Drilling: Underbalance Drilling with Liquid Single-Phase System. In 'Underbalanced Drilling: Limits and Extremes'. Chap 2, pp. 39-108. (Elsevier, Inc.: Amsterdam) DOI: https://doi.org/10.1016/C2013-0-15513-4

Schlumberger. Fluid caliper. In *Schlumberger Oilfield Glossary*. Retrieved September 1, 2021, from https://glossary.oilfield.slb.com/en/terms/f/fluid_caliper

Schlumberger. non-Newtonian fluid. In *Schlumberger Oilfield Glossary*. Retrieved September 1, 2021, from https://glossary.oilfield.slb.com/en/terms/n/non-newtonian_fluid

Wisen, J., Chesnaux, R., Werring, J. et al. 2019. A portrait of wellbore leakage in northeastern British Columbia, Canada. Proceedings of the National Academy of Sciences Jan 2020, 117 (2) 913-922; DOI: https://doi.org/10.1073/pnas.1817929116

Yin, X. et al. 2001. Poiseuille and hele-shaw cell flows of non-newtonian fluids. Theses and Dissertations. Paper 703. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.820.7193&rep=rep1&type=pdf

Appendix

Tables

	Cubic feet (ft^3)	Barrels (bbl)
Volume pumped	1,796	319.9
Volume circulated	494	88.0
Actual volume	1,302	231.9
Fluid caliper volume	1,314	234.0
Difference	+12	+2.1

Table 1 – Case Study #1.

	Cubic feet (ft^3)	Barrels (bbl)
Volume pumped	1,657	295.2
Volume circulated	421	74.9
Actual volume	1,236	220.1
Fluid caliper volume	1,251	222.8
Difference	+15	+2.7

Table 2 – Case Study #2, Well #1.

	Cubic feet (ft^3)	Barrels (bbl)
Volume pumped	3,197	569.3
Volume circulated	937	166.9
Actual volume	2,260	402.5
Fluid caliper volume	2,198	391.5
Difference	-62	-11.0

Table 3 – Case Study #2, Well #2.

	Cubic feet (ft^3)	Barrels (bbl)
Volume in prognosis	6,449	1,148.6
Volume pumped	4,854	864.5
Difference	-1,595	-284.1

Table 4 – Case Study #2, combined.

Figures

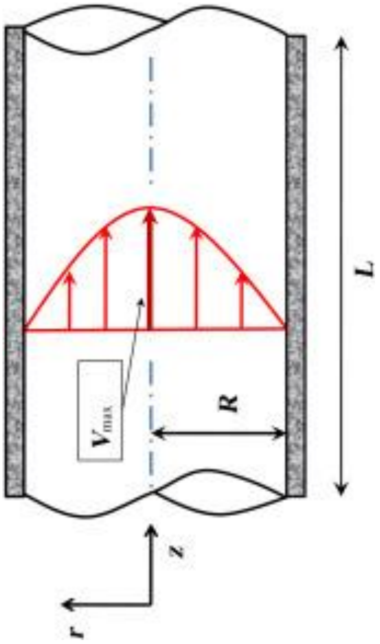


Fig. 1 – A graphical representation of a flow curve, Hagen–Poiseuille Equation (Ostadfar 2016).

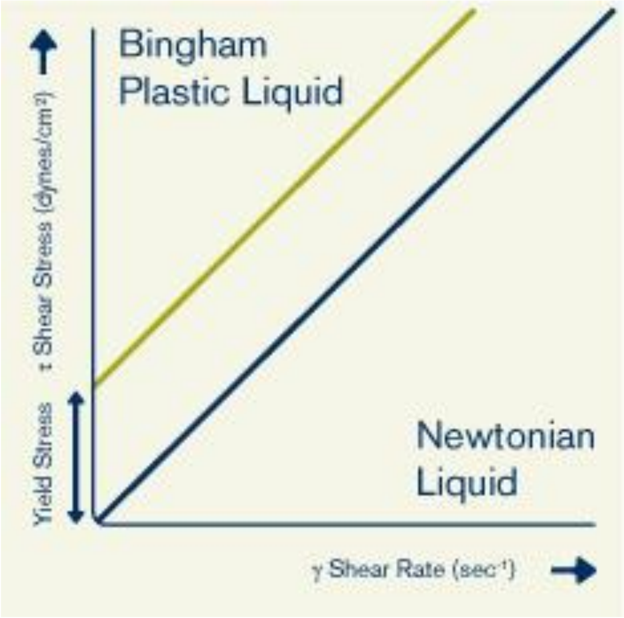


Fig. 2 – The Bingham Plastic's Model. Courtesy of Typhoon

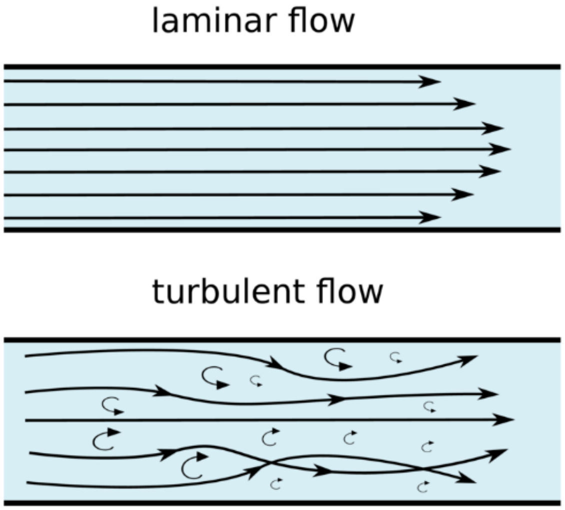


Fig. 3 – Laminar flow vs. turbulent flow. Courtesy of CFD support.

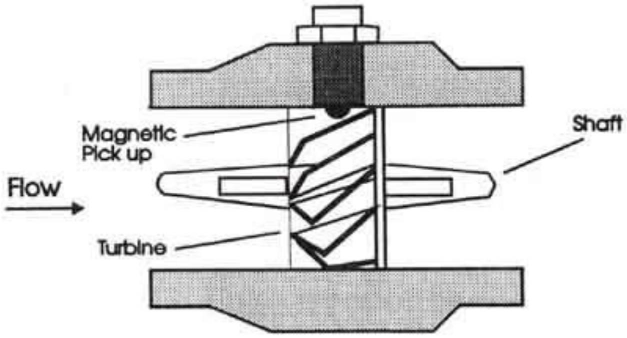


Fig. 4 – The inner workings of a turbine flow meter. Courtesy of Industrial-Electronics.com.

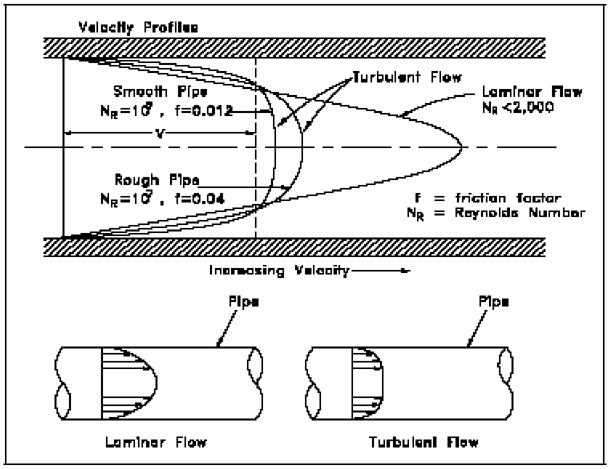


Fig. 5 – **Velocity profile examples in different flow regimes. Courtesy of Engineers Edge, LLC.**

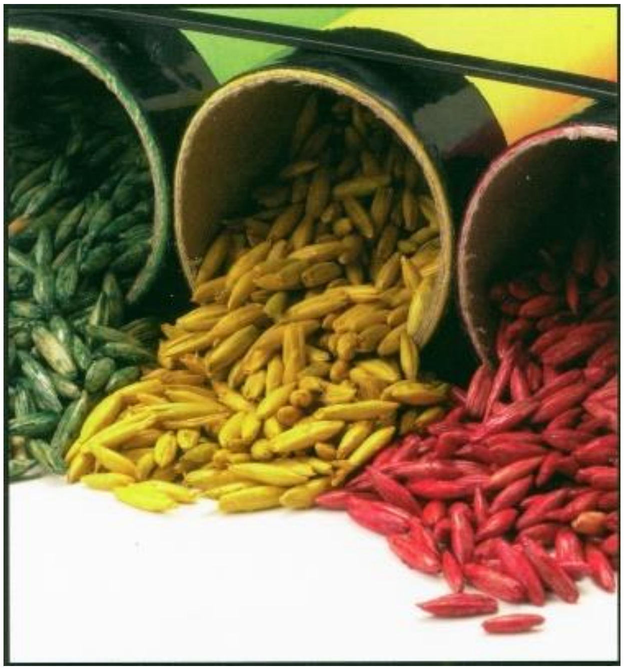


Fig. 6 – **Whole oats (painted), used as marker. Courtesy of Ellison Fluid Calipers.**

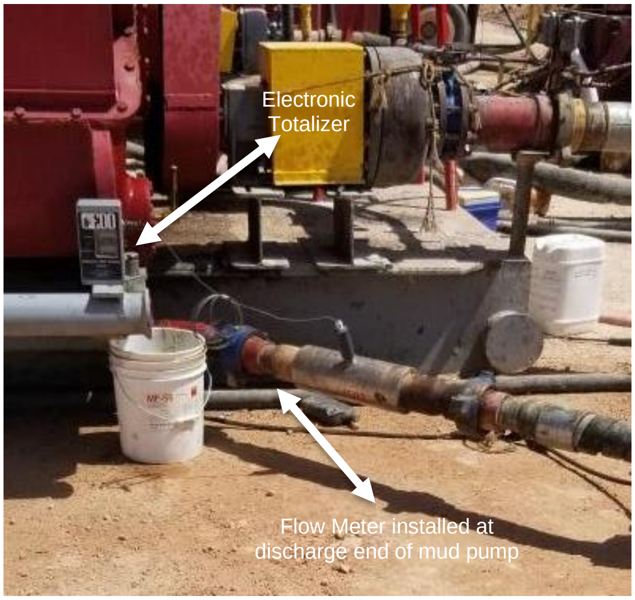


Fig. 7 – Actual flow meter hooked up on rig. Courtesy of Ellison Fluid Calipers.

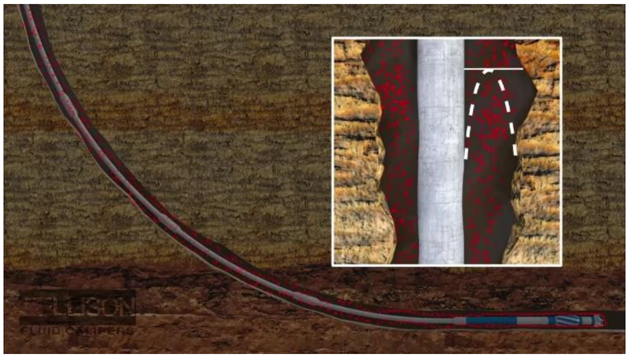


Fig. 8 – The apex of the flow curve in the annulus. Courtesy of Ellison Fluid Calipers.

A fluid caliper was run to a depth of **3,814 ft**.

To circulate to surface behind **7 in** casing:

0 ft to 3,814 ft - **1,294 ft^3** (Annular Volume to Present Depth)
0 ft to 3,872 ft - **1,314 ft^3** (Annular Volume to TD)

Average Hole Size and Washout are reported for the **open hole ONLY (449 ft to 3,882 ft)**:

Average Hole Size - **10 ¾ in**
Washout O.T.H. Annular Volume - **141%**

Fig. 9 – Fluid caliper report for Case Study #1. Courtesy of Ellison Fluid Calipers.

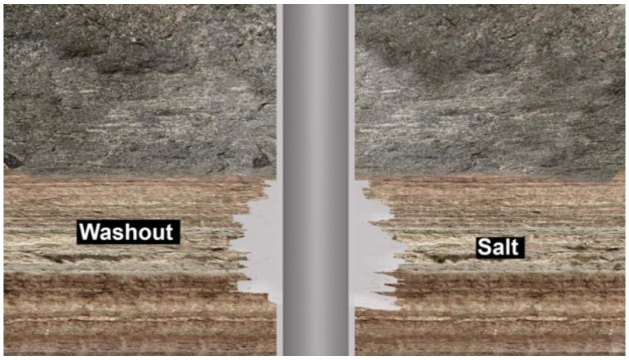
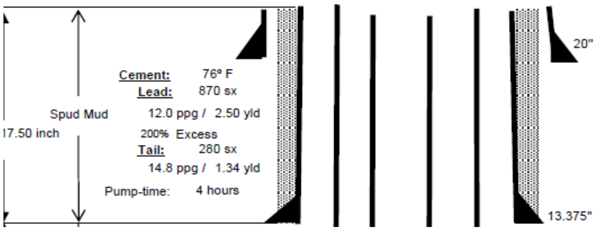


Fig. 10 – Example of a washout in a salt zone. Courtesy of Hart Energy.

Well #1



Well #2

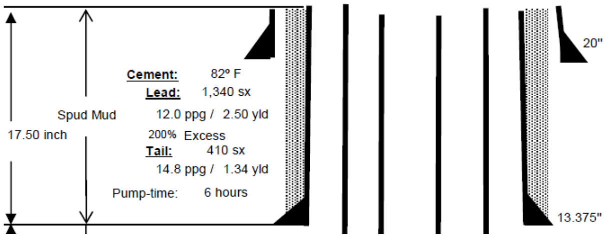


Fig. 11 – Case Study #2 wellbore diagrams with predetermined cement volumes. Courtesy of West Texas Cementers.