Comparative Analysis between Mechanical and Non-Mechanical Homogenization Techniques for Field-used Drilling Fluid Laboratory Testing

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Abstract

Drilling fluid property measurements play a significant role in the drilling industry. They provide critical information to maintain wellbore integrity and offer an indication of potential drilling process issues. Standardizing the drilling fluid homogenization and testing procedure used on a synthetic-based field drilling fluid is essential. Standardization will reduce variability and generate more accurate and precise testing results. The focus of this study is to determine the effect diverse types of agitation have on laboratory tested drilling fluid properties. This homogenization technique comparison studies the difference between shaking fluid by hand (nonmechanical homogenization) and using a mechanical mixer (mechanical homogenization). Data was collected from 30 internal drilling fluids laboratories, including multiple technical centers and operations support laboratories, located in different geographic areas throughout the world. Participants were sent blind, field-used, drilling fluid samples and given specific instructions to conduct the homogenization and property testing using each lab's procedure. They documented their data by completing a questionnaire. The data was categorized into three groups of drilling fluid property types: rheological, non-rheological, and chemical. Based on the statistical inferences, results suggest that the difference between homogenization techniques have (a) a significant impact in the rheological properties of the fluid, (b) a varied impact on the non-rheological properties (i.e., electrical stability (ES), viscometer sag shoe testing (VSST), High Temperature High Pressure (HTHP) fluid loss), and (c) no impact on chemical properties. This study indicates that a standardized homogenization procedure is needed to ensure accurate results.

Introduction

The mixing procedure has a strong influence in the stability of the drilling fluid used in the field. Proper mixing is essential to produce stable rheology, electrical stability, and HTHP fluid loss properties of the fluid. Analogously, the small laboratory-scale mixing needs to have the same level of validated influence to achieve equivalent results. In many cases, laboratory testing directly contributes to field applications by translating lab-batch concentrations and properties to field-batch scale. Mixing procedures must be properly simulated to achieve more accurate results with minimum variability. The American Petroleum Institute (API) provides widely accepted recommendations for testing and mixing of water-base and oil-base drilling fluids, specifically in API RP 13B-1, API RP 13B-2, and API RP 13I, respectively. Recommended procedures for mixing fresh drilling fluids are given in API, however, reconstitution, or pre-mixing a field used drilling fluid before laboratory testing is only properly defined for HTHP filtration testing in API RP 13B-2 Sections 8.2–8.3.

There is a high level of importance placed on drilling fluid testing results comparison between values achieved in the field and those obtained in the lab, whether as an operator requested QA/QC or for pilot testing reasons. Good precision between field operations and technical laboratories is essential to allow better interpretation of data and provide more accurate drilling operation plans. As will be shown in this manuscript, this can be achieved and rooted from having better and standardized premixing of the fluid to be tested.

The purpose of the study is to evaluate the differences in measured values obtained from drilling fluids testing in samples where various levels of shear are introduced. Samples were sent to 30 different drilling fluids laboratories throughout the drilling service company internal network of laboratories – three technology centers and 27 operational support laboratories – spread across different geographic markets within six continents. Participation was voluntary and the coordination, communication, samples distribution, data collection, and analysis were conducted from the corporate technology center. Overall, it took approximately 11 months from introduction to distribution of results.

Scope of Experiment and Hypothesis

For this study, synthetic-based drilling fluid from the field was sent to all the participating laboratories. Samples were from the same batch of fluid, homogenized, and apportioned to identical containers. There were two main reason for using a field-used fluid, 1) good fluid stability, and 2) to evaluate reconstitution in a field operational setting. Instructions were

provided to all laboratories to reconstitute sample by a) shaking the container for 2 minutes by hand "vigorously", and b) mixing sample on a mechanical mixer according to local practice. API drilling fluid checks were conducted on each of the samples and the sets of data were compared. Rheological data was taken at both 80 degrees Fahrenheit (°F) and 150 °F.

For the purposes of this study, data were grouped into three different subsets within each of the categories of non-mechanical and mechanical reconstitution. First was the rheological data from a direct-indicating rotational viscometer. Second was the non-rheological data, which includes ES, HTHP volume, and VSST. And the third was the chemical data, which includes solids (% vol), oil (% vol), water (% vol), low gravity solids, high gravity solids, corrected solids (% vol), $CaCl_2$ content, whole mud chlorides, alkalinity of whole mud (P_{om}), and excess lime. Auxiliary data was also collected on the type of equipment used, length of time, and mixing speed. Auxiliary data was collected to provide supplementary information for variability root-cause analysis.

The overall hypothesis posed for this study is 'there is no significant difference between testing data obtained from mechanically and non-mechanically homogenized drilling fluid.' For the remainder of this study, non-mechanical homogenization is defined as drilling fluid shaken "vigorously" by hand for 2 minutes, and mechanical homogenization as mixing using available laboratory mechanical mixer. In this study, the terms reconstitution, homogenization, and mixing are used interchangeably.

Data Analysis

Data solicited from each of the 30 laboratories was analyzed objectively through comparative analysis statistics. Comparative analysis provides a more sound process to infer relative to the null hypothesis (H_0). For this study, the technique used was the analysis of variance (ANOVA) specifically, ANOVA: Single factor, as there was only one variable considered during the evaluation, which was the reconstitution method.

Statistical evaluation started by defining the H_0, which will be true to all the analyses of the fluid properties involved. The H_0 statement was established as there is no significant difference between the two homogenization techniques–mechanical and nonmechanical (hand shaking). The next step was conducting the analysis of variance for the two sets of data using the Microsoft Excel data analysis tool kit at 95% confidence interval, with the probability value (P-value) or alpha value, of 0.05. Any P-value greater than 0.05 is inferred to show data supporting the H_0 at 95% confidence interval.

Table 2 provides a visual example of the ANOVA analysis. The convention is reconstitution–shaking (RS) and reconstitution–mechanical (RM).

Table 1. Raw Data on Yield Point (YP) at 80°F.

Lab#	RSRT80 PV, cP	RMRT80 PV, cP
1	34	32
2	42	42
3	38	37
4	39	29
5	37	36
6	38	33
7	38	36
8	38	33
9	39	34
10	36	32
11	40	32
12	40	35
13	42	35
14	40	36
15	42	39
16	42	37
17	37	31
18	34	27
19	42	35
20	36	27
21	36	36
22	40	36
23	41	35
24	39	31
25	37	34
26	38	31
27	40	33
28	39	35
29	39	33
30	37	34
31	40	37

Table 2. ANOVA: Single Factor Analysis

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
RSRT80 PV, cP	31	1200	38.70968	5.012903
RMRT80 PV, cP	31	1053	33.96774	10.23226

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	348.5323	1	348.5323	45.72366	6.36E-09	4.001191
Within Groups	457.3548	60	7.622581			
Total	805.8871	61				

Where:
SS = Sum of squares, df = Degree of freedom, MS = Mean sum of squares, F = F-value, P-value = Probability value, F crit = F-value critical

Note: SS, df, and MS are statistical parameters in the calculation of variances for the ANOVA analysis to determine F, F crit, and P-value. For simplicity, in the purposes of evaluation, only P-value was used.

Table 2 presents descriptive statistics and ANOVA analysis on the data collected from each lab. Note from **Table 1** that there are 31 sets of data for the subset rheological data. This is because analysis of the fully automated viscometer was conducted at the Houston technology center for data comparison.

As with **Table 1** and **Table 2**, all comparative analyses were done similarly, and results were presented in the following tables which were split into three subset property groups, rheological, non-rheological, and chemical, as detailed in the Scope of Experiment and Hypothesis sections.

I. Rheological Properties–RS vs. RM

Table 3. Rheological Properties

Properties	P-Value	Statistical Inference
At 80 ºF		
600 rpm	0.00000006	Significant difference
300 rpm	0.00001	Significant difference
200 rpm	0.005	Significant difference
100 rpm	0.424	No significant difference
6 rpm	0.044	Significant difference
3	0.002	Significant difference
PV	0.000000006	Significant difference
YP	0.004	Significant difference
10-sec gel	0.046	Significant difference
10-min gel	0.0001	Significant difference
At 150ºF		
600 rpm	0.244	No significant difference
300 rpm	0.317	No significant difference
200 rpm	0.013	Significant difference
100 rpm	0.007	Significant difference
6 rpm	0.002	Significant difference
3 rpm	0.001	Significant difference
PV	0.002	Significant difference
YP	0.002	Significant difference
10-sec gel	0.012	Significant difference
10-min gel	0.062	No significant difference

Where: PV = Plastic Viscosity, YP = Yield Point.

Table 3 represents the ANOVA testing conducted on the rheological data subset. Out of the 20 rheological properties analyzed, 16 were inferred to have statistically significant differences between the two homogenization techniques. Overall, a generalization can be inferred that the data does not support the H_0, regardless of the testing temperature.

II. Non-rheological Properties–RS vs. RM

Table 4. Non-rheological Properties

Properties	P-Value	Statistical Inference
ES @ 120ºF	0.005	Significant difference
VSST	0.168	No significant difference
HTHP fluid loss @ 250ºF	0.068	No significant difference

Table 4 represents the ANOVA testing for the non-rheological data subset. electrical stability (ES) showed a statistically significant difference between reconstitution methods. This can be explained by the property dependence on the emulsion nature of the sample. High level of emulsion can be achieved through high shear rate mixing, and therefore

through mechanical mixing. On average, ES was 352 Volts for mechanical mixing vs. only 159 Volts for manual shaking.

Viscometer sag shoe test (VSST) statistical inference can be attributed to the test method itself. The testing method includes a conditioning mixing step prior to the actual measurement, which rendered the test independent of the initial homogenization–either mechanical or nonmechanical.

High temperature, high pressure (HTHP) fluid loss (FL) statistical inference can be accredited to the density and nature of the test sample. The test sample was a premade field-used drilling fluid batch with an established density. It was fully homogenized prior to portioning and distribution to the different laboratories. Therefore, as the data showed, the difference in homogenizing the sample prior to testing was not enough to induce variability to the fluid loss volume.

III. Chemical Properties–RS vs. RM

Table 5. Chemical Analysis (Solids and Chemical Analysis)

Properties	P-Value	Statistical Inference
Solids, % vol	0.948	No significant difference
Oil, % vol	0.411	No significant difference
Water, % vol	0.265	No significant difference
Corrected solids, %	0.921	No significant difference
LGS, %	0.906	No significant difference
LGS, lb/bbl	0.978	No significant difference
HGS, %	0.868	No significant difference
HGS, lb/bbl	0.935	No significant difference
CaCl₂, % by wt	0.974	No significant difference
Cl-, Whole mud, mg/L	0.220	No significant difference
POM	0.983	No significant difference
Excess lime, lb/bbl	0.972	No significant difference

Where: LGS = Low gravity solids, HGS = High gravity solids.

Under the data subset of chemical properties, there were 12 data points collected. **Table 5** shows the homogenization techniques do not have an influence on the chemical makeup and properties of the drilling fluid. Based on the statistical inferences, the data favored support of the null hypothesis.

IV. Variability and Limitations–Equipment/Procedures

Part of the general study was to determine the root causes or the probable causes or both that could explain the observed inconsistencies. Interestingly, it was of absolute importance to study the types of mechanical mixers and mixing methods used by the participating laboratories due to their direct influence on rheological and non-rheological testing.

As initially stated, the instructions on fluid reconstitution given to the laboratories were minimal leading to subjective interpretation of mixing. This point was evident in the variability which is present in the types of mixers as shown in **Fig. 1.**
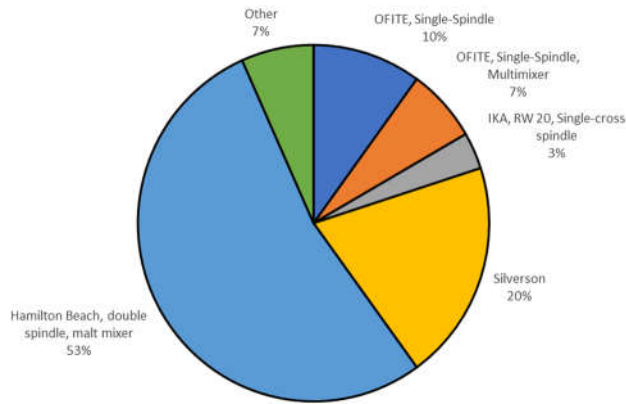
Fig. 1—Breakdown by mixer type used.

From the chart, majority (53%) of the mixers used were double spindle "malt" (DBHB) type mixers, and 20% mixed using a basket type (Silverson) mixer, with other types of mixers being used in smaller, varying percentages. It is worth understanding the statistical relationships between these majority type of mixers, and as such, the results between the use of Silverson mixers vs. the DBHB were evaluated, see **Table 6** and **Table 7**.

Table 6. Rheological Properties–Silverson vs. DBHB

Properties	P-Value	Statistical Inference
At 80 ºF		
600 rpm	0.819	No significant difference
300 rpm	0.546	No significant difference
200 rpm	0.622	No significant difference
100 rpm	0.942	No significant difference
6 rpm	0.200	No significant difference
3 rpm	0.794	No significant difference
PV	0.319	No significant difference
YP	0.046	Significant difference
10-sec gel	0.082	No significant difference
10-mi gel	0.592	No significant difference
At 150ºF		
600 rpm	0.492	No significant difference
300 rpm	0.443	No significant difference
200 rpm	0.985	No significant difference
100 rpm	0.475	No significant difference
6 rpm	0.605	No significant difference
3 rpm	0.180	No significant difference
PV	0.769	No significant difference
YP	0.559	No Significant Difference
10-sec gel	0.679	No significant difference
10-min gel	0.960	No significant difference

Table 7. Non-rheological Properties–Silverson vs. DBHB

Properties	P-Value	Statistical Inference
ES @ 120ºF	0.305	No significant difference
VSST	0.152	No significant difference
HTHP fluid loss @ 250ºF	0.356	No significant difference

Based on the above tables, generally, at 95% confidence interval, the data supported the H_0 that there is no significant difference between the use of the Silverson and the DBHB mixers. Results imply each equipment type was efficient in inducing highly stable emulsions through high shearing or mixing or both through fine screens.

Another point of variability inherent to this study was the time and speed used to reconstitute the drilling fluids, which was not specified to the laboratories. Speed and time of shear introduced to a drilling fluid were direct contributing factors to stability and consequently the properties, with higher shear and longer time assumed to give higher stability in drilling fluids. Refer to **Fig. 2** for the variability in mixing speed and time introduced by the laboratories.
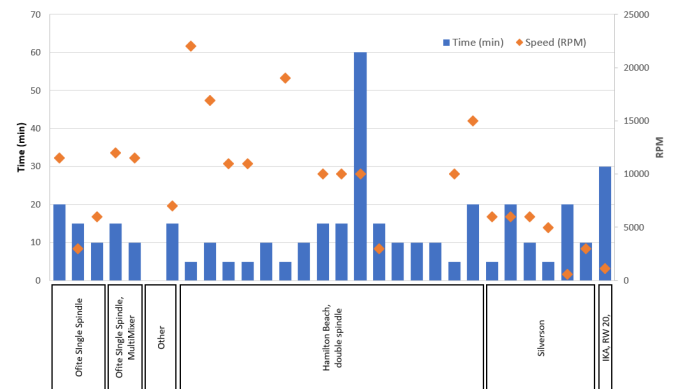

Fig.2—Mixing speed and time.

Fig. 2 shows the differences in speeds and times introduced to the drilling fluid before testing. This should also be considered a limitation of the study because variability is inherent with varying speeds and times. However, considering the varied speeds relative to the use in the study of the Silverson vs. the DBHB, the identified differences have minimum to no significant effect.

This study only examined one type of fluid: Synthetic-base drilling fluid. Results of this study cannot be considered transferable to other fluid types, i.e., water-base or oil-base, etc. Some limitations were discussed in the previous section that include the failure to consolidate mixer type and mixing procedure leading to variability, which becomes inherent when not accounted for.

Conclusions
From the analysis conducted in this study it is concluded that the difference between homogenization techniques has (a) a significant impact in the rheological properties of the fluid, (b) a varied impact on the non-rheological properties, and (c) no impact on chemical properties. The implications of these findings promote the importance of using mechanical methods to increase stability of fluids, where necessary, for lab-scale use. These findings also show that from a comparative standpoint, from field to laboratory, it is necessary to

consolidate procedures for reconstituting/homogenizing field drilling fluids.

It is shown in this study that the electrical stability of a mechanically reconstituted drilling fluid is significantly different than that which is not. This implies ES is a function of the shear introduced into a field drilling fluid.

The general hypothesis, presented in this paper is not specific enough to predict significant differences within the different data subsets, in particular the chemical subset. With industry experience, it can be implicitly predicted that the chemical properties of a previously homogenized drilling fluid would not change even with induced shear in the pre-testing mixing procedure. This prediction was proven to be true where the validation showed no significant difference in chemical fluid properties. This could very well be predicted by an experienced professional, but this study provides evidentiary support.

In the industry, the stability of a field fluid is considered to be higher than a lab-mixed or large-batch mixed fluid. This can be assumed to be because of the shear introduced to the fluid in the drilling process (i.e., pumps, bit nozzles, wellbore). This study shows a statistically significant difference between nonmechanically and mechanically homogenized fluids in drilling fluid laboratory testing results.

Acknowledgments

References

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