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Rheology Predictions for Drilling Fluids after Incorporating Lost Circulation Material

Garima Misra, Dale E. Jamison, Donald L. Whitfill, Halliburton

Abstract

Lost circulation is one of the most expensive problems encountered in drilling and is a major contributor to non-productive time (NTP).[1] Sometimes the measurement of drilling fluid rheology for fluids containing lost circulation material (LCM) is difficult or impossible using a standard bob and sleeve rheometer. The development of a predictive model for drilling fluid rheology would make the rheology determination easier, more efficient, and possibly more accurate.

A valid hydraulic model with the resultant viscosity-predicting algorithms has been developed to account for the effects of additions of LCM to non-aqueous drilling fluids (NAF). Rheology predictions can be made for non-aqueous fluids containing LCM with sufficient accuracy to minimize error on equivalent circulating density (ECD) predictions. Further work has been done to evaluate the application of this model to water-based mud (WBM) and to determine what effect drill solids have on the accuracy of the predicted rheology values when LCM is added.

Laboratory experiments have been conducted for different types of dispersed and non-dispersed water-based systems containing LCM to test the efficacy of the existing hydraulics modeling software with the LCM viscosity module. The rheology measurements were conducted after adding three different LCM types: ground marble (GM), resilient graphite carbon (RGC) and fiber containing natural oil (F). These materials were added individually and in combination, maintaining the appropriate ratio. Good agreement has been observed between measured versus predicted rheological values for non-dispersed WBMs. Three different types of drill solids were added before the addition of LCM. Satisfactory results were obtained between measured and predicted rheological values for the fluids containing specified amounts of drill solids.

The results of the laboratory work will be discussed for both the extension of the model to WBM and the effect of drill solids on both WBM and OBM.

Introduction

A hydraulically valid model with the resultant viscosity predicting algorithms has been developed for LCM additions to non-aqueous drilling fluids.[2] The rheology predictions obtained are very useful for predicting ECD values after LCM treatment. Due to frequent demand and the perceived environmental friendliness of WBMs, the extension of this model to these systems is needed. Accordingly, a project was initiated to verify the efficacy and prediction accuracy of the existing model for WBM.

Prediction of Rheology for Non-Aqueous Fluids after the Addition of LCM

The model allows multiple products at different concentrations to be added to a fluid and the resultant dial readings predicted. **Figure 1** shows how the standard six-speed oilfield rheometer dial readings are input under the "Starting Fluid" section. The algorithm then sequentially processes the products under the "Added Products" section and outputs the final dial readings under the "Predicted Rheology" section. The predicted dial readings are then used to calculate PV, YP, n, k and tau0 for hydraulics along with the new fluid density. Only GM, RGC and F are included in the current version where very good agreement has been observed between predicted and measured data for LCM addition. **Table 1** presents measured vs predicted rheology data for 20 lb/bbl addition of GM to 12.0-lb/gal synthetic-based mud (SBM). The ECD percentage error was calculated for an 8.5" x 5" annulus with a 10,000-ft MD and TVD at a 500-gpm flow rate, and is very acceptable for hydraulic calculations. In addition, the model algorithm has a built-in analysis method to determine the constants for other products.

Experimental Results and Discussion

An experimental project was undertaken in three parts. Part I verifies the efficacy of the existing model for three different WBMs, which includes (i) dispersed water-based mud (DWBM; (ii) non-dispersed, low solid high performance water-based system (NDWBS); and (iii) clay-free, high-performance water-based system (CFHPWBS).

Part II presents the extension of the current model by development of parameters for (a) natural oil containing fiber as new LCM; and (b) addition of drill solids to SBM.

Part III deals with the prediction accuracy of the current model for LCM addition after drill solids are added to the water-based system.

Part I: Predicting Rheology for WBM Using the Model

A series of tests were conducted for the three different water-based systems. These tests were conducted for seven different combinations of LCM, individually and in combination. The amount of LCM was calculated (**Table 2**) to maintain a constant volume of LCM in each mud sample. These tests investigated the accuracy of rheology predictions after LCM addition for the current model. **Tables 3 and 4** show good agreement between measured and predicted data for the CFHPWBS after addition of GM-25 and RGC-50 individually (**Figures 2 and 3**). Slightly higher predictions were observed for addition of 20.4 lb/bbl F. Regardless, the data accuracy is acceptable for use in hydraulics analysis, since the ECD % error calculated for an 8.5" x 5" annulus with 10,000-ft MD and TVD at 500-gpm flow rate is only 1.45 (**Figure 4 and Table 5**).

ECD calculations were performed using proprietary hydraulics design software (HDS)[1] for both measured and predicted rheology data and the %ECD error was calculated assuming the measured value for the rheology to be correct. Figure 1 is a screen shot of the model where standard six-speed rheometer dial readings are input under the "Starting Fluid" section. By selecting and entering the amount of LCM, the algorithm sequentially processes the products and displays the resultant readings under the "Predicted Rheology" section. For the two and three LCM product additions, the predicted results were very close to the measured values (**Figures 5-8**). Even though the current model was designed for clay-free OBM, the results provide good rheology predictions for this clay-free WBM.

Another set of experiments was conducted on the NDLSWBS utilizing the same ratio of LCM vs fluid. **Tables 6 and 7** show the complete set of rheology data for different combinations of LCM for this system. The measured vs predicted rheology values were not in as good agreement as before for some LCMs. Some good predictions were observed for individual F additions at 20.4 lb/bbl, and in combination with GM-25. The additive assumption was also tested for three products: RGC-50@11.2 lb/bbl, GM-25@16.9 lb/bbl and F@6.1 lb/bbl. Very good agreement was observed between measured and predicted data for these product additions (**Table 8**).

A dispersed water-based system was also investigated in order to verify the prediction competence of the current model for WBM containing clay and chemical dispersants. Maintaining the same ratios of LCM as before, rheology measurements were conducted on a FANN® Model 35 viscometer at 120°F. Lower rheology predictions were observed as compared to the measured values. For some LCM additions fluid thickening was observed which hindered the rheology measurements. **Tables 9 and 10** show comparative results of measured vs predicted rheology for RGC 50 and GM 25 additions. Reducing the LCM amount by half for RGC-50 and GM-25 resulted into good agreement of the rheology data between measured and predicted values before hot rolling, but hot rolling resulted into higher rheology and poorer agreement with the predicted values.

The model does not take into account chemical interactions, thus does not work as well on dispersed systems, as shown by these data.

Part II: Development of Parameters for New LCM F and Drill Solids for NAFs as an Extension of Current Model

a. Natural oil-containing fiber as new LCM

The rheology prediction accuracy of the current model after addition of the new fiber (F) LCM was carried out on a 12.0-lb/gal clay-free SBM. The same ratios of LCM vs fluid volume were maintained throughout. Rheology predictions for the new fiber were surprising. A drop in viscosity after F addition was observed after hot rolling. **Table 11** presents the comparison of measured and predicted rheometer dial readings with an increase in concentration of F from 6 lb/bbl to 24 lb/bbl. Increasing the concentration of F resulted in higher rheology predictions while lower values were measured. Again, this is likely attributed to the model not taking into account chemical interactions, since the current model utilizes an equation where addition of solids will result in higher viscosity, but the reverse case has been observed for F addition, possibly because of the natural oil in the fiber. This indicates that a different set of model parameters must be developed for use with this fiber.

b. Effect of drill solids in NAFs on model prediction accuracy

A series of tests were conducted to determine the prediction accuracy of the current viscosity model after drill solids addition to SBM. The study was conducted with 12.0-, 15.0- and 18.0-lb/gal mud weights. Three different types of drill solids, A, B and C, were selected for the addition, individually and in combination. The mineralogical data for the drill solids are presented in **Table 12**. A drill-solids-free base system was formulated for each mud weight. Drill solids at 3% by volume (27.3 lb/bbl) were added to the base system and rheology measurements were performed before and after hot rolling. The additive assumption is tested using two- and three-product combinations: (I) 14.5 lb/bbl RGC-50 and 26.7 lb/bbl GM-25; (II) 11.2 lb/bbl RGC-50, 16.9 lb/bbl GM-25 and 6.1 lb/bbl F.

For the 12.0-lb/gal systems very good agreement was observed for all types of drill solids for Set (I) LCM combination using RGC-50 & GM-25 (**Tables 13-16**) For the Set (II) LCM combination, Measured vs Predicted dial readings were also in good agreement. (**Tables 17-20**). This confirms the good predictive accuracy of the current model in the presence of drill solids.

Further testing was performed on 15.0-lb/gal SBM with drill solids. For Set (I) LCM combination (**Table 21**) measured vs predicted rheology data were not as close as observed in the 12.0-lb/gal system. For Set (II) LCM combinations, (**Table 22**) better results were obtained, which showed closer predictions when all types of drill solids were included.

Drill solids addition was also performed on an 18.0-lb/gal system where both types of LCM combinations were tested (**Tables 22 and 23**). For the LCM Set (I) combination (RGC-50/ GM-25) predictions were not good (Table 23). For the LCM Set (II) combination, good agreement was observed between measured and predicted rheology (**Table 24**).

Part III: Prediction Accuracy of the Rheology Model after Drill Solids Addition in a WBM

In another set of experiments, drill solids addition was studied in a 12.0-lb/gal non-dispersed, low solid HPWBS. All drill solids were tested while maintaining the same ratios of LCM. For the 12.0-lb/gal mud, drill solids [A] addition followed by addition of Set (I) LCM combination resulted in good prediction accuracy between measured and predicted rheology. For the Set (II) LCM combination, predicted rheology was low compared to the measured values (**Table 25**). For the drill solids [B] addition, Set (I) LCM combination resulted in good rheology predictions with the exception of the 600 rpm reading. For the Set (II) LCM combination, predicted values were lower than measured values (**Table 26**). In the [C] type drill solids addition, where smectite is 82%, for the LCM (I) combination, lower predicted values were observed as compared to measured rheology values. The same observation was made for the Set (II) LCM combination, where predicted values were again lower compared to measured values (**Table 27**). In the last case where all three types of drill solids were added, lower values were predicted for both types of LCM combination (**Table 28**).

Conclusions

Part I: Tests made on different WBM systems conclude that the current predictive rheology model works well for non-dispersed water based systems and can simulate several additions of various LCM materials. With some modifications a better model is possible which can predict the LCM-laden viscosity for both WBM and OBM.

Part II: The behavior for fiber containing natural oil was surprising. The current model version uses an equation where increasing the amount of solid results in higher viscosity. The addition of a new fiber LCM containing natural oil resulted in a rheology drop in the SBM, which indicates that a different set of model parameters must be developed for use with this material. The prediction accuracy of the current model in presence of drill solids for 12.0- and 15.0-lb/gal systems was found to be acceptable, but for the 18.0-lb/ gal mud weight system a noticeable difference was observed between measured and predicted rheology data.

Part III: The accuracy of the current model was tested in the presence of different drill solids for WBM and SBM. The current model provides acceptable data in most cases. Further work to better define model parameters at higher mud weights may improve the accuracy.

In conclusion, the current model has been proven to be an effective tool to predict LCM-laden viscosity of drilling fluids, which can simulate several additions of various LCM materials and the determined model parameters are found to be independent of particle size, mud weight and OWR.

Acknowledgments

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Nomenclature

lb/gal = *Pounds per gallon*
LCM = *Lost circulation material*
ECD = *Equivalent circulation density*
NPT =*Non productive time*
RGC =*Resilient Graphite Carbon*
GM =*Ground Marble*
F = *Fiber*
WBM =*Water based Mud*
OBM =*Oil Based Mud*
gpm =*Gallon Per minute*
HPWBS =*High Performance water based system*
SBM =*Synthetic based mud*
OWR = *Oil Water Ratio*

References

1. Whitfill D.L., Jamison D.E.., Wang H, and C. Thaemlitz. 2006 "New Design Models and Materials Provide Engineered Solutions to lost Circulation," Paper 101693 presented at the SPE Russian Oil and Gas Technical Conference and Exhibition, Moscow, Russia, 3-6 October.
2. Jameson D.E. and D. Whitfill. "New Model Predicts the Impact of LCM Addition on Non-Aqueous Drilling Fluid Rheology", *Hart's E&P*, September 1, 2006.

Figures

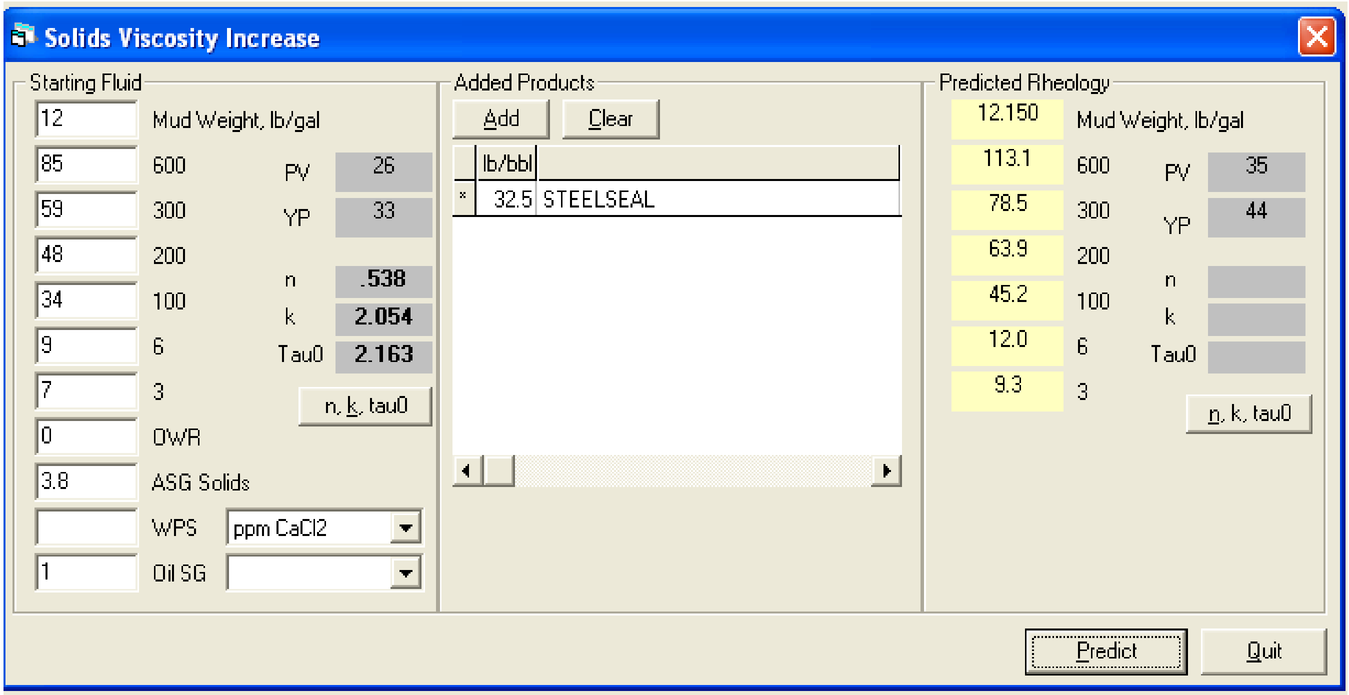

Figure 1 Screen shot of Display from the Model

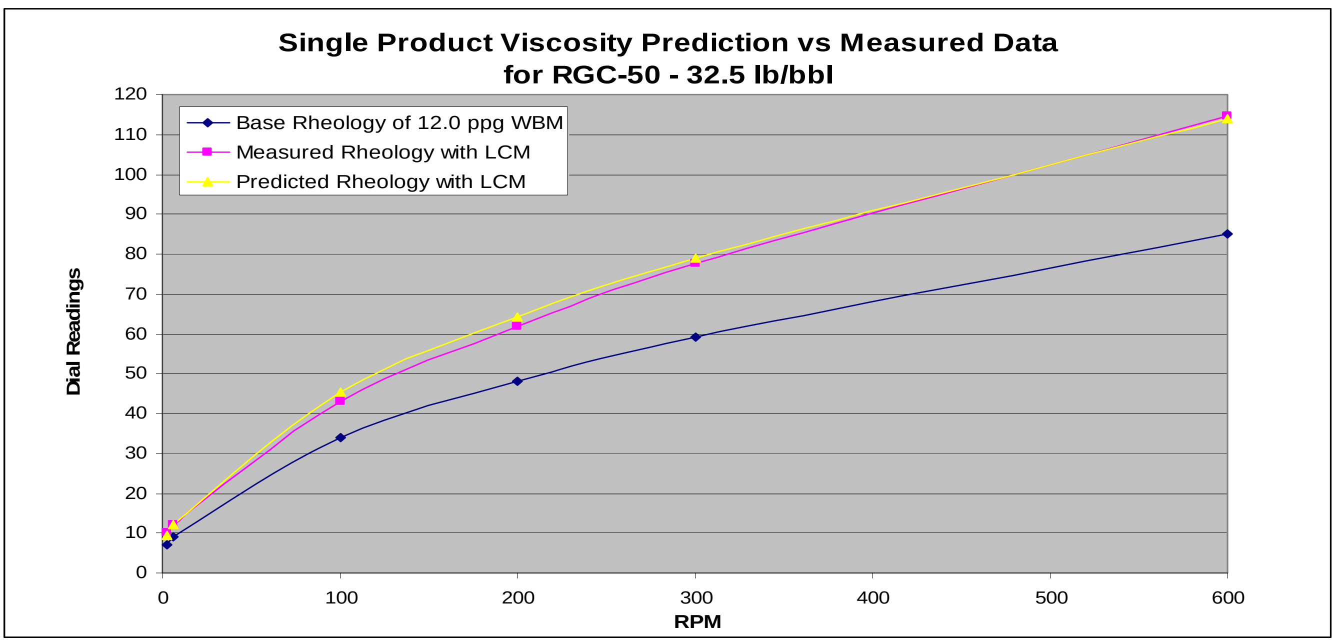

Figure 2 Rheology Prediction after Mixing RGC-50 LCM to 12.0 lb/ gal Clay Free HPWBS

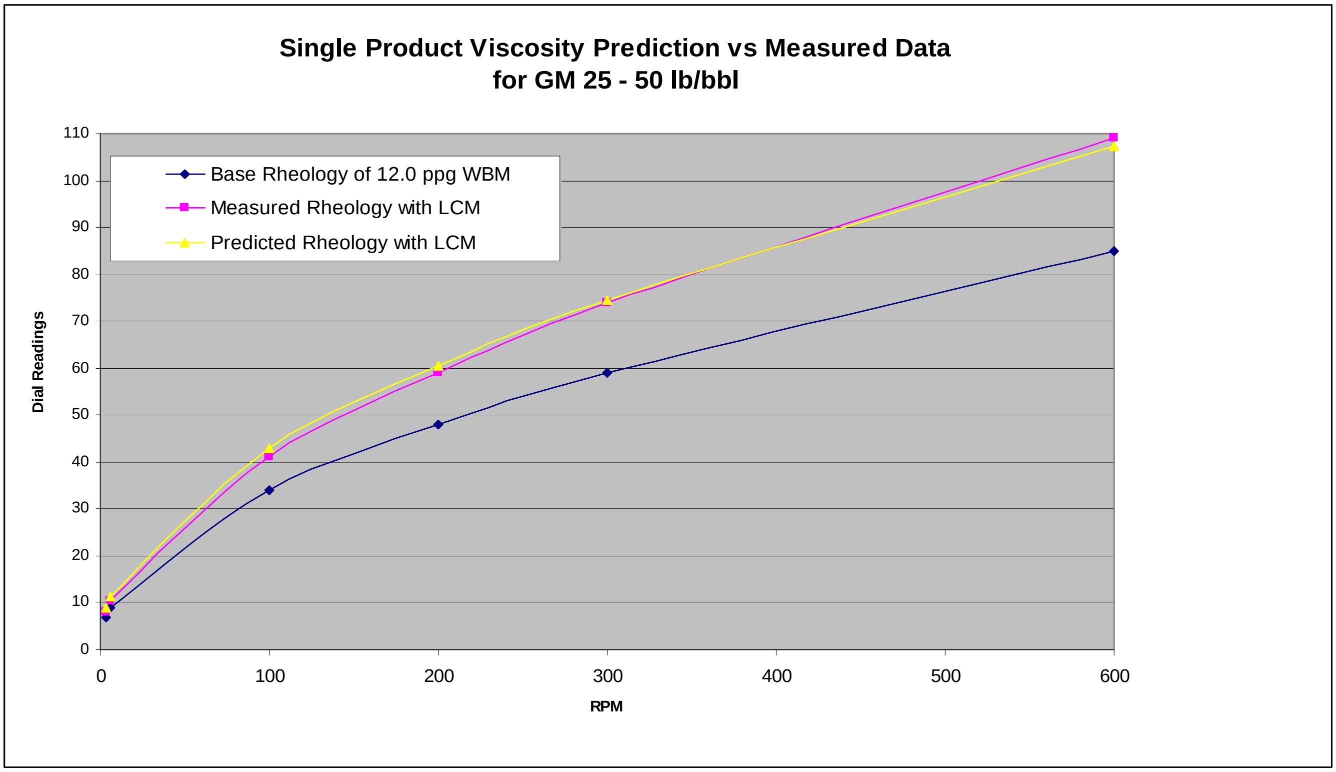

Figure 3 Rheology Prediction after Mixing GM-25 LCM to 12.0-lb/ gal Clay Free HPWBS

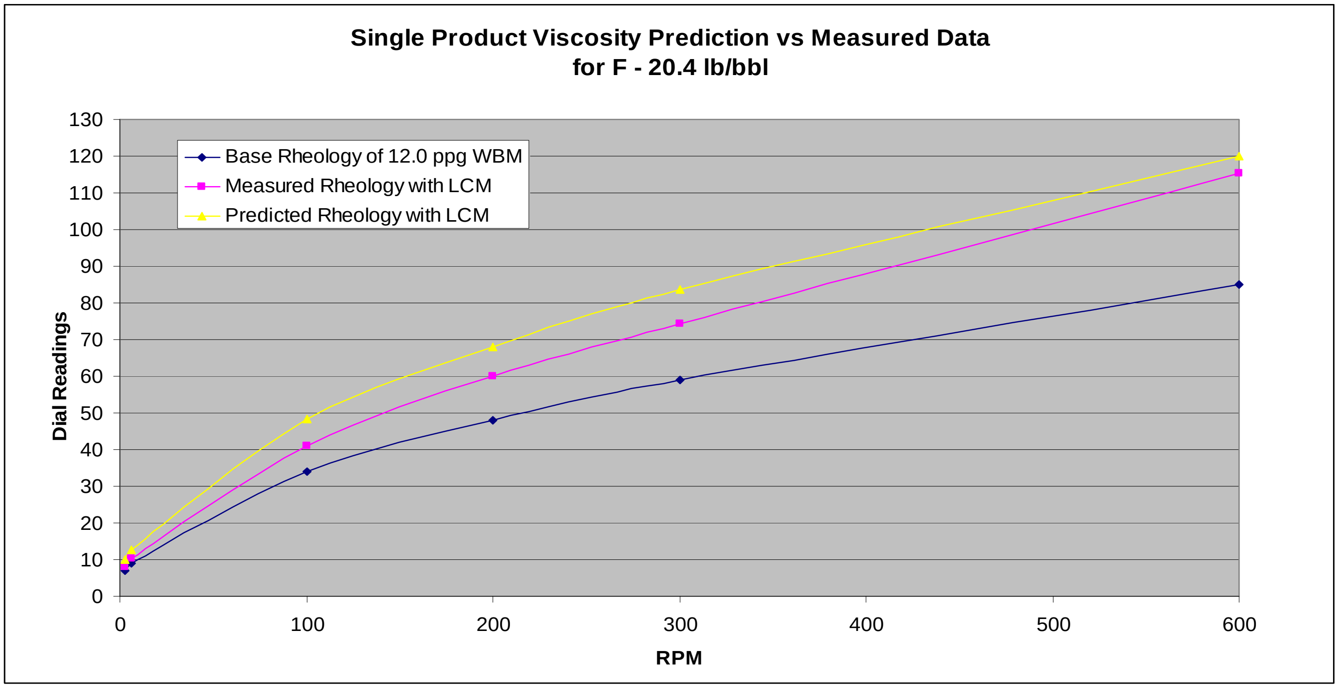

Figure 4 Rheology Prediction after Mixing F LCM to 12.0-lb/ gal Clay Free HPWBS

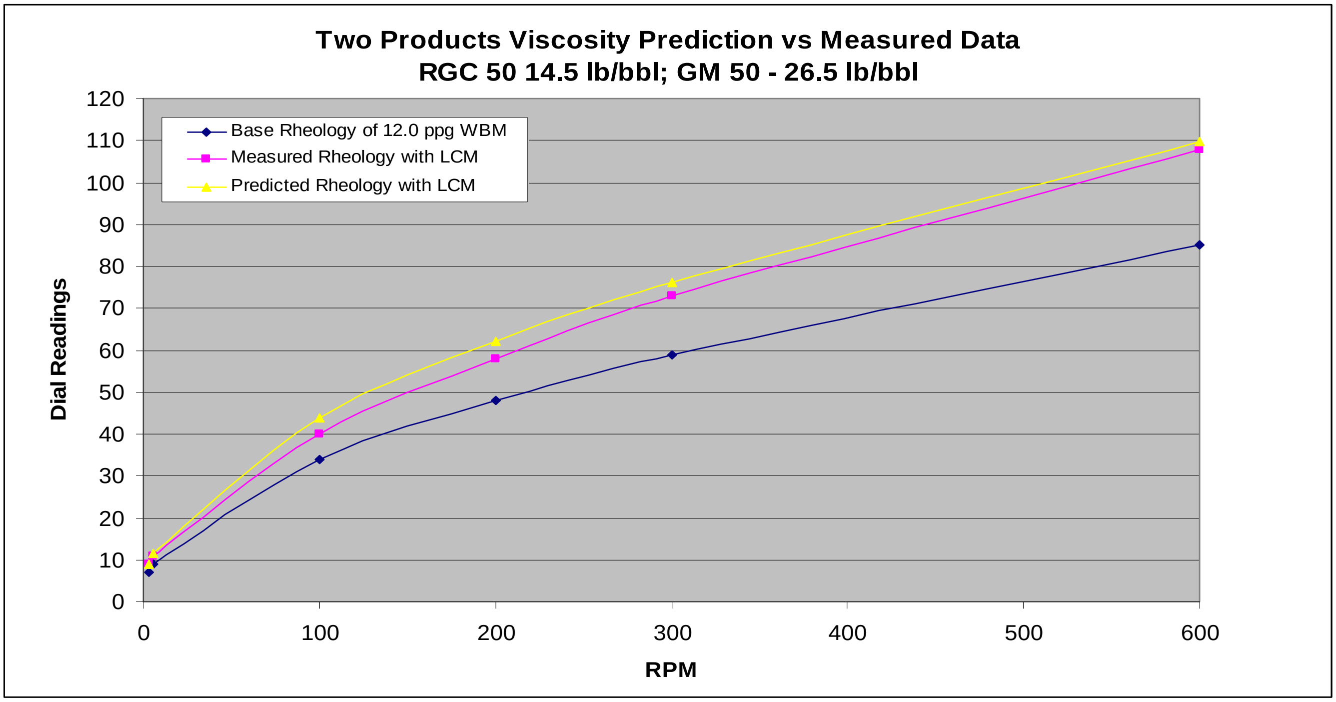

Figure 5 Rheology Prediction after Mixing RGC 50/ GM 25 LCM to 12.0-lb/ gal Clay Free HPWBS

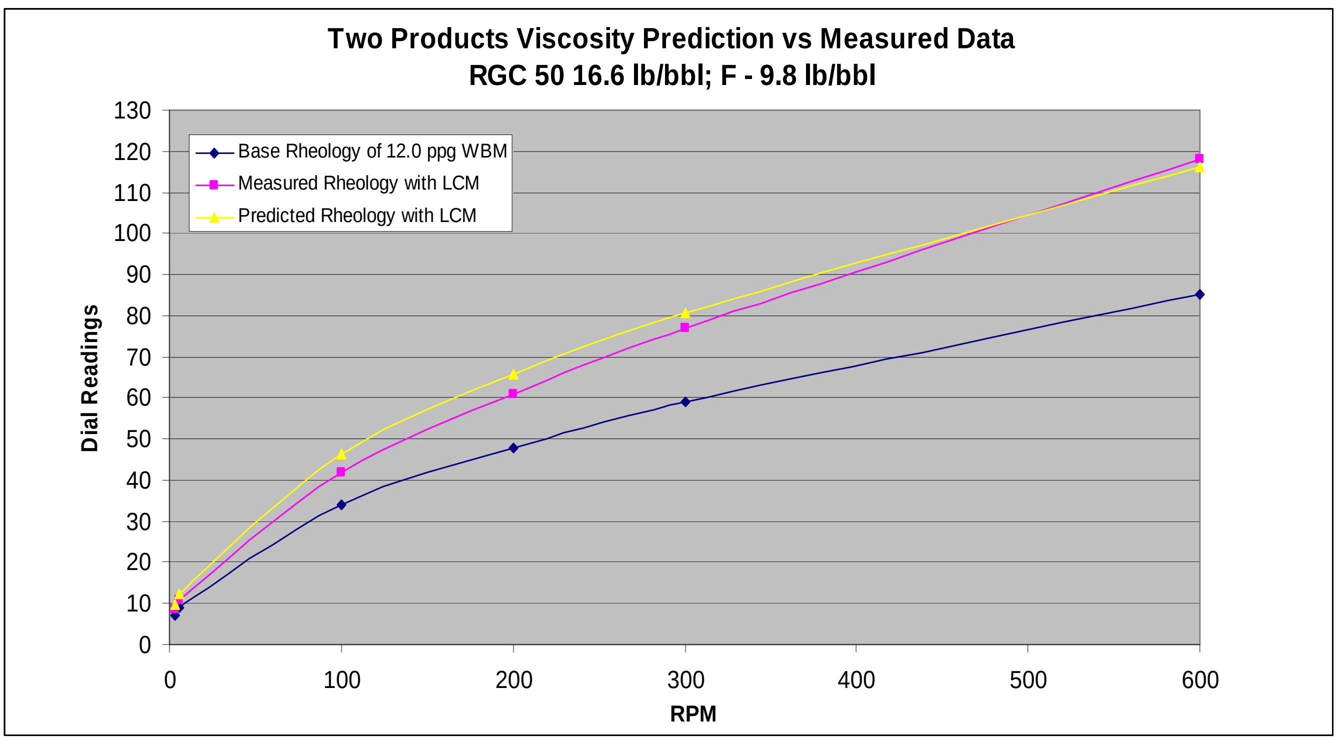

Figure 6- Rheology Prediction after Mixing RGC 50/ F Components to 12.0-lb/ gal Clay Free HPWBS

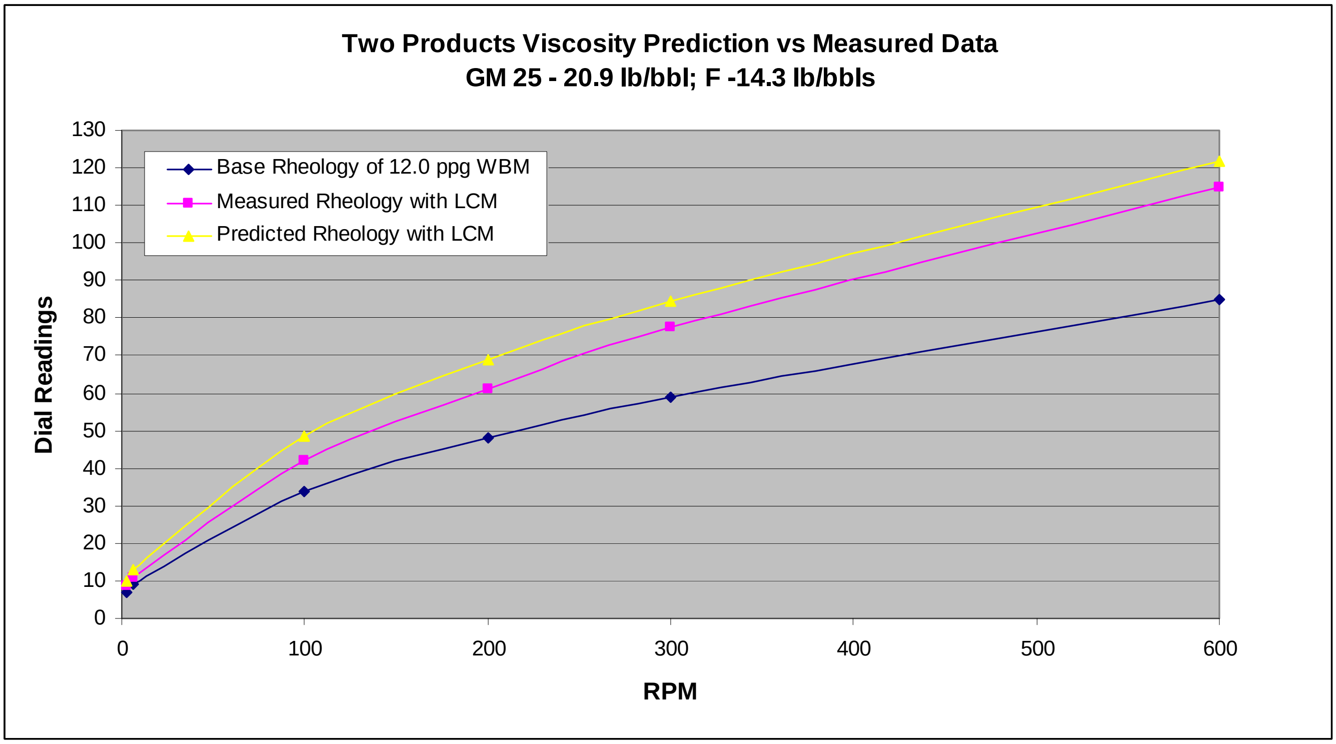

Figure 7 Rheology Prediction after Mixing GM 25/ F LCM to 12.0-lb/ gal Clay Free HPWBS

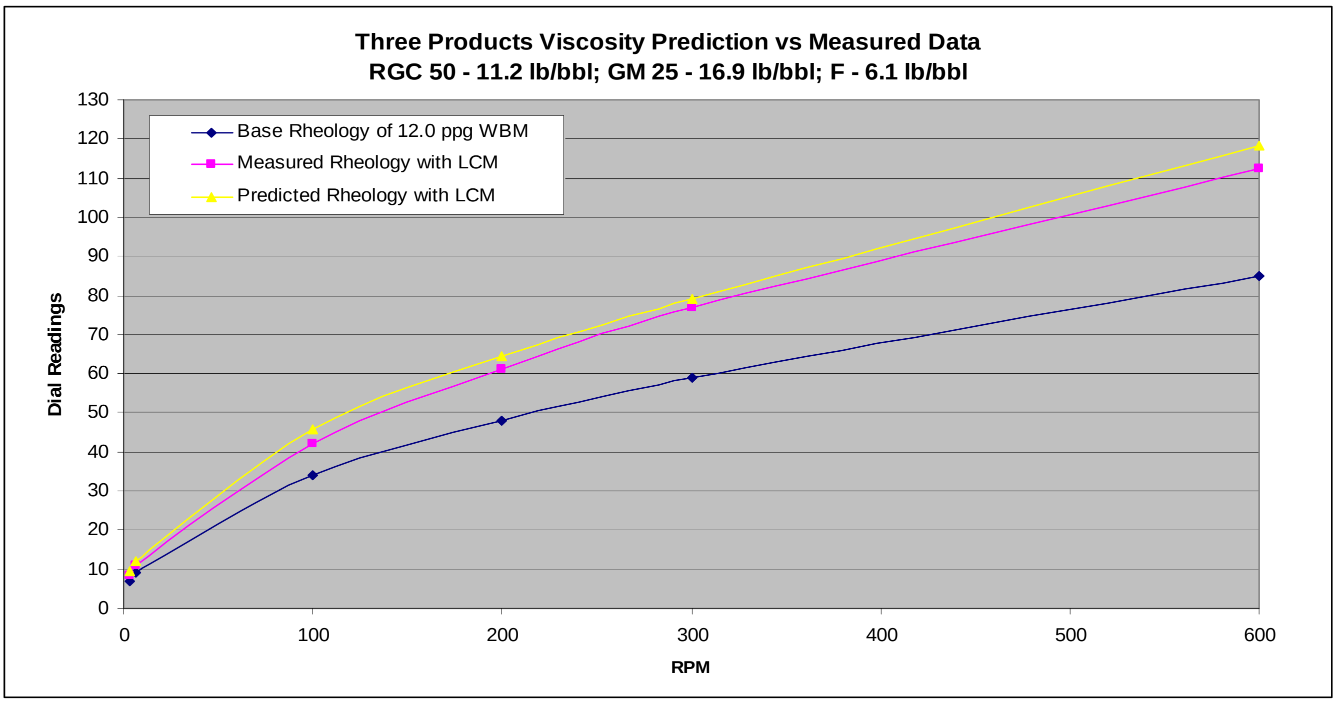

Figure 8 Rheology Prediction after Mixing RGC 50/ GM 25/ F LCM to 12.0-lb/ gal Clay Free HPWBS

Tables

Table 1: Measured vs. Predicted Rheology for GM Addition			
RPM	**Base Rheology**	**20 lb/bbl of GM addition Measured**	**20 lb/bbl of GM addition Measured**
600	53	58	57.7
300	35	39	38.1
200	27	30	29.4
100	19	21	20.7
6	8	9	8.7
3	6	7	6.5
ECD ERROR %			0.15

Table 2: Combinations of LCM and Treating Rates (lb/bbl)		
RGC - 50	**GM 25**	**F**
32.5	-	-
-	50	-
-	-	20.4
14.5	26.7	-
16.6		9.8
	20.9	14.3
11.2	16.9	6.1

Table 3: Measured vs. Predicted Rheology RGC 50 Product Addition to 12.0-lb/ gal Clay Free HPWBS		
RPM	**Measured 32.5 lb/bbl RGC 50**	**Predicted 32.5 lb/bbl RGC 50**
600	114.5	113.9
300	77.5	79
200	62	64.3
100	43	45.5
6	12	12.1
3	10	9.4
ECD ERROR %		0.39

Table 4: Measured vs. Predicted Rheology GM 25 Product Addition to 12.0-lb/gal Clay Free HPWBS		
RPM	Measured 50 lb/bbl GM 25	Predicted 50 lb/bbl GM 25
600	109	107.2
300	74	74.4
200	59	60.6
100	41	42.9
6	10.5	11.4
3	8	8.8
ECD ERROR %		0.34

Table 5: Measured vs. Predicted Rheology F Product Addition to 12.0-lb/gal -Clay Free HPWBS		
RPM	Measured 20.4 lb/bbl F	Predicted 20.4 lb/bbl F
600	115.5	120.5
300	74.5	83.6
200	60	68
100	41	48.2
6	10.5	12.8
3	8	9.9
ECD ERROR %		1.45

Table 6: Measured vs. Predicted Rheology Data for Single Product Addition to Non-dispersed, Low Solids HPWBMS						
	RGC 50 addition 32.5 lb/bbl		GM 25 Addition 50 lb/bbl		F Addition 20.4 lb/bbl	
RPM	Measured	Predicted	Measured	Predicted	Measured	Predicted
600	81	90.1	77	87.4	99.5	92.8
300	49	55.3	46	54.3	65	57
200	37	42.5	34	41.7	51	43.8
100	23	27.0	21	26.5	34	27.8
6	5	6.4	4	6.3	10.5	6.6
3	3.5	4.5	3	4.4	8	4.6

Table 7 : Measured vs. Predicted Rheology Data for Two Product Addition to Non-dispersed, Low Solids HPWBMS						
	14.5 RGC 50 and 26.7 GM 25 lb/bbl addition		16.6 RGC 50/9.8 F lb/bbl		20.9 GM 25 and 14.3 F lb/bbl addition	
RPM	Measured	Predicted	Measured	Predicted	Measured	Predicted
600	80	88.1	128	91	98	94.9
300	47	54	74	58.9	60	58.3
200	35	41.5	56	45.2	45	44.7
100	22	26.4	36	28.8	28	28.5
6	5	6.3	8	6.9	5	6.8
3	4	4.4	5	4.8	3.5	4.7

Table 8: Measured vs. Predicted Rheology Data for Three Product Addition to Non-dispersed, Low Solids HPWBMS		
	11.2 RGC 50/16.9 GM 25 and 6.1F lb/bbl addition	
RPM	**Measured**	**Predicted**
600	95	89.7
300	58	55.1
200	44	42.3
100	27	26.9
6	5	6.4
3	3.5	4.5

Table 9: Measured vs. Predicted Rheology Data for RGC50 Addition to Dispersed Water Based Mud				
RPM	**Base Mud Rheology**	**RGC 50 addition 32.5 lb/bbl**		
		Measured (BHR)	**Measured (AHR)**	**Predicted**
600	62.5	102	134	84.3
300	36.5	62	85	49.2
200	27	47	65	36.4
100	17	30	42	22.9
6	4.5	8	11	6.1
3	3.5	6	9	4.7

Table 10: Measured vs. Predicted Rheology Data for GM25 Addition to Dispersed Water Based Mud				
RPM	**Base Mud Rheology**	**GM 25 addition 50 lb/bbl**		
		Measured (BHR)	**Measured (AHR)**	**Predicted**
600	62.5	94	123	79
300	36.5	57	77	46.2
200	27	43	59	34.1
100	17	27	38	21.5
6	4.5	7	10.5	5.7
3	3.5	6	8.5	4.4

Table 11: Measured vs. Predicted Rheology Data for F Addition to Dispersed Water Based Mud							
RPM	**Base Mud Rheology**	**Measured 6 lb/bbl F**	**Predicted 6 lb/bbl F**	**Measured 12 lb/bbl F**	**Predicted 12 lb/bbl F**	**Measured 24 lb/bbl F**	**Predicted 24 lb/bbl F**
600	76	81	82.6	84	90.3	78	110.2
300	50	55	54.3	55	59.4	46	72.5
200	39	45	42.4	44	46.3	36	56.5
100	29	33	31.5	31	34.4	24	42.0
6	14	14	15.2	11.5	16.6	8	20.3
3	12.5	12	13.6	10	14.8	7	18.1

Table 12: Mineralogical Data for Different Drill Solids			
Drill solids	**[A]**	**[B]**	**[C]**
Quartz, wt %	96 %	26	16
K Feldspar- wt%	2 %	tr	1
Na-feldspar wt%	1%	3	1
Plagioclase Feldspar, wt%	-	3	1
Smectite, wt %	-	20	82
Illite, wt %	1%	49	-
Kaolin, wt %	-	1	-
Chlorite	-	2	-
Calcite	trace	-	-

Table 13: Measured vs. Predicted Rheology Data 12.0-lb/gal SBM with Type [A] Drill Solids and RGC-50/GM-25 LCM			
RPM	**Measured Rheology for 27.3 lb/bbl [A] drill solids addition**	**Measured Rheology for [14.5 RGC-50 / 26.7 GM-25] lb/bbl LCM addition**	**Predicted Rheology for [14.5 RGC-50 / 26.7 GM-25] b/bbl LCM addition**
600	67	84	85.8
300	44	57	56.3
200	35	46	44.8
100	25	33	33.3
6	10.5	14	13.4
3	9	12	11.5

Table 14: Measured vs. Predicted Rheology Data 12.0-lb/gal SBM with Type [B] Drill Solids and RGC-50 / GM-25 LCM			
RPM	**Measured Rheology for 27.3 lb/bbl [B] drill solid addition**	**Measured Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**	**Predicted Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**
600	81	104	103.8
300	54	71	69.2
200	44	57	56.4
100	31	41	39.7
6	13.5	17	17.3
3	12	15	15.4

Table 15: Measured vs. Predicted Rheology Data 12.0-lb/gal SBM with Type [C] Drill Solids and RGC-50 / GM-25 LCM			
RPM	**Measured Rheology for 27.3 lb/bbl [C] drill solid addition**	**Measured Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition**	**Predicted Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**
600	83	113	106.3
300	55	76.5	70.5
200	45	62.5	57.7
100	33	45	42.3
6	14	18.5	17.9
3	12	16.5	15.4

Table 16: Measured vs. Predicted Rheology Data 12.0-lb/gal SBM with Type [A/B/C] Drill Solids and RGC-50/GM-25 LCM			
RPM	**Measured Rheology after 27.3 lb/bbl addition Combination**	**Measured Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**	**Predicted Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition**
600	81	104	103.8
300	54	71.5	69.2
200	43	57	55.1
100	32	42	41
6	13.5	17	17.3
3	12	15	15.4

Table 17: Measured vs. Predicted Rheology Data 12.0-lb/gal SBM with Type [A] Drill Solids and RGC-50/GM-25/F LCM			
RPM	**Measured Rheology for 27.3 lb/bbl [A] drill solids addition**	**Measured Rheology for [11.2 RGC-50/16.9 GM-25 /6.1 F] lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F] lb/bbl LCM addition**
600	67	92	89.5
300	44	61	59.7
200	35	49	47.5
100	25	35	35.3
6	10.5	12	14.2
3	9	10	11.5

Table 18: Measured vs. Predicted Rheology Data 12.0-lb/gal SBM with Type [B] Drill Solids and RGC-50 / GM-25/ F LCM			
RPM	**Measured Rheology for 27.3 lb/bbl [B] drill solid addition**	**Measured Rheology for [11.2 RGC-50/16.9 GM-25 /6.1 F]lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F]lb/bbl LCM addition**
600	80	113	108.5
300	54.5	76	73.9
200	44	61	59.7
100	32	42.5	43.4
6	13.5	17.5	18.3
3	12	15.5	16.3

Table 19: Measured vs. Predicted Rheology Data 12.0-lb/gal SBM with Type [C] Drill Solids and RGC-50 / GM-25/F LCM			
RPM	**Measured Rheology for 27.3 lb/bbl [C] drill solid addition**	**Measured Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F]lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F]lb/bbl LCM addition**
600	82.5	110	111.9
300	55	74	74.6
200	45	59.5	61
100	32	42	43.4
6	13	17	17.6
3	11	15	14.9

Table 20: Measured vs. Predicted Rheology Data for 12.0-lb/gal SBM with Type [A/B/C] Drill Solids and RGC-50 / GM-25/F LCM			
RPM	**Measured Rheology after 27.3 lb/bbl addition Combination**	**Measured Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition**
600	80	112	108.7
300	54	74	73.4
200	43	59	58.4
100	32	41	43.5
6	12.5	15.5	17
3	11	13.5	14.9

Table 21: Measured vs. Predicted Rheology Data for 15.0-lb/gal SBM with Drill Solids and RGC-50 / GM-25 LCM												
RPM	**Rheology for 27.3 lb/bbl [A] drill solids addition**	**Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**		**Rheology for 27.3 lb/bbl [B] drill solids addition**	**Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**		**Rheology for 27.3 lb/bbl [C] drill solids addition**	**Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition**		**Rheology for [27.3 lb/bbl] drill solids addition (Combined)**	**Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition**	
		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.
600	114.5	170	151.6	130	186.5	172.1	141	201	186.7	137	185	181.4
300	77	115	101.9	89	126	117.8	98	134	129.8	92	125.5	121.8
200	63	94	83.4	75	104	99.3	81	112	107.2	75.5	104	100
100	48	70	63.6	55	77.5	72.8	60.5	82.5	80.1	56	77	74.1
6	24	34	31.8	30	40	39.7	33.5	44	44.4	32	42	42.4
3	22	31	29.1	28	37	37.1	30.5	40	40.4	30	39	39.7
Meas. = Measured; Pred. = Predicted												

Table 22: Measured vs. Predicted Rheology Data for 15.0-lb/gal SBM with Drill Solids and RGC-50/GM-25/F LCM

RPM	Rheology for 27.3 lb/bbl [A] drill solids addition	Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition		Rheology for 27.3 lb/bbl [B] drill solids addition	Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition		Rheology for 27.3 lb/bbl [C] drill solids addition	Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition		Rheology for 27.3 lb/bbl drill solids addition (Combined)	Rheology for [11.2 RGC-50/ 16.9 GM-25/6.1 F] lb/bbl LCM addition	
		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.
600	116	147	165.3	132	179	188.1	138	195	196.7	131	181	186.7
300	71	101	101.2	90	122	128.3	96.5	130.5	137.5	87	123	124
200	58	82.5	82.7	75	102	106.9	80	108	114	72.5	101	103.3
100	42.5	61.5	60.6	57	76	81.2	61	80	86.9	55	74.5	78.4
6	21.5	30.5	30.6	34	44/5	48.5	34	52	48.5	32	43	45.6
3	20	28	28.5	32	41	45.6	32	50	45.6	29	41	41.3

Meas. = Measured; Pred. = Predicted

Table 23: Measured vs. Predicted Rheology Data for 18.0-lb/gal SBM with Drill Solids and RGC-50 / GM-25 LCM

RPM	Measured Rheology for 27.3 lb/bbl [A] drill solids addition)	Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition		Measured Rheology for 27.3 lb/bbl [B] drill solids addition	Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition		Measured Rheology for 27.3 lb/bbl [C] drill solids addition	Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition		Measured Rheology for 27.3 lb/bbl drill solids addition (Combined)	Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition	
		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.
600	91	138	124.9	111	175	152.4	110	293	151	103	o/s	141.4
300	48	74	65.9	64	100	87.9	63	162	86.5	59	185	81
200	35	52	48.1	48	75	65.9	47	117	64.5	44	132	60.4
100	21	30.5	28.8	31	46.5	42.6	30.5	68	41.9	28	73	38.4
6	6	7.5	8.2	13	19	17.8	11.5	13	15.8	11	17	15.1
3	5	6	6.9	12	17	16.5	10.5	11	14.4	10	15	13.7

Meas. = Measured; Pred. = Predicted

Table 24: Measured vs. Predicted Rheology Data for 18.0-lb/gal SBM with Drill Solids and RGC-50 / GM-25/F LCM

RPM	Measured Rheology for 27.3 lb/bbl [A] drill solids addition)	Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition		Measured Rheology for 27.3 lb/bbl [B] drill solids addition	Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition		Measured Rheology for 27.3 lb/bbl [C] drill solids addition	Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition		Measured Rheology for 27.3 lb/bbl drill solids addition (Combined)	Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition	
		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.		Meas.	Pred.
600	91	149	134.8	111	171	164.4	110	174	162.9	103	164	152.6
300	49	78	71.1	64	98.5	94.8	63	98	93.3	59	92	87.4
200	35	55	51.8	48	74	71.1	47	73	69.6	44	68	65.2
100	21	33	31.1	31	48	45.9	30.5	46	45.2	28	42	41.5
6	6	9	8.9	13	17.5	19.3	11.5	16	17	11	14	16.3
3	5	7	7.4	12	16	17.8	10.5	14.5	15.6	10	13	14.8

Meas. = Measured; Pred. = Predicted

Table 25: Measured vs. Predicted Rheology 12.0-lb/gal WBM with drill solid [A] and LCM					
RPM	**Measured Rheology for 27.3 lb/bbl [A] drill solids addition)**	**Measured Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition**	**Predicted Rheology for [14.5 RGC-50/26.7 GM-25] lb/bbl LCM addition**	**Measured Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/16.9 GM-25/6.1 F] lb/bbl LCM addition**
600	72	90	93.2	123	96.9
300	44	53	57	68	59.2
200	31	40	40.1	53	41.7
100	20	25	25.9	34	26.9
6	4	4	5.2	7	5.4
3	3	3	3.9	5	4

Table 26: Measured vs. Predicted Rheology 12.0-lb/gal WBM with Drill Solids [B]and LCM					
RPM	**Measured Rheology for 27.3 lb/bbl [B] drill solids addition)**	**Measured Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition GM]**	**Predicted Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition GM]**	**Measured Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F] lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F] lb/bbl LCM addition**
600	86	116	111.3	134	115.8
300	53	70	67.3	80	70
200	39	52.5	50.5	62	52.5
100	24	33	31.1	39	32.5
6	5.5	6	7.1	8	7.4
3	4	4.5	5.2	6	5.4

Table 27: Measured vs. Predicted Rheology 12.0-lb/gal WBM with Drill Solids[C] and LCM					
RPM	**Measured Rheology for 27.3 lb/bbl [C] drill solids addition)**	**Measured Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**	**Predicted Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition**	**Measured Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F] lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F] lb/bbl LCM addition**
600	110	159	142.4	164	148.1
300	67	100	86.7	104	90.2
200	52	77	67.3	80	70
100	34	49	44	54	45.8
6	8	10.5	10.4	15	10.8
3	6	9	7.8	13	8.1

Table 28: Measured vs. Predicted Rheology 12.0-lb/gal WBM with Drill Solid[A/B/C] and LCM					
RPM	**Measured Rheology for 27.3 lb/bbl Combined drill solids addition)**	**Measured Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition GM]**	**Predicted Rheology for [14.5 RGC-50/ 26.7 GM-25] lb/bbl LCM addition GM]**	**Measured Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F] lb/bbl LCM addition**	**Predicted Rheology for [11.2 RGC-50/ 16.9 GM-25 /6.1 F] lb/bbl LCM addition**
600	84	122/4	108.8	144	113.1
300	51	75	66	87	68.7
200	38	57	49.2	65	51.2
100	24	35	31.1	41	32.3
6	5	7	6.5	8	6.7
3	4	5	5.2	6	5.4