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Cut-Point Data: Relevant, Irrelevant, or Irreverent?

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Abstract

Recent advertisements and publications regarding shale shaker screens have demonstrated that the term "cut-point" is poorly understood. This paper discusses how cut-point curves are developed and how they differ from potential separation curves. A graph of the mass fraction of solids in the feed stream reporting to the discharge stream versus a range of particle sizes will create a lazy "S" shaped curve known as a "cut-point" curve. Each point found on such a curve is a "cut-point" which relates the likelihood that a particle of a given size will be rejected by a separator.

The solids control industry relies upon cut-point curves to describe the performance of shakers, hydrocyclones and centrifuges. Screens are perceived differently by some and thought to perform like a "go" or "no go" gauge by rejecting particles of a specific size or larger, for example, 74 microns. The cut-point of a screen is not a unique function of the size of the screen apertures because other variables affect the cut-point. Information regarding the cut-point of a screen cannot be derived by plotting the distribution of openings in a screen even though the plot looks similar to a cut-point curve.

Cut-points are specific to the test or operating conditions used to collect the data. Like cut-point curves for other separators, the cut-point of a screen varies with changes to the distribution of solids in the feed, solids characteristics, type of fluid, and rheological characteristics of the fluid. API RP-13C describes the largest openings in shale shaker screens. This allows a direct comparison of screens without trying to predict cut-point curves. Screens with smaller openings should remove more solids when compared under identical conditions

Introduction

When an entire industry adopts a new metric, it is important that the metric be understood. It can be said about any endeavor that "you get what you measure". API established new methods for comparing shale shaker screens over two years ago. These methods were subsequently adopted by the International Standard Organization as ISO-13501. The Recommended Practice API RP-13C has sparked discussion of the term "cut-point" in technical papers, in advertising, and in places where solids control hands tend to gather.

The term "cut-point" as used in some of these conversations has demonstrated that the term is poorly understood and sometimes misused. This paper describes the need for an industry wide standard to characterize shaker screens, the rationale behind the writing of RP-13C, how the methodology of RP-13C differs from a "cut-point" analysis, and the reason why the term "cut-point" is not used or referenced in API RP-13C.

Background

Some in the oil patch might be surprised to know that the API published a recommended practice to characterize shaker screens over a decade ago. Many more might question whether shaker screens really warrant the time and attention of an API workgroup or the creation of an international standard. The need is more compelling in light of:

- Global annual expenditure for shaker screens exceeds 160,000,000 US dollars
- Shaker screens remove the bulk of the drilled solids on rigs worldwide
- A screen is the only solids control device that removes solids based primarily on particle size
- Screens are the gate keepers for the drilling fluid because drilled solids that make it past the screens will negatively affect well operations and drilling costs.

Two criteria are important when selecting solids control equipment like shakers and centrifuges. The size and quantity of drilled solids that will be rejected by the equipment is the first criteria. Volumetric flow rate or "capacity" that the equipment effectively handles is the second. Even the newest hand on the rig recognizes when the circulation rate exceeds the shaker's maximum capacity. In fact, the "newest hand" will probably be the first to know as he or she will be handling the water hose by the shale shakers.

The problem is not that there are two criteria. The problem stems from the fact that capacity is easily measured on a drilling rig, but the ability to measure a screens rejection of solids of a certain size can only be accomplished with great difficulty. Consequently, screens were marketed, developed, and labeled with a focus on capacity expectations, and the importance of solids removal became marginalized. Capacity is the only performance characteristic most end users measure, and remember “you get what you measure”. The end result of this focus on capacity was that the man on rig could not confidently determine whether the shakers were being “screened up” or “screened down” by relying upon screen labeling. The API Task Group addressed this specific problem.

Screen Characterization

An industry wide standard for characterizing shaker screens may seem to be of questionable benefit when time could have been spent writing a recommended practice for field measurement of the solids being rejected by the solids control equipment on a rig. As anyone who has attempted it will testify, determining the size and quantity of drilled solids rejected by solids removal equipment under drilling conditions is a tedious task. The obstacles to obtaining meaningful results under field conditions are numerous and apply equally to shaker screens, hydrocyclones, and centrifuges.

Drilling conditions are notoriously non-steady state because the cuttings report to the surface in slugs and in jumbled order from the drilling sequence due to circulation interruption, connections, and formation changes. Particle size analyses on the “clean” fluid downstream of a separator cannot prove that solids of a certain size range have been removed much less predict the quantity of particles that have been removed. Simultaneous and representative samples of either the discarded solids or feed solids must also be analyzed along with the downstream sample if any claim of effective particle removal is to be substantiated. For example, the absence of particles in the range of 100 to 150 microns in a fluid sample collected downstream of a shaker does not prove that the screens removed solids in that range because no particles in that size may have been present in the feed. Lastly, the size of solids rejected by any separator will be affected by the distribution of solid sizes in the feed, the characteristics of those solids, and the rheological characteristics of the fluid.

This last point is recognized for hydrocyclones and centrifuges because changes in fluid viscosity obviously affects settling rates. The rheological effect on shaker screens is frequently not appreciated. Each opening in a shaker screen will be wet by some liquid phase. This makes the openings effectively smaller because of the ring of liquid around each screen wire. This fluid ring will have different thicknesses depending upon the surface tension of the fluid and the rheological characteristics of the fluid. An illustration of this phenomenon occurs when a shale shaker screen becomes water-wet while drilling with a non-aqueous fluid causing screen flooding. Re-using a drilling fluid to drill multiple wells from one location, causes the colloidal content of the fluid to increase which increases the surface tension between the fluid and air so that the fluid will not easily pass through a fine screen.

The screen manufacturers, vendors, and users in the API Task Group were well aware of the pit-falls, time, and effort needed to determine the size and quantity of drill solids removed by equipment on the rig. The committee also realized that field testing does not lend itself to establishing a meaningful and objective method for labeling shaker screens because field testing done properly gives “cut-point” data which is inherently test specific. The task group had many discussions concerning developing common standard tests to characterize the shaker screen based on a cut-point analysis, and rejected them all. In fact, the term “cut-point” does not appear in RP-13C but an earlier recommended practice for designating screens did refer to “separation potential curves” that look a lot like cut-point curves.

In 1993, API RP-13E introduce a method of comparing screens. RP-13E attempted to place screen designation and selection on a sound scientific footing by using an optical image [OI] analysis. The OI method used a digital microscope and computer software to characterize the openings in a screen. This analysis gave a curve that was shaped like a cut-point curve and was called a “separation potential” curve. The separation potential curve is different from a cut-point curve. The cut-point curve for any separator varies with many variables as previously discussed whereas as the “separation potential curve” was an invariable characteristic of the screen. Perhaps the cosmetic similarity of the two curves may have led to the belief that screens can be described by cut-point curves based on field results.

RP-13E never became a practical standard because the lab apparatus was costly and was purchased by only one or two screen manufacturers. Also, the method based the calculated particle size on light shining through a stationary, non-vibrating wire cloth. An important physical property of wire cloth was neglected. Wire cloth openings, particularly oblong weaves, are not perfectly rigid. The wires that form the openings in the screen will move and distort when vibrated. Lastly, large diameter spheres were calculated for screens that had long narrow openings. These spheres were much larger than the screen openings and created erroneous concepts about the screens.

RP-13C API Task Group considered many methods to define or describe screens. One of the initial concepts was to establish a “standard” set of tests where fluid containing sand was pumped across a shale shaker screen. The problem is that there are too many variables to establish a single or even a series of tests. The screen acceleration and type of motion imparted to the screen will affect the performance. The “standard” slurry would have to match field drilling fluids which vary from water-based to synthetic based fluids. These variables made a universal “standard” untenable. Shaker performance is a function of many variables, including: shaker design, configuration, motion type, acceleration forces, screen construction, and properties of the slurry mentioned earlier.

RP-13C Methodology

The purpose of the RP-13C [ISO 13501] document is to describe the screen and not predict its performance. The recommended practice is an empirical method requiring minimal expense for laboratory equipment. It has proven to be simple to perform, gives repeatable results, and provides a sound basis for selecting screens. The result of the test is an "API number" that is recognizable, intuitive, and useful for company representatives and mud engineers when selecting screens for their ability to remove fine solids.

The laboratory methods used to test a screen sample can be summarized as below.

1. A screen sample must be specifically prepared for the laboratory test and must be the same as a production run shale shaker screen in its construction technique and materials
2. This sample screen is then mounted in a frame suitable for nesting into a test sieve shaker
3. A sample of appropriately sized aluminum oxide particles are then carefully weighed out using a scale and combined into an aggregate sample
4. This aggregate sample of approximately 50 grams of aluminum oxide grit is built from grits of known size so that (a) 10% or more percent of the grit sample will be retained on the screen of interest and (b) the balance of the grit sample will be retained on the US test sieves that bracket (above and below) the screen of interest.
5. Some of the grit sample will invariably wind up in the pan. The first US test sieve stack in the stack should retain little and acts as a control screen.
6. The sample of aluminum oxide grit is introduced to the stack and "dry sieved" to "completion" so that the largest particles have time to pass through the largest openings in each sieve.
7. Each sieve in the stack is weighed before and after the test to determine the mass of grit retained
8. The data is analyzed by solving a linear equation between two points defined by the cumulative percentage retained versus the nominal opening size for the two US test sieves that bracket the screen of interest in the stack.
9. This equation then enables a theoretical D_{100} to be calculated for the screen of interest with "D_{100}" being the particle size in microns of aluminum oxide that will be retained on the test screen.
10. The resulting micron size is then used to assign an "API number" to the screen as defined in RP-13C

Simply stated, screens labeled with an API number must closely match the performance of a US test sieve of the same denomination in their ability to retain the same size range of aluminum oxide grit when dry sieved under identical specific test conditions. There is familiarity in the oilfield with the US Sieve number scale because it is known that a 200 mesh screen US test Sieve retains 75 micron particles and larger when an API Sand Content test is conducted.

Cut-points and Cut-Point Curves

The term "cut-point" is used either to describe specific points on a cut-point curve or to describe the curve itself. "Cut-point" in the sense of being a point on a curve is most simply defined as:

> *The ratio of the mass of discarded solids in a particular size range to the mass of solids in the same size range presented to the removal equipment.*

For example, suppose 10 pounds of solids are known to be in size range between 1 mm and 2 mm are introduced to a screening device. If 4 pounds of solids that fall in the size range between 1 mm and 2 mm are discarded by the device. Then the mass ratio of discharged solids to feed solids is 40%. This ratio is a cut-point and would be labeled as "D40" because the removal equipment rejected 40% of the particles in the 1 to 2 mm size range.

To determine a cut-point curve, the mass of solids discarded in each of multiple size ranges would be compared to the mass of solids presented in that size range. When presented with graphical data, human nature tends to try to condense the curve into a few points or, even better, a single point. In the oilpatch, the D50 is often quoted as if it were "THE" cut-point for solids removal equipment. This is a commonly accepted practice but does not describe the entire separation curve.

Cut-point Curve Generation

Cut-point curves, as shown in Figure 1, are useful graphical representations of the performance of a solid separator based on physical tests. The curves generated relate only to the physical conditions existing at the time of the test. These curves are not an invariant property of the device. In other words, these cut-point curves may change significantly during the course of drilling a well.

Again referring to Figure 1, any individual point of the curve is a cut-point. It represents the fraction of a specific size particle that is discarded from the feed stream and the curve has infinite number of cut-points. When a cut-point is denominated "D_{80}", it means the size particle that would have 80% of its mass in the discard stream. In Figure 1, D_{80} is about 50 microns and D_{50} is around 40 microns.

Suppose the cut-point curve in Figure 1 was known to be that of four-inch desilter cone. Then important information is missing because test conditions are unknown. Was the unit tested with water or a viscous mud? Were the rejected solids sand or barite? The solids control industry has long adhered to an unwritten rule about designating hydrocyclone cut-points. The published “cut-point” for a hydrocyclone unit will be the particle size in microns for which the unit rejects 50% of the mass of the solids presented to it in a dilute sand and water slurry. For example, the cut-point of a four-inch desilter described as having a 20 microns will be understood as having a D_{50} cut-point 20 microns.

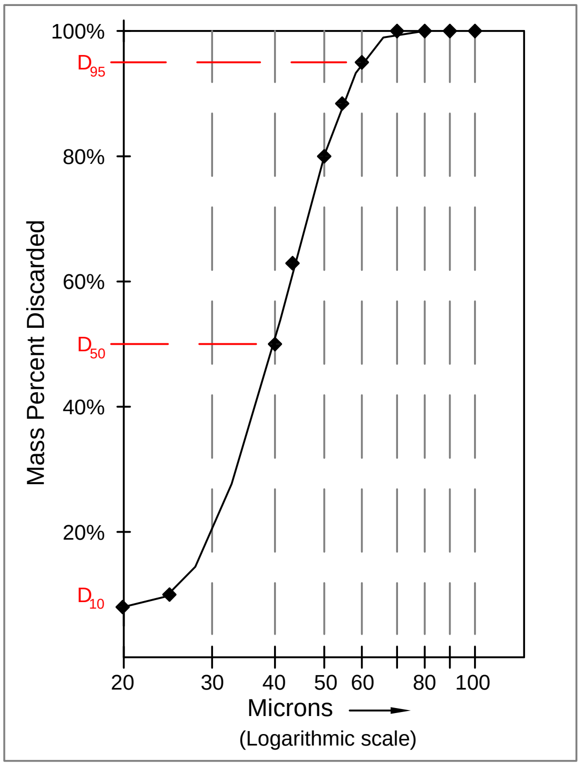

Figure 1: Cut-Point Curve

Understanding Cut-Point Curves

The information contained in Figure 1 indicates about 95% of all particles larger than 60 microns were discarded. All particles larger than 75 microns are discarded. Data needed to create these graphs are not easily acquired. The flow rate and density of each stream must be determined. If the discard is captured for 10 minutes, the mass of all the particles presented to the separation device during that 10 minute period must be determined. The distribution of solids in the feed and discard stream must be measured. This is frequently accomplished with stacks of ASTM standard sieves and/or with commercial particle size analyzers. Commercial units use either laser diffraction or x-rays to determine settling rates and translate those data into equivalent spherical diameters.

Since each piece of solids control equipment is designed to remove solids in a certain size range, it is instructive to show multiple cut-points curves on a single graph as show in Figure 2. These curves depict the concept that shale shakers remove large particles with desanders, desilters, and centrifuges remove sequentially smaller particles.

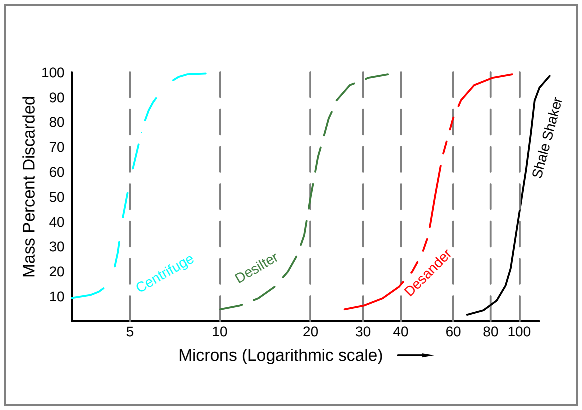

Figure 2: Stylized Cut-Point Curve

A typical feed solids distribution, shown in Figure 3, was used to calculate a cut-point curve. This curve indicates that 38% of the solids are smaller than 30 microns and 18% of the solids are smaller than 20 microns. This means that 20% of the solids in the flow stream are between the sizes of 20 to 30 microns. The mass flow rate of solids the feed stream must be calculated. The flow rate of the feed stream is determined or measured. The flow rate times the slurry density gives the mass flow rate of the feed stream. The volume percent of solids is determined with retort or with other methods. The mass of the liquid phase can then be subtracted from the mass of the total stream to determine the mass of the solids contained in the feed stream.

This same procedure is used on the discard stream to determine the mass flow rate of individual size fractions that match those selected for the feed stream. The cut-point curve actually starts with a discontinuous curve that indicates the size ranges selected to determine the fraction of solids removed in that size range. The cut-point curve in Figure 1 was developed using this procedure except that intervals of 5 microns were used along the x-axis for the discard and feed slurries.

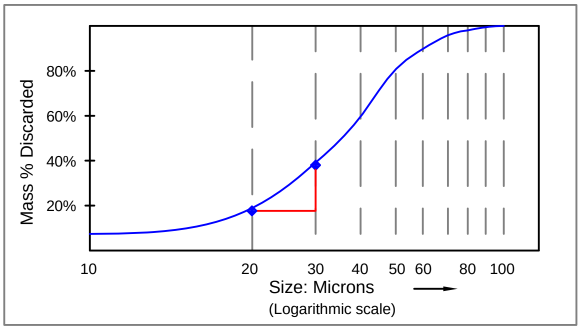

Figure 3: Selecting Interval for Cut-Point Calculations

Desilter Cut-Points

A mud cleaner is designed to take the underflow from hydrocyclones and sieve it through a shaker screen. API barite is primarily smaller than 74 microns. If an API200 screen is used on a mud cleaner, most of the barite should pass the screen as would all drilled solids smaller than 74 microns. The equipment will remove drilled solids larger than 74 microns and, surprisingly, in most drilling fluids, a considerable quantity of those size particles are in the drilling fluid even thought the main shale shakers are dressed with API200 screens. This is most easily observed even with unweighted drilling fluids because desilters are frequently plugged with particles as large as ¼ inch after supposedly passing through a screen that should remove all of those solids.

If the cut-point for a desilter was in the range of 25 microns for a weighted drilling fluid, the total quantity of barite would abruptly and quickly destroy the screens. The increase in solids content greatly changes the separation curve as shown in Figure 4. The cut-point curve in Figure 4 is significantly different from the cut-point curve for a four inch hydrocyclone shown in Figure 2. The cut-point curve in Figure 2 was calculated from field data taken on location while drilling with an 11.0 lb/gal water-based drilling fluid. The rheological properties of the drilling fluid differ significantly from the sand and water slurry used to obtain the cut-point curve in Figure 2. The curve is also discontinuous showing the intervals of sizes selected to determine the ratio of discarded solids to feed solids.

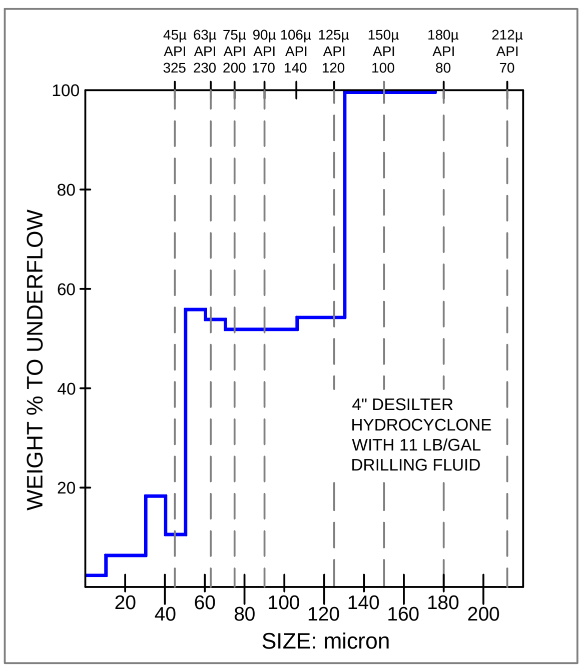

Figure 4: Cut-Point Curve for 4" Desilter

The drilling fluid in this well had been used for about a month so the colloidal content was relatively high. The quantity of barite contained in the underflow of the desilters was relatively small because most of the barite so small little passed through the bottom of the desilters. A bank of twenty 4" desilters was processing the drilling fluid. To measure the flow rate through the cones, a rough-neck flow meter was used. The overflow from the hydrocyclones was routed horizontally along the top of the discharge tank. A tee was installed with the opening pointed upward. A six-foot long piece of 30" casing with a flat plate bottom was mounted vertically above the tee. A butterfly valve was placed at the end of the discharge line. When the valve was closed, the entire fluid overflow from the cones was directed into the casing. Two lines were painted inside the casing and the volume between the lines accurately determined. The valve could be kicked shut and the time required for the known volume to fill the casing was measured with a stop watch. The underflow stream was captured in a bucket made from a short piece of 20 inch casing. The bucket was mounted so that it could be rotated into the underflow stream before the stream reached the shaker below. Again, a stop watch measured the time required for a specific volume to flow from beneath the cones.

The quantity of solids in a specific size interval in the drilling fluid and the quantity of solids in the same specific size interval in the underflow cannot be determined from a cut-point curve. The cut-point curve in Figure 4 indicates only that 50% of the solids in the size ranges from 50 microns to 125 microns reported to the hydrocyclone underflow. The curve does not indicate how many solids were in that size range.

Centrifuge Cut-Points

The underflow [or heavy slurry discharge] from a decanting centrifuge contains about 60% by volume solids. The concentration is so large that the discharge will not flow. This makes measurements of the discard flow rate difficult. For the data presented here, the discard was captured in a specially-built container. A welder cut a metal drum in half vertically and welded one inch pipes on each side to create a catch pan that resembled a stretcher. The pipes were long enough to reach across the mud tank and support the half barrel. Parallel lines were painted horizontally inside the half barrel. The volume between the lines was calculated and confirmed with measurements. Water filled the bottom part of the barrel. The half barrel was moved under the centrifuge. As the discharge from the centrifuge fell into the water, the liquid level rose to the first line. A stop watch was used to determine the time required for the liquid level to rise to the second line. As the solids dropped into the barrel, samples were taken to determine particle sizes and density of the underflow, or heavy slurry discharge, from the decanting centrifuge.

Flow rate of the centrate from the centrifuge was measured at the same time. The flow rate of water into the centrifuge was also measured. The flow rate of drilling fluid into the centrifuge had to be calculated from these measurements. Before particle size of solids in the three flow streams was measured, care was taken to make certain that the mass flow into the centrifuge matched the calculated mass flow out of the centrifuge. Mass flow is determined by multiplying the flow rate times the mud weight of each stream. Although this sounds simple, usually the test had to be repeated several times before the balance was achieved. The cut-point curve for a decanting centrifuge processing a 15.2 lb/gal drilling fluid is shown in Figure 5.

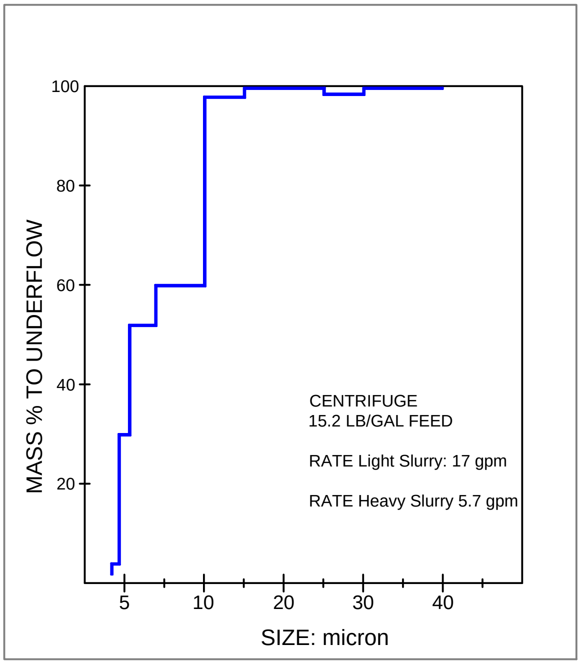

Figure 5: Cut-Point Curve for Decanter Centrifuge

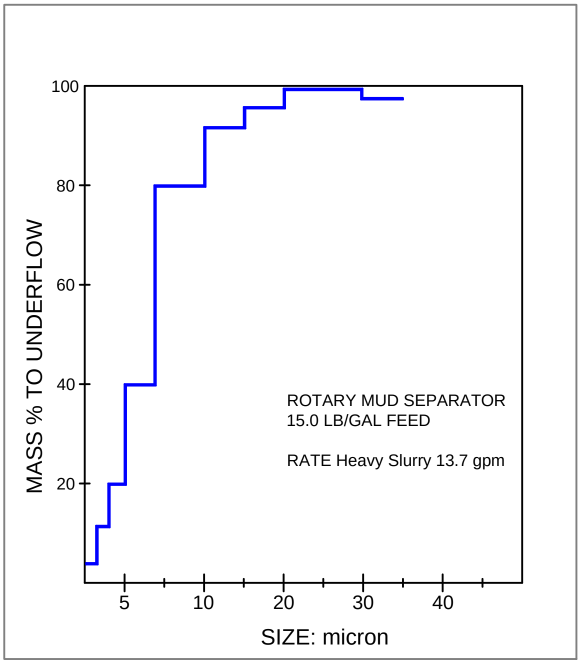

Figure 6: Cut-Point Curve for Rotary Mud Separator

The cut-point curve for a rotary mud separator is close to the curve for a decanting centrifuge. See Figure 6 which was developed during a field test. Since the discharge streams are pumpable it is assumed that the cut-points for the rotary mud separator are not as low as a decanter. The difference was the quantity of small particles associated with the liquid phase in the heavy slurry. Validation tests in three other locations confirmed the general shape and low cut-point.

Solids distribution

Frequently, the particle size distribution in a fluid is presented as a bar graph with mass shown in multiple size ranges. These charts can be misleading depending on what size intervals are selected for the x-axis. Changing the size range can give misleading perceptions of the actual distribution. Both of the charts illustrated in Figures 7A and 7B were constructed from the data of Figure 1 and have identical distribution of solids.

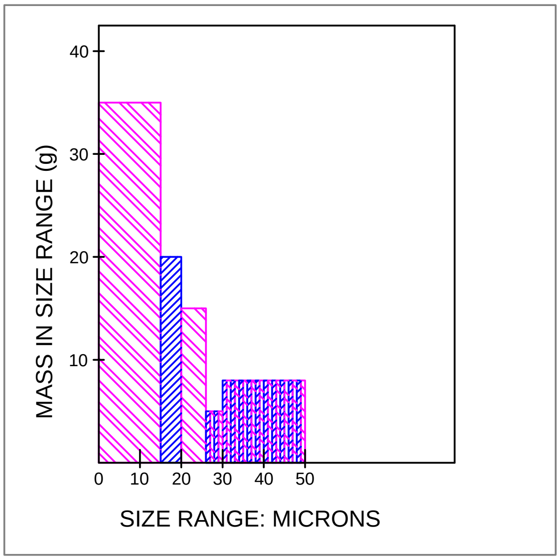

Figure 7A: Bar Chart Particle Size Distribution

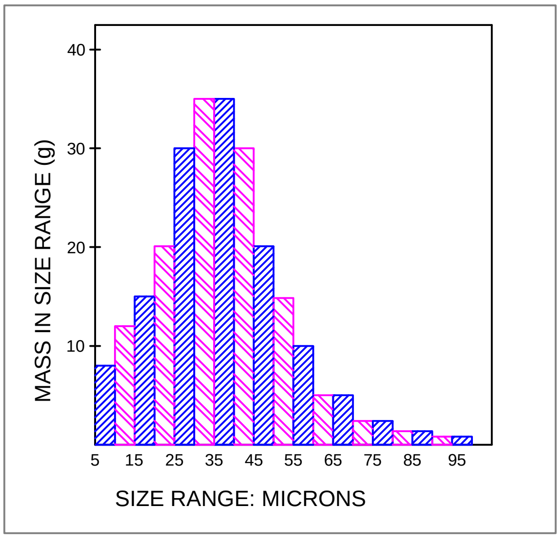

Figure 7B: Bar Chart Particle Size Distribution

Conclusions

1. API RP-13C does not try to measure or predict actual screen performance under drilling conditions
2. API RP-13C provides a sound basis for the man on the rig to select shaker shakers by identifying the largest openings in a shaker screen as a primary screen characteristic.
3. API RP-13C makes no prediction about the cut-point to be expected from a screen under drilling conditions nor is the word "cut-point" to be found in the document.
4. API RP-13C gives meaningful information that can be used by the man on the rig. If in a dry sieve test, Screen A" retains 177 micron size and larger particles and Screen "B" retains particles down 74 microns and larger, rationality would conclude that on the same shaker, for the same drilling fluid, then Screen "B" with the smaller openings would remove more dirt from the drilling fluid.
5. Cut-points are not invariant and are not a unique property of any piece of solids removal equipment. They change with many factors and are only specific for the particular set of conditions existing at the time to the test.
6. Cut-point analysis is performance measurement that will change with test conditions. For this reason, that API 13C focused on characterizing screens in terms of a known standard set of test sieves rather than attempting to develop a test method based on cut-point analysis that would require a "standard" shaker and or "standard" drilling fluid.

Acknowledgments

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Nomenclature

API = *American Petroleum Institute*
μm = micron (10^{-6} m)
lb/gal = pound per gallon
gpm = gallons per minute