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Drilling Fluid Yield Stress: Measurement Techniques for Improved Understanding of Critical Drilling Fluid Parameters

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Abstract

Drilling fluid yield stress has been embraced by the industry as a key rheological parameter for evaluating hole cleaning, barite sag, equivalent circulating density, surge/swab pressures, and other drilling concerns. Because this parameter is particularly difficult to quantify with standard field and lab viscometers, different conventional measurements and regression-analysis techniques routinely are used to approximate the true yield stress. This paper presents results from a study conducted to determine the most appropriate option in order to promote standardization within the industry.

The study focused on yield-stress measurements using a vane rheometer and statistical analysis of nearly 50,000 mud reports. A wide range of water, oil, and synthetic-based field muds was involved. Results were encouraging, but not entirely conclusive. Inconsistencies with vane-rheometer measurements, especially with the oil-based muds tested, indicate that refinement of the technique is in order. However, there was enough evidence to propose that the low-shear yield point (LSYP) is the most suitable alternate for yield stress using standard viscometers until more definitive correlations suggest otherwise.

Introduction

Drilling fluids, both aqueous and non-aqueous, exhibit complex non-Newtonian rheological behavior. The yield stress is a key rheological parameter that the drilling industry has recognized as critical to the performance of drillings fluids. Hole cleaning, barite sag, equivalent circulating density, surge and swab pressures, and other important drilling issues are impacted directly by the yield-stress characteristics. Successful completion of challenging wells, especially deepwater, high-temperature / high-pressure, and other narrow-margin wells, can be compromised unless yield-stress values are measured consistently and managed properly.

The yield stress can best be described as the stress that must be applied to a material to initiate flow. If the applied stress is below the yield stress, then the fluid will display strain recovery when the stress is removed. Once the yield stress has been exceeded, the fluid displays viscous flow characteristics.

Previous work[1] highlighted both the importance of yield stress and difficulties encountered in determining this value, whether via direct measurement, extrapolation, or curve fitting. Most advanced hydraulics models rely on Herschel-Bulkley-type rheological models that incorporate a yield-stress term and consider shear-thinning behavior. Conventional Couette viscometers used at the wellsite and in the laboratory are ideal instruments[2] for high-shear-rate measurements where fluid samples are completely sheared within the viscometer gap. Unfortunately, fluids exhibiting yield-stress characteristics may not be fully sheared in the viscometer gap at low shear rates. This can generate misleading data by artificially distorting the measurement geometry through the presence of a plug-flow region.[3]

Presented in this paper are results from a study designed to determine the most appropriate option using existing techniques and viscometer data. This would help promote the much-needed standardization within the industry. The study involved vane-rheometer yield-stress measurements on various field muds in current use, and statistical analysis of nearly 50,000 mud checks conducted on a wide range of water-based (WBM), oil-based (OBM), and synthetic-based (SBM) field muds.

Yield Stress

Drilling fluids are designed such that under static conditions they are capable of suspending barite and drill cuttings. In order for this to be possible, drilling fluids must exhibit yield-stress behavior, or a very high zero-shear-rate viscosity. It has been the assumption in the drilling industry that most drilling fluids do in fact display yield-stress characteristics, even though this property is not measured directly. Problems often are encountered in the field that are assumed to be related to inadequate yield-stress properties

Traditionally, three rheological models have been applied in drilling fluid hydraulics and rheological analyses: Bingham plastic, power law, and yield-power law (Herschel-Bulkley). These models adequately cover the range of yield-stress values that are encountered in the field. The power law represents the case of zero yield stress, while at the other end of the spectrum the Bingham plastic model covers the case where the yield stress (τ_y) equals the yield point (YP). The Herschel-Bulkley model covers both these conditions, as well as all cases in between. By definition, the yield stress of drilling fluids is limited by the criteria in **Eq. 1**.

$$0 \leq \tau_y \leq \text{YP} \qquad (1)$$

Options for Determining Yield Stress

Fluid yield stress can be obtained via a number of different routes – direct measurement, and interpolation, and regression analysis of Fann viscometer data. The following section discusses the merits of each method.

Ideally, the yield stress of a drilling fluid should be measured directly, as it is a material property. Unfortunately, standard Fann-type viscometers do not take readings below 5.1 s^{-1} shear rate, and as discussed earlier, the accuracy of low-shear-rate measurements can be suspect. One of the most common and simplest yield-stress measurement techniques uses the vane geometry rotating at very low rotary speeds. Vane rheometers were used in this study to establish the true yield stress. There was no intent, however, to suggest that vane rheometers should routinely be used in the field.

While direct measurement offers a sound approach for determining the yield stress, the most practical option for the drilling industry would be to use data provided by existing viscometers. The challenge then becomes to determine which of these data to use for the yield stress. Experimental data generated from a vane viscometer were used to help resolve this challenge.

Fann 35 data can be used to estimate the yield stress; however, a number of options using these data have been proposed by different groups over time. As discussed in a previous publication,[1] the following options are available for measuring reasonable, usable values for τ_y:

1. Fann R_3
2. Fann R_6
3. Low-shear yield point (LSYP = $2R_3 - R_6$)
4. “Zero” gel strength (no time delay)
5. Initial gel strength (10-sec delay)
6. 10-min gel strength (10-min delay)

The first three options are based on stabilized readings and the last three on gel-strength-type measurements. It could be argued at this point that LSYP is the best choice from the first group and the initial gel strength is the best from the second group. For cases where $R_3 > R_6$, the LSYP should be set to R_6.

Curve-fitting techniques to determine τ_y are common; however, computer processing is required to establish the yield stress. This can be an inconvenience in the field and detracts from the premise that τ_y is a material property. Nevertheless, regression analysis can be very useful to help identify true yield-stress values.

Three options for curve-fitting techniques include the unweighted-average, weighted-average, and “3-point” method. Each option requires a convergence or trial-and-error solution. The unweighted method, as the name implies, gives equal weight to the six standard dial readings. This could potentially skew the true fluid properties because of the less accurate and more numerous low-shear-rate readings. Mathematically, the weighted-average method[4] probably is the superior of the three, but it is somewhat complex and requires nontrivial software programming.

The 3-point method forces the regression curve through R_{600}, R_{300}, and iteratively through one other point, as opposed to using a least-square technique with all six data points. This approach preserves values for PV and YP. The additional point can be R_3, R_6, or the average of R_3 and R_6. As seen later, the 3-point method using the R_3 and R_6 average at 4.5 rpm gives results almost identical to the weighted-average curve fit.

Vane Measurements

The vane-rheometer method is based on the stress overshoot behavior associated with yielding materials. As a solid material begins to deform plastically, a maximum in the applied stress is observed immediately prior to the structure of the material failing catastrophically. Yield-stress fluids will display a maximum in applied stress when sheared at very low shear rates prior to flowing. A thorough discussion of the yield stress and various measurement techniques is given by Nguyen and Boger.[5]

While the vane technique is an established method for direct measurement of the yield stress, it has not been widely used in the drilling fluids industry. The vane technique is derived from stress-growth experiments conducted in rotational viscometers. The vane, fully immersed in a fluid, is slowly rotated until the fluid begins to deform plastically as indicated in **Fig. 1**. The stress-versus-time data for a yield-stress fluid will exhibit a stress overshoot, with the maximum value of the stress corresponding to the true yield stress. Though simple in concept, the method is not straight-forward and care should be exercised defining the experimental parameters. In order to remove any viscous effects, the shear rate (proportional to the rate of rotation of the vane) should be very low. This is particularly important for fluids with low yield-stress values, as was evident from the OBM data.

The advantage the vane method has over conventional rotational devices is the fact that the vane overcomes the wall-slip problem. The assumption is made that when using a vane, the fluid yields across a cylindrical surface defined by the diameter and length of the vane. In this work, the vane was attached to a Brookfield constant shear-rate viscometer.

The vane used in this study, shown in **Fig. 2**, had a length of 43 mm and diameter of 7.5 mm. The minimum rate of rotation for the Brookfield viscometer was 0.3 rpm, and this value was used for all tests. Further work is required in order to assess the impact varying vane dimensions and shear rates have on the measured yield stress. As indicated in the OBM data, different shear rates may be necessary when measuring the yield stress via the vane method for fluids displaying low yield-stress values. In this case, the viscous properties of the material may have masked the yield-stress value and the maximum torque value may not have been properly detected.

Statistical Analysis

The primary goals of the statistical analysis were (a) to narrow the potential options for determining τ_y, (b) to determine τ_y from regression analysis, and (c) to provide a background perspective for data obtained from the vane rheometer. An extensive central database of historical well records proved to be a great source of rheological data representing how muds actually are being run in the field.

For this study, 2,400 wells drilled over the past 5 years were selected from the United States (Gulf of Mexico, Louisiana, Texas, Alaska, California, Colorado, New Mexico, Montana, Wyoming, and Utah), North Sea, Norway, Shetland Basin, Canada, Austria, Germany, Croatia, and Angola. In all, 48,310 wellsite mud checks were evaluated - 12,371 SBM, 11,169 OBM, and 24,770 WBM. The large data sample made it possible to statistically consider a wide range of drilling muds used in an even wider range of environments.

Data of particular interest were mud type, mud weight, temperature, YP, R_6 and R_3 readings, and 10-sec and 10-min gel strengths. Unfortunately, "zero-gel" values were not available, so this option was categorically eliminated from this study. Rheological parameters were measured using Fann 35 viscometers at the wellsite at 120°F (WBMs) and 150°F (SBMs and OBMs). Two parameters calculated from the data were LSYP and yield-stress value based on the 3-point curve-fit method.

Much of the regression analyses focused on evaluating the individual rheological parameters vs mud weight. Despite the expected scatter in nearly all of the data, conventional statistical-analysis techniques found in Microsoft Excel were adequate to complete the analysis. Third-order polynomial curve fits worked particularly well and were used throughout for consistency.

Fig. 3 shows regression analyses of YP vs mud weight for the SBM, OBM and WBM data. In order to "normalize" the data, it was convenient to evaluate the parameter τ_y/YP, where τ_y could be any of the available options for specifying the true yield stress. For example, **Fig. 4** plots this τ_y/YP ratio vs mud weight, where the τ_y values were calculated using the 3-point regression analysis of the viscometer data. The table below summaries averages of this ratio for the three mud data sets:

Mud Type	Minimum τ_y/YP	Maximum τ_y/YP	Curve-Fit τ_y/YP
SBM	0.50	0.68	0.57
OBM	0.48	0.59	0.50
WBM	0.20	0.40	0.30

It is noteworthy that the variations by mud type illustrated in **Figs. 3** and **4** reflect more of how and where the different mud types were used, rather than their intrinsic rheological characteristics. Higher yield points at lower mud weights and lower yield points at higher mud weights, for the most part, were generally in line with field operations. Typically, lower weight muds are used at shallow depths where hole cleaning is a major concern in larger-diameter intervals. Conversely, high-weight muds are more common at deep depths, where elevated yield points are neither required (small holes) nor desired (high pressure losses).

To provide better definition based on mud weight, the data were also evaluated using frequency counts for muds < 9.5 lb/gal, 9.5 – 12 lb/gal, 12 – 16 lb/gal, and > 16 lb/gal. The results are given for SBMs, OBMs, and WBMs in **Figs. 5 - 7**, respectively. This type of analysis tended helped minimize the dependence on the number of mud samples in the different mud-weight ranges. Similar correlations were developed for the other rheological parameters. Because τ_y/YP ratios for the 10-sec and 10-min gels were highly skewed above 1.0, the two gel-strength measurements were essentially removed from contention as alternatives for the yield stress.

Based on the statistical analysis, R_3 and the curve-fit τ_y were consistently between LSYP and R_6. This provided the opportunity to eliminate R_3 from contention and use R_6 and LSYP to establish the range for maximum and minimum expected yield-stress values. Combinations of data such as that provided in **Figs. 5 – 7** were used to establish expected minimum and maximum values of τ_y/YP used to contrast the measured vane viscometer data. For WBMs, curve-fit τ_y values were less than the LSYP at the lower mud weights, so the minimum curve was adjusted accordingly.

Vane-Rheometer Results

As discussed previously, one major goal of this work was to determine which conventional oilfield viscometer parameter is best suited to estimate the true yield stress of drilling fluids. As the vane method allowed direct determination of a material property, the data from the vane was used to establish the true yield stress of the fluids tested. With a direct measurement of the yield stress, indirect parameters were compared directly to the vane yield stress.

Vane test results on the SBMs, OBMs and WBMs are given in **Tables 1 – 3**, respectively. Also included are the Fann properties and several other useful relationships. Of the six methods available for determining the yield stress using conventional oilfield viscometer data, the LSYP appeared to offer the best correlation with data generated using the vane. With the exception of OBMs, ratios of the vane yield stress to the LSYP were very close to 1.0, as indicated in **Figs. 8 - 10**. **Fig. 8**, for example, compares the ratio of the vane yield stress to the LSYP across a broad range of mud weights for SBMs. These fluids in particular appeared very well suited for approximating the yield stress by using LSYP. The same comparison is made for OBMs and WBMs in **Figs. 9** and **10**, respectively.

Further work is required on all fluid types, but problems with OBM data indicate that more detailed analysis is needed using a broader range of shear rates and possibly different vane dimensions. For the OBMs, distinct maxima in the torque readings were difficult to discern. Also, a larger vane may be required to capture these low yield-stress values. The fact that the ratio of measured yield stress to LSYP for the OBMs was relatively high suggests that the shear rate used to perform the measurement may have been excessive. The YP, R_6 and R_3 readings of the OBMs were all significantly lower on average than other mud systems tested. Interestingly, the ratio of plastic viscosity to yield point for both the SBMs and WBMs was in the range of 4.3 to 4.5, while for the OBMs, this ratio was significantly higher (PV/YP for OBMs = 8.7) indicating the inherently higher viscous nature of the OBMs tested.

Also in **Tables 1 - 3**, the correction factor of 1.066 for Fann data was applied to all LSYP values of the fluids tested in order to achieve constant units of lb/100 ft^2. In all cases, including the OBMs, the corrected LSYP shows very good agreement with the yield stress determined from the 3-point and weighted-average curve fits. This analysis helped to support the recommendation that the weighted average or 3-point curve-fit methods provide the better fit for Fann 35 data measured in the field. The 3-point method is preferred for practical purposes, as this procedure is simpler and provides almost exactly the same numbers as the weighted average method.

Figs. 11 - 13 compare measured yield stress to LSYP, both parameters normalized by dividing by the yield point. In each case, statistical data from the 48,310 mud reports were used to set upper and lower limits to indicate the range where the yield stress would be expected to fall. These limits were defined by taking the maximum and minimum yield-stress parameters determined using data extracted from the field database.

In the case of the SBMs, the measured data suggest an average value of 0.47 for measured τ_y/YP, while the lower boundary, defined by the LSYP, indicated a ratio of LSYP to YP of 0.5. As discussed previously, the SBM systems provided a good data set, with clear trends discernable. The OBMs, on the other hand, did not allow definitive trends to be established between measured yield stress or LSYP. The WBM data indicated that the normalized yield stress was much lower, in the range of 0.27. The normalized LSYP for these fluids showed the same average value, strengthening the argument that the LSYP is a solid indication of a WBM actual yield stress.

Conclusions

1. The low-shear yield point (LSYP) is the most suitable alternative for determining drilling fluid yield stress from industry standard Couette viscometer data. This is based on a study involving direct measurements using the vane technique and statistical analysis of 48,310 mud reports.
2. Average values for the vane τ_y/LSYP ratio were 0.94 for SBMs and 1.09 for WBMs. Results for OBMs were inconclusive, indicating that refinement of the vane technique is in order. This would involve investigation of a range of vane sizes and shear rates.
3. The ratio τ_y/YP is a useful parameter to characterize fluids rheologically. The acceptable range of τ_y/YP values is 0 – 1 for rheological models used in drilling.
4. Statistical analysis of historical data established reasonable correlations for the expected range of

τ_y/YP for different mud types: 0.50 – 0.68 for SBMs, 0.48 – 0.59 for OBMs, and 0.2 – 0.4 for WBMs. Average values for curve-fit τ_y/YP were 0.57 (SBMs) 0.50 (OBMs), and 0.30 (WBMs)

5. A weighted-average technique is preferred if regression analysis of viscometer data is used to estimate the true yield stress. However, a simpler 3-point method yields almost identical results and preserves the measured values for plastic viscosity and yield point.

Nomenclature

YP = *Bingham yield point*
PV = *Bingham plastic viscosity*
LSYP = *low-shear yield point*
R_{600} = *Fann shear stress at 600 rpm*
R_{300} = *Fann shear stress at 300 rpm*
R_6 = *Fann shear stress at 6 rpm*
R_3 = *Fann shear stress at 3 rpm*
τ_y = *Ty = yield stress*
ECD = *equivalent circulation density*
SBM = *synthetic-based mud*
OBM = *oil-based mud*
WBM = *water-based mud*

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References

1. Zamora, M. and Power, D.: "Making a Case for AADE Hydraulics and the Unified Rheological Model," AADE-02-DFWM-HO-13, AADE Technical Conference on Drilling & Completion Fluids and Waste Management, Houston, April 2-3, 2002.
2. *API RP 13D, Recommended Practice on the Rheology and Hydraulics of Oil-Well Drilling Fluids*, 3rd ed., American Petroleum Institute (June 1, 1995).
3. Savins, J. G. and Roper, W. F.: "A Direct-Indicating Viscometer for Drilling Fluids," *Drilling and Production Practices*; API (1954) 7-22.
4. Klotz, J. A. and Brigham, W. E.: "To Determine Herschel-Bulkley Coefficients," *Journal of Petroleum Technology* (November 1998) 80-81.
5. Nguyen, Q. D. and Boger, D. V.: "Measuring the Flow Properties of Yield Stress Fluids", *Annual Review of Fluid Mechanics*, 24 (1992) 47-88.

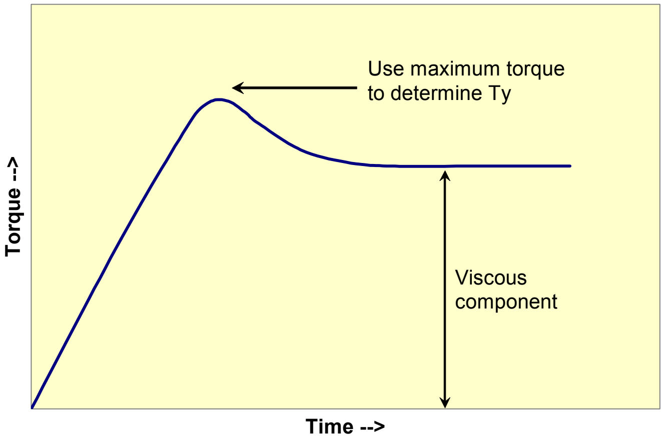

Fig. 1: Stress over-shoot for determining yield stress.

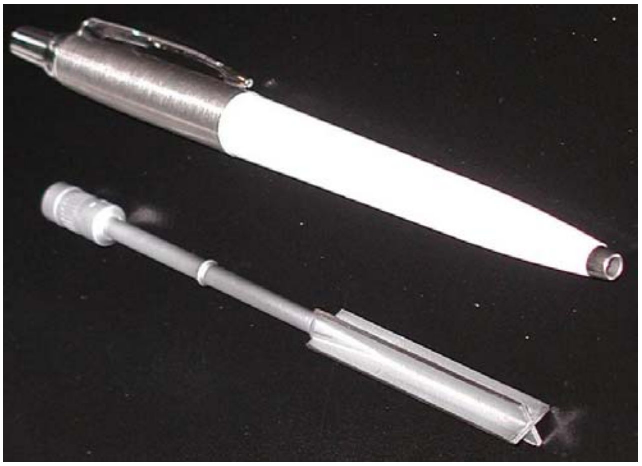

Fig. 2: 4-blade vane used to measure yield stress – 43-mm x 7.5-mm.

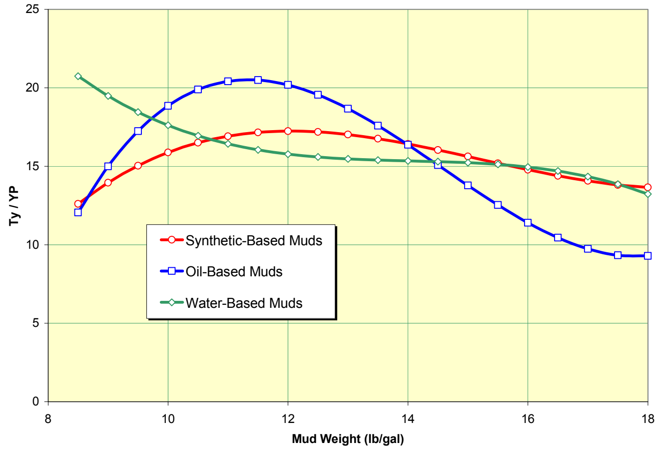

Fig. 3: YP vs mud weight curves based on regression analysis of 12,371 SBM, 11,169 OBM, and 24,770 WBM mud checks.

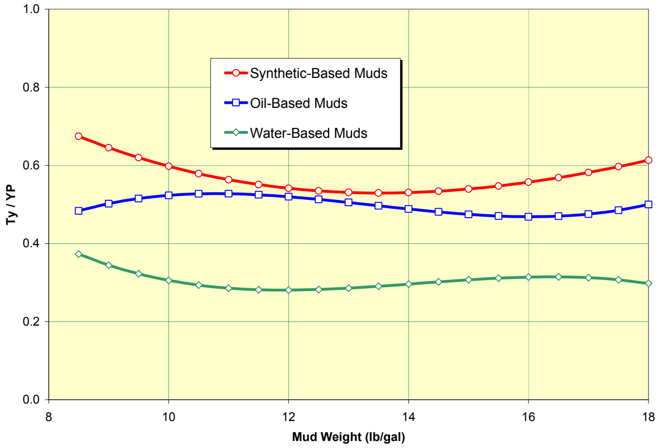

Fig. 4: τ_y/YP vs mud weight curves where τ_y values are based on 3-point curve-fitting technique.

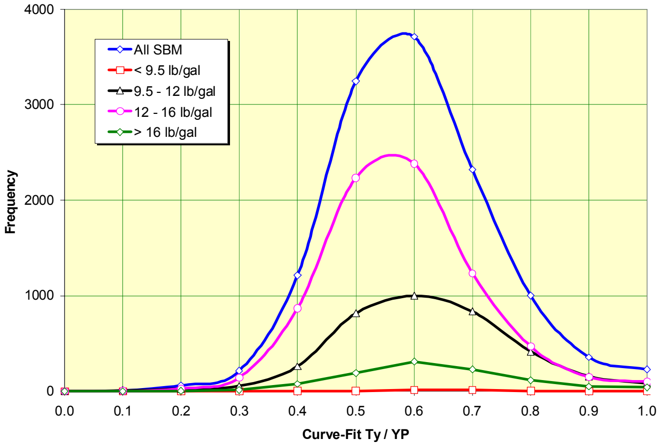

Fig. 5: Frequency chart for SBM data set.

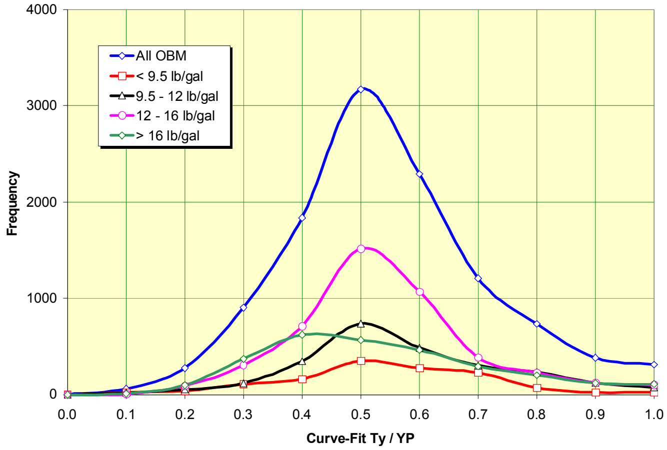

Fig. 6: Frequency chart for OBM data set.

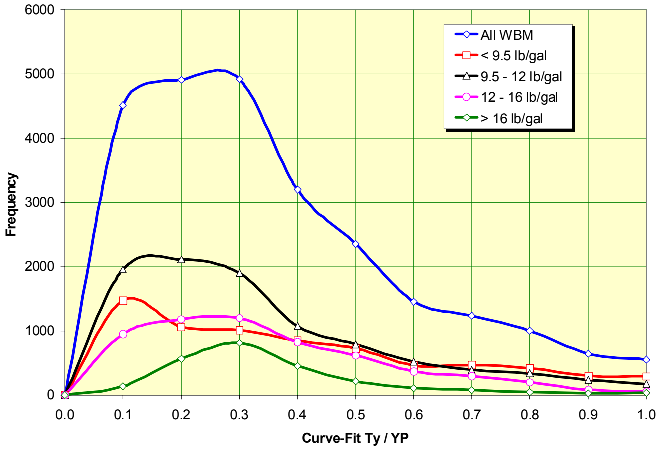

Fig. 7: Frequency chart for WBM data set.

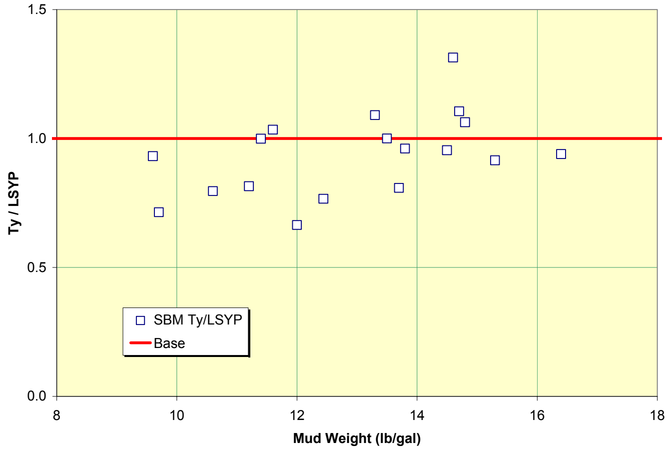

Fig. 8: SBM comparison of the ratio of measured yield stress (vane) and LSYP to mud weight.

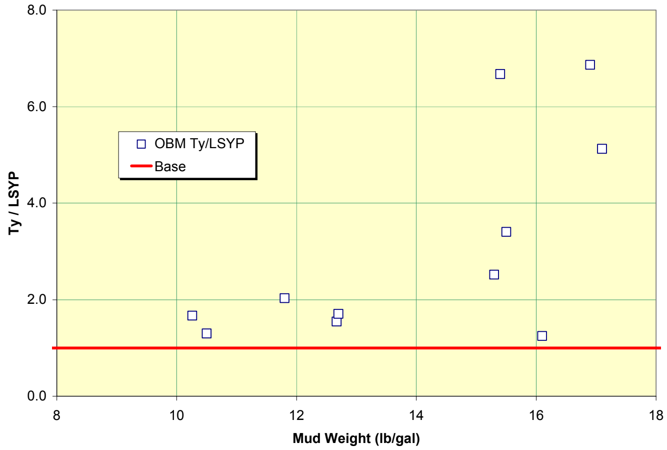

Fig. 9: OBM comparison of the ratio of measured yield stress (vane) and LSYP to mud weight.

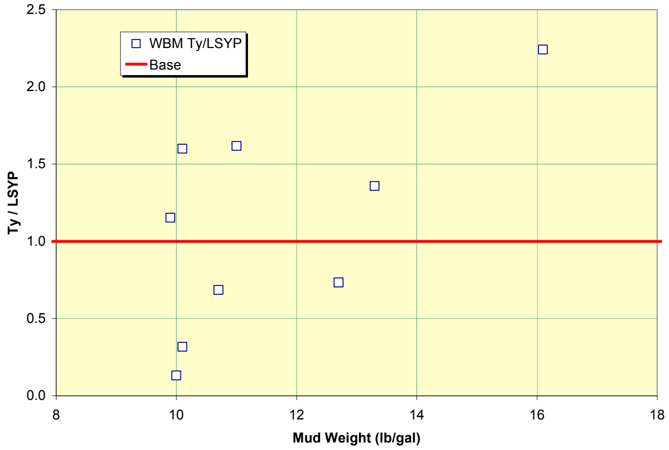

Fig. 10: WBM comparison of the ratio of measured yield stress (vane) and LSYP to mud weight.

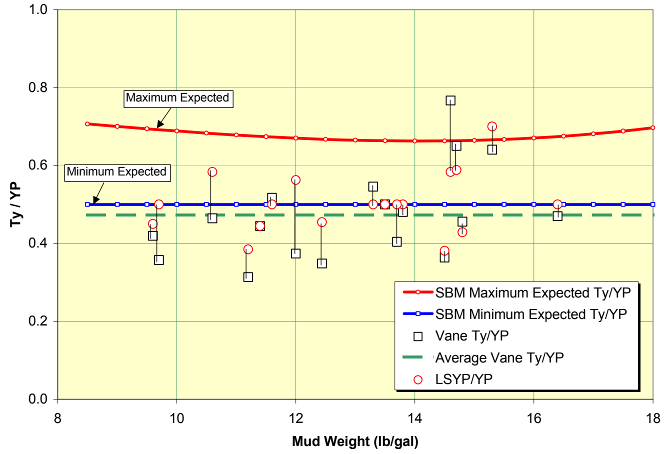

Fig. 11: SBM vane yield stress-yield point ratio as a function of mud weight.

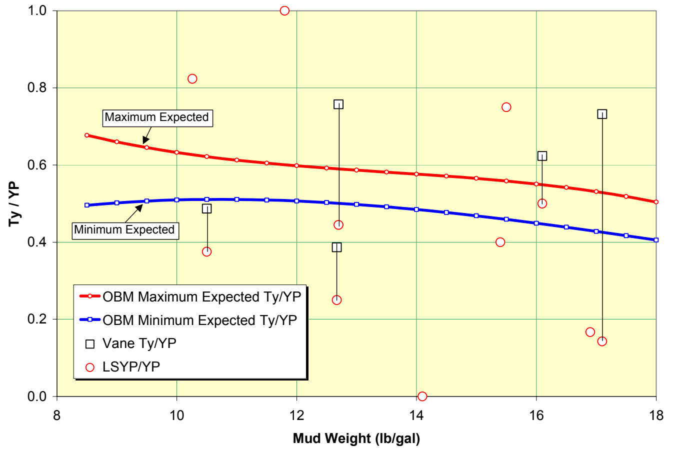

Fig. 12: OBM vane yield stress-yield point ratio as a function of mud weight.

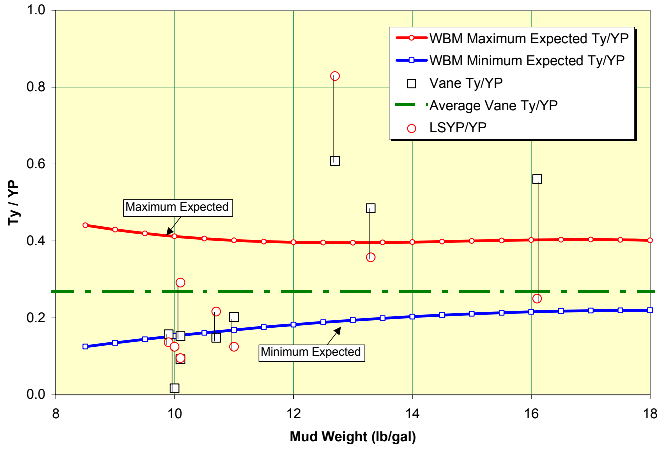

Fig. 13: WBM vane yield stress-yield point ratio as a function of mud weight.

Table 1: SBM mud weight, Fann 35 readings and vane-rheometer measurements.

Mud Type	MW (lb/gal)	Temp (°F)	R600	R300	R200	R100	R6	R3	Gels 10-s	Gels 10-m	LSYP	YP	LSYP/YP	Vane Ty (lb/100ft^2)	Ty/YP	Ty/LSYP	WACF Ty (lb/100ft^2)	3-PCF Ty (lb/100ft^2)
SBM	11.4	150	72	45	35	25	10	9	10	15	8	18	0.44	7.99	0.44	1.00	8.68	8.72
SBM	14.6	150	76	44	35	24	9	8	12	24	7	12	0.58	9.20	0.77	1.31	8.03	8.22
SBM	11.6	150	86	54	43	30	13	12	14	26	11	22	0.50	11.38	0.52	1.03	11.61	11.76
SBM	14.8	150	102	58	43	26	8	7	18	23	6	14	0.43	6.38	0.46	1.06	6.64	6.66
SBM	13.8	150	66	41	32	23	10	9	14	23	8	16	0.50	7.69	0.48	0.96	9.01	9.03
SBM	13.3	150	90	52	40	26	9	8	15	22	7	14	0.50	7.64	0.55	1.09	7.80	7.92
SBM	10.6	150	58	41	34	26	16	15	20	20	14	24	0.58	11.15	0.46	0.80	15.17	15.06
SBM	15.3	150	104	57	41	25	7	7	19	23	7	10	0.70	6.41	0.64	0.92	6.55	6.43
SBM	13.5	150	52	29	20	13	5	4	6	8	3	6	0.50	3.00	0.50	1.00	4.22	4.27
SBM	12.4	150	60	41	32	24	12	11	18	23	10	22	0.45	7.66	0.35	0.77	10.71	10.38
SBM	14.5	150	75	48	37	25	10	9	14	22	8	21	0.38	7.64	0.36	0.95	8.35	8.20
SBM	11.2	150	47	30	23	16	7	6	9	12	5	13	0.38	4.07	0.31	0.81	5.97	5.85
SBM	9.7	150	32	20	15	10	4	4	5	8	4	8	0.50	2.86	0.36	0.71	3.73	3.61
SBM	14.7	150	77	47	38	27	12	11	16	22	10	17	0.59	11.05	0.65	1.11	11.03	11.24
SBM	9.6	150	50	35	28	21	11	10	12	15	9	20	0.45	8.38	0.42	0.93	9.71	9.40
SBM	13.7	150	60	38	30	21	8	8	13	19	8	16	0.50	6.47	0.40	0.81	7.23	7.22
SBM	12.0	150	60	38	30	21	9	9	13	23	9	16	0.56	5.98	0.37	0.66	8.51	8.45
SBM	16.4	150	82	47	36	23	8	7	10	13	6	12	0.50	5.64	0.47	0.94	6.91	7.00
Avg													**0.50**		**0.47**	**0.94**		

Table 2: OBM mud weight, Fann 35 readings and vane-rheometer measurements.

Mud Type	MW (lb/gal)	Temp (°F)	R600	R300	R200	R100	R6	R3	Gels 10-s	Gels 10-m	LSYP	YP	LSYP/YP	Vane Ty (lb/100ft^2)	Ty/YP	Ty/LSYP	WACF Ty (lb/100ft^2)	3-PCF Ty (lb/100ft^2)
OBM	10.3	150	63	40	31	21	14	14	24	29	14	17	0.82	23.39	1.38	1.67	14.39	14.29
OBM	12.7	150	56	34	25	11	5	4	9	21	3	12	0.25	4.64	0.39	1.55	3.82	3.54
OBM	12.7	150	65	37	28	18	6	5	12	18	4	9	0.44	6.82	0.76	1.70	5.08	5.07
OBM	18.9	150	130	70	49	30	8	7	19	29	6	10	0.60	14.55	1.46	2.43	6.94	6.78
OBM	15.4	150	69	37	27	15	4	3	5	45	2	5	0.40	13.35	2.67	6.67	3.09	3.05
OBM	11.8	150	55	31	23	15	9	8	19	33	7	7	1.00	14.22	2.03	2.03	8.51	7.47
OBM	15.3	150	72	37	25	16	3	3	3	37	3	2	1.50	7.56	3.78	2.52	2.92	2.13
OBM	16.9	150	80	43	31	17	3	2	7	31	1	6	0.17	6.87	1.14	6.87	1.71	1.71
OBM	16.1	150	74	40	29	16	3	3	5	29	3	6	0.50	3.74	0.62	1.25	2.38	2.38
OBM	15.5	150	76	42	31	19	8	7	26	36	6	8	0.75	20.42	2.55	3.40	7.40	7.37
OBM	10.5	150	52	34	28	19	8	7	13	22	6	16	0.38	7.79	0.49	1.30	6.35	6.54
OBM	17.1	150	85	46	32	18	3	2	6	29	1	7	0.14	5.12	0.73	5.12	1.66	1.58
OBM	14.1	150	79	41	28	15	2	1	3	22	0	3	0.00	5.10	1.70	–	0.93	0.77
OBM	18.1	150	92	47	33	18	3	2	9	21	1	2	0.50	10.43	5.21	10.43	2.00	1.90
Avg													**0.53**		**1.78**	**3.61**		

Table 3: WBM mud weight, Fann 35 readings and vane-rheometer measurements.

Mud Type	MW (lb/gal)	Temp (°F)	R600	R300	R200	R100	R6	R3	Gels 10-s	Gels 10-m	LSYP	YP	LSYP/YP	Vane Ty (lb/100ft^2)	Ty/YP	Ty/LSYP	WACF Ty (lb/100ft^2)	3-PCF Ty (lb/100ft^2)
WBM	11.0	120	126	90	75	53	13	10	13	33	7	54	0.13	11.32	0.21	1.62	0.00	0.00
WBM	16.1	120	66	37	27	17	4	3	4	14	2	8	0.25	4.48	0.56	2.24	2.89	2.81
WBM	10.7	120	81	59	49	36	12	10	9	14	8	37	0.22	5.48	0.15	0.69	4.42	3.95
WBM	12.7	120	77	56	47	39	31	30	28	38	29	35	0.83	21.27	0.61	0.73	31.96	31.75
WBM	10.1	120	51	36	29	21	6	4	4	14	2	21	0.10	3.20	0.15	1.60	1.16	0.91
WBM	9.9	120	62	42	34	24	7	5	6	15	3	22	0.14	3.46	0.16	1.15	2.65	2.87
WBM	13.3	120	60	37	29	20	7	6	8	55	5	14	0.36	6.79	0.48	1.36	5.57	5.68
WBM	10.1	120	50	37	32	25	11	9	11	13	7	24	0.29	2.22	0.09	0.32	5.98	6.80
WBM	10.0	120	44	30	24	15	4	3	3	5	2	16	0.13	0.26	0.02	0.13	1.27	0.79
Avg													**0.27**		**0.27**	**1.09**		