Gypsum Mud Rheological Behavior

Wissam, H., AL-Hashimi,

Baghdad Oil Training Institute

Abstract:

Gypsum muds are considered as the most important ones used in oil well drilling due to their thermal stability in addition to the durability of their ingredients. The main aim of this work is to study the effect of the gypsum mud compositions on their rheological behavior under the conditions of high-pressure and high temperature. Eleven samples of gypsum mud were tested using Fann viscometer model 50-C. All the tested samples had the same trend of reduction in both plastic viscosity and yield point with increasing temperature. The results showed that with 5 ppb of Q Broxine thermal degradation is obtained at approximately 150 ^{0} F; this is due to the over treatment with thinner which result in more soluble solids and higher rheological properties while the decrement in NaOH concentration from 0.7 ppb to 0.35 ppb results in an increase in both yield point and plastic viscosity; this is due to the loss of OH^{-1} ions. Six rheological models were adopted: Bingham, power law, modified power law, Robertson stiff, modified Robertson stiff and Casson. Both Robertson stiff model and Casson model showed more acceptable values that fit the experimental data accurately.

Keywords: Gypsum, Gypsum drilling fluids, Types of drilling mud, Inhibitive muds, Gypsum mud rheology, Rheological models, Borehole stability.

الخلاصة:

تعتبر سوائل الحفر الجبسية احد أهم السوائل المستخدمة في عملية حفر الابار النفطية وذلك لاستقراريتها الحرارية وثبات مكوناتها الداخلية.

أن الغرض الرئيسي من اعداد هذا البحث هو دراسة تأثير مكونات الاطيان الجبسية على خواصها الجريانية في ظروف البئر الحقيقية والمتمثلة بالضغط العالي ودرجة الحرارة العالية حيث تم اجراء الفحوصات المختبرية لأحد عشر نموذج من هذه الاطيان بأستخدام جهاز (Fann 50-C) حيث اثبتت النتائج ان جميع النماذج المفحوصة كان لها نفس الميل من الانخفاض لكل من اللزوجة اللدائنية ونقطة المطاوعة مع زيادة درجة الحرارة وان اضافة ٥ (باون/برميل) من مادة Q Broxine ادت الى حدوث تحلل حراري عند درجة حرارة ١٥٠ درجة فهرنهايت بسبب الزيادة المفرطة للمخفف المذكور بينما اظهرت النتائج حدوث انخفاض في قيم الخواص التيارية لسائل الحفر عند تقليل تركيز مادة NaOH من ٠.٧ الى ٠.٣٥(باون / برميل) وذلك بسبب نقصان تركيز ايون الهيدروكسيل (OH^{-1}) كما تم في هذا البحث تطبيق ستة أنظمة ريولوجية وفق برنامج يعمل بالحاسوب وبنظام الـ(Excel) لمعرفة مدى مطابقة نتائج فحوصات هذه النماذج لتلك الانظمة وهي :-

1- نظام بنكهام بلاستك.

٢- نظام القانون ألأسي.

٣- نظام القانون الأسي المطور.

٤- نظام روبرتسون ستف.

٥- نظام روبرتسون ستف المطور.

٦- نظام كاسون.

لقد اثبتت النتائج ان كل من نظامي روبرتسون ستف وكاسون كانا الاكثر تطابقا مع نتائج البيانات المختبرية للنماذج المفحوصة.

Introduction:

The composition of any drilling mud depends mainly on the requirement of the particular drilling operation. Economics, contamination, available make up water, pressure, temperature and many other factors are all significant in the choice of the drilling fluids [1]. Water alone is sometimes an ideal drilling fluid and frequently used to drill areas where the trouble of low pressure formation exists. When water cannot perform the necessary function of drilling fluid, it becomes necessary to add other ingredients to improve its performance or perhaps, even to change the nature of the fluid itself. Gypsum is the base materials for gypsum-based drilling fluids that are designed to convert smectitic clays by ion exchange to their calcium form and thereby limit their hydration and swelling [2].They were introduced in Western Canada as a means of drilling Anhydrite and prepared by adding calcium sulfate ($CaSo_4$) to bentonite dispersed in fresh water, starch or CMC was added to reduce filtration rate. These muds are normally formulated by converting existing sodium based fluid at a predetermined depth during drilling operations. The conversion can be made on fresh, brackish and sea water muds. Gypsum is added to the system to create soluble calcium content of 600-800 mg/l in the filtrate to inhibit the swelling and dispersion of the hydratable clays. An excess of 2-6 ppb of Gypsum should be monitored in the fluid to ensure that the soluble calcium will not drop below the desired levels [3] .The main purpose of this experimental work done is to study the effect of ingredients concentrations of Gypsum mud on their rheological properties, thermal stability and rheological models. Six rheological models were adopted: Bingham [4], power law [1], modified power law [5], Robertson stiff [6], modified Robertson stiff [7] and Casson [8].

Experimental work:

To ensure accurate results, the viscometer must be calibrated for both shear rate and shear stress. A fluid of known viscosity is used for shear stress calibration. Viscometer is rotated automatically to a speed of 600 rpm in which the shear stress is plotted vs. shear rate on recorder chart. Then rheological parameters of the tested mud sample are easily determined at elevated temperature and pressure [9, 10].

After preparing a number of mud samples with different concentrations of components, one sample with the most acceptable rheological properties (plastic viscosity and yield point) and more thermal stability, has been selected. Then the concentration of components of the selected sample, which will be considered as a base mud, was changed. Eleven samples of Gypsum mud ($CaSO_4$ $2H_2O$) were prepared with different concentrations of components to be tested at different temperatures using the Fann-viscometer model 50-C. The temperatures used in the tests were, room temperature 70, 100, 150, 200, and 250 ^{0} F, while the applied pressure was held constant at 100 psi.

The basic composition of the base mud and the resultant rheological behavior were as follows:

500cc tab water (82.88%Water ratio) +35ppb Bentonite+6 ppb Gypsum +3ppb Q Broxine + 1ppb (H.V) CMC, weighted with Barite to 9.56ppg. See table (1).

Table (1) Rheological Behavior of Gypsum Base Mud.

Mud wt.9.56 ppg.	35ppb Bentonite+ 6ppb Gypsum+0.7ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	20.32	18.81	12.35	9.98	11.39
Yield point ,(1b/100Ft^2)	12.42	7.02	5.41	4.86	6.99
Gel 10 sec ,(1b/100Ft^2)	2.1	1.0	1.0	0.8	2.6
Gel 10 min ,(1b/100Ft^2)	10.52	8.55	7.02	6.82	9.25
n	0.497	0.632	0.560	0.612	0.476
K	1.35	0.503	0.521	0.31	0.919
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	68.07	120.05	98.16	133.95	72.41
Power Law	10.11	13.41	18.34	11.73	10.41
Modified Power Law	10.89	15.90	21.00	13.01	-
Robertson Stiff	8.69	13.18*	15.75	2.22	3.62
Modified Robertson Stiff	7.30	16.20	16.02	4.93	-
Casson	6.55	15.37	14.48	3.42	3.28

Results and Discussions:

Figures (1, 2) and tables (2, 3) show the effect of 25 and 45ppb of Bentonite on the rheological properties of the tested mud respectively. It is shown clearly that with 45 ppb of Bentonite and due to the Base Exchange with $Ca^{+٢}$ ions, the Na^{+1} ions of Bentonite suspension would dissociate from the silica surface of the clay resulting in more swelling and rapid increase in the hydrate volume as indicated by higher rheological values of both plastic viscosity and yield point. With 25 ppb

*** The shadow cells represent minimum values of AAPE at certain temperature.**

Of Bentonite, due to the increase in number of hydratable particles, much lower values of viscosity would be obtained.

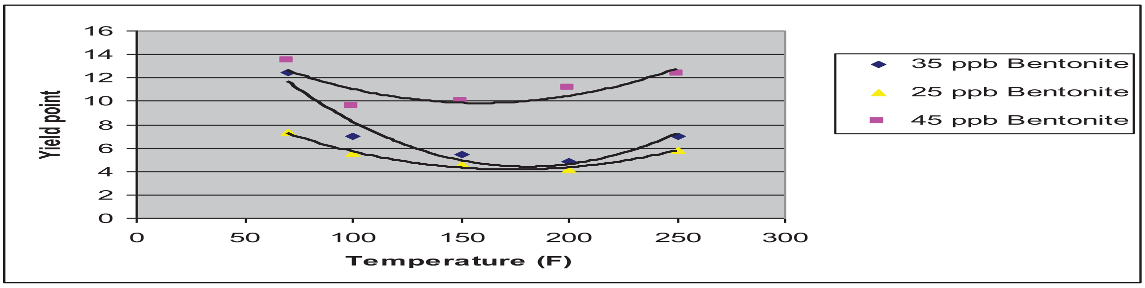

Fig. (1) Effect of Bentonite on Plastic Viscosity at different temperatures.

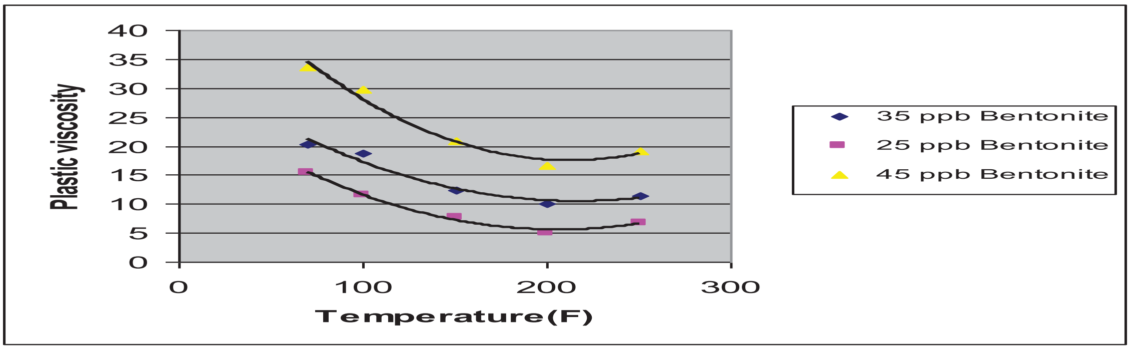

Fig. (2) Effect of Bentonite on Yield point at different temperatures.

Table (2) Effect of Bentonite on Gypsum Mud Rheology.

Mud wt.9.56 ppg.	35ppb Bentonite+ 6ppb Gypsum+0.7ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	20.32	18.81	12.35	9.98	11.39
Yield point ,(1b/100Ft^2)	12.42	7.02	5.41	4.86	6.99
Gel 10 sec ,(1b/100Ft^2)	2.1	1.0	1.0	0.8	2.6
Gel 10 min ,(1b/100Ft^2)	10.52	8.55	7.02	6.82	9.25
n	0.497	0.632	0.560	0.612	0.476
K	1.35	0.503	0.521	0.31	0.919
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	68.07	120.05	98.16	133.95	72.41
Power Law	10.11	13.41	18.34	11.73	10.41
Modified Power Law	10.89	15.90	21.00	13.01	-
Robertson Stiff	8.69	13.18	15.75	2.22	3.62
Modified Robertson Stiff	7.30	16.20	16.02	4.93	-
Casson	6.55	15.37	14.48	3.42	3.28

Table (3) Effect of Bentonite on Gypsum Mud Rheology.

Mud wt.9.29 ppg.	25ppb Bentonite+ 6ppb Gypsum+0.7ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	15.46	11.65	7.65	5.12	6.78
Yield point ,(1b/100Ft^2)	7.31	5.50	4.55	4.12	5.80
Gel 10 sec ,(1b/100Ft^2)	1.81	1.45	1.02	0.75	1.52
Gel 10 min ,(1b/100Ft^2)	8.51	6.52	5.00	3.75	8.31
n	0.556	0.533	0.520	0.523	0.98
K	0.723	0.586	0.45	0.325	0.253
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	85.39	110.44	94.25	128.62	207.52
Power Law	6.36	14.28	11.18	17.07	5.39
Modified Power Law	10.50	15.6	12.02	15.76	-
Robertson Stiff	1.88	6.20	1.72	5.59	5.94
Modified Robertson Stiff	12.31	6.01	2.82	5.81	-
Casson	6.64	6.50	1.61	7.51	9.27

The effect of Q Broxine on the rheological properties values are plotted in figures (3,4) and tabulated in Tables (4 ,5).It can be seen that ,with 4 ppb of Q Broxine ,the rheological properties (PV,YP,and gel strength) show a significant decrease, this is due to the inhibition effect of the thinning character which tend to prevent swelling of sodium Bentonite. At about 200^{o} F. The thinning effect losses effectiveness due to the thermal degradation and evaporation of some water molecules which result in higher values of both plastic viscosity and yield point. With 5 ppb of Q Broxine, thermal degradation is obtained at approximately 150 ^{o} F ,this is due to the over treatment with thinner which result in more soluble solids and higher rheological properties.

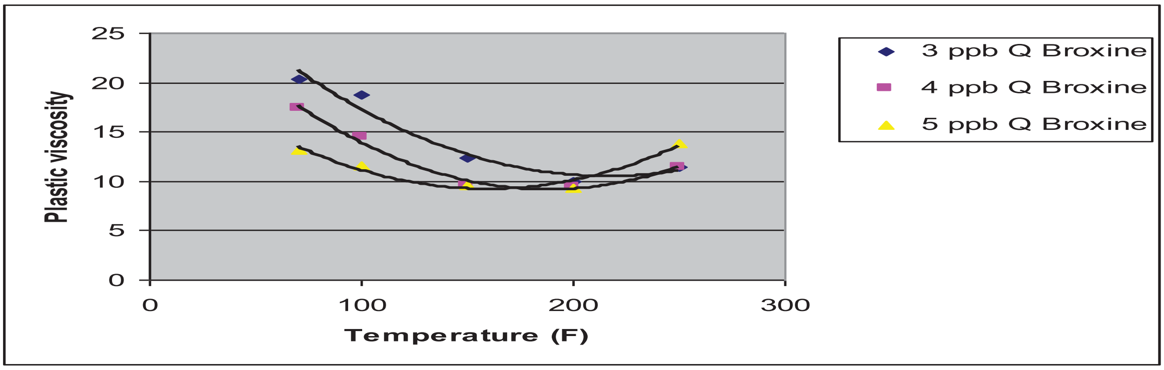

Fig (3). Effect of Q Broxine on Plastic Viscosity at different temperatures.

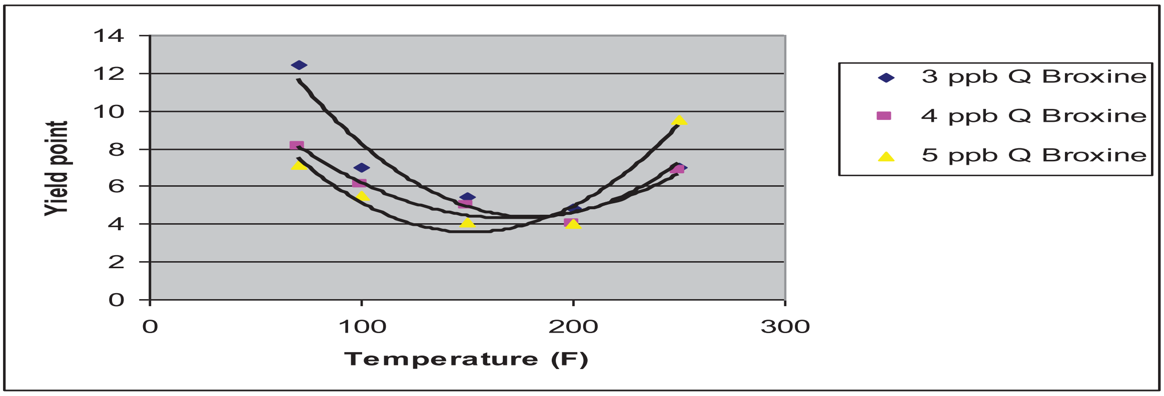

Fig.(4) Effect of Q Broxine Yield point at different temperatures.

Table (4) Effect of Q Broxine on Gypsum Mud Rheology.

Mud wt. 9.59 ppg.	35ppb Bentonite+ 6ppb Gypsum+0.7ppbNaOH+4ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	17.47	14.43	9.61	9.41	11.39
Yield point ,(1b/100Ft^2)	8.09	6.11	4.98	4.01	6.84
Gel 10 sec ,(1b/100Ft^2)	1.33	0.92	0.73	0.53	2.55
Gel 10 min ,(1b/100Ft^2)	6.76	4.11	3.00	3.11	9.34
n	0.532	0.531	0.509	0.575	0.376
K	0.891	0.726	0.598	0.357	1.735
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	80.36	72.56	74.89	96.64	32.81
Power Law	12.84	12.72	9.505	10.05	11.33
Modified Power Law	14.43	14.71	11.07	11.39	13.26
Robertson Stiff	0.92	1.65	2.62	4.28	2.60
Modified Robertson Stiff	1.10	1.46	2.31	3.54	4.64
Casson	2.68	2.39	1.97	2.50	2.36

Table (5) Effect of Q Broxine on Gypsum Mud Rheology.

Mud wt.9.64 ppg.	35ppb Bentonite+ 6ppb Gypsum+0.7ppbNaOH+5ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	13.11	11.61	9.62	9.26	13.86
Yield point ,(1b/100Ft^2)	7.18	5.50	4.08	4.01	9.56
Gel 10 sec ,(1b/100Ft^2)	0.65	0.49	0.32	0.53	4.42
Gel 10 min ,(1b/100Ft^2)	3.25	2.04	3.00	8.14	16.04
n	0.566	0.579	0.600	0.561	0.347
K	0.568	0.445	0.316	0.390	2.69
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	114.13	108.5	107.88	88.35	29.33
Power Law	10.24	9.15	8.51	9.52	11.83
Modified Power Law	11.61	10.65	9.95	10.91	13.03
Robertson Stiff	1.71	5.48	2.62	3.07	0.97
Modified Robertson Stiff	1.61	4.89	2.82	2.96	3.02
Casson	2.71	3.86	2.61	2.83	1.832

A series of interesting experiments is illustrated in figure (5, 6) and tables (6, 7). It is shown that, as the concentration of gypsum increases, there is a slight increase in the rheological values. In fact there are two adverse effects. The first is the base exchange of the Na^{+1} ions by Ca^{+2} ions which result in more liquid volume and lower viscosity while the second effect is the soluble sodium sulphate which increases the number of particles and causes higher attractive and friction forces resulting in higher viscosity. The results clearly show that the second effect is greater than the first. Thus, an increase in Gypsum would increase the mud viscosity slightly.

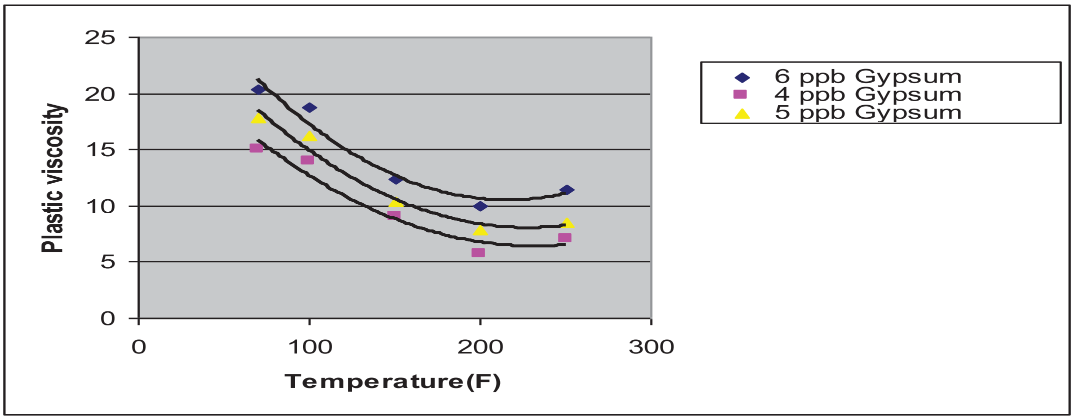

Fig.(5) Effect of Gypsum on Plastic Viscosity at different temperatures.

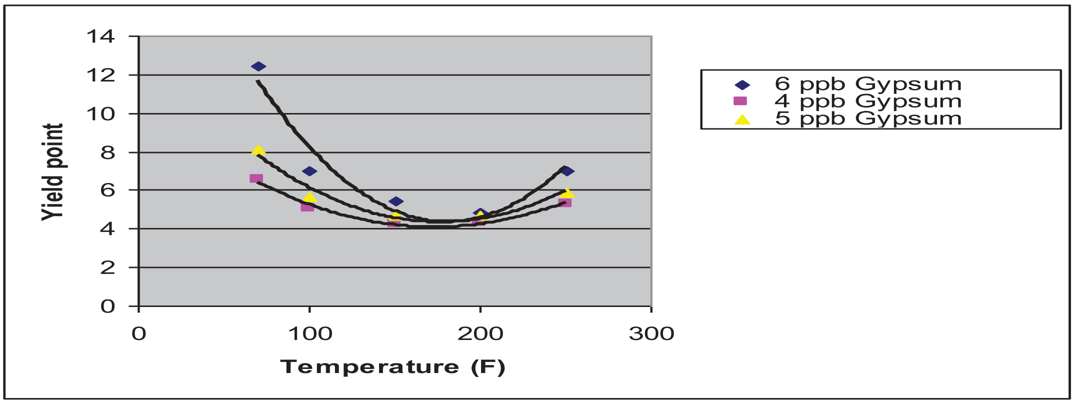

Fig.(6) Effect of Gypsum on Yield point at different temperatures.

Table (6) Effect of Gypsum on gypsum Mud Rheology.

Mud wt. 9.42 ppg.	35ppb Bentonite+ 4 ppb Gypsum+0.7ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	15.01	13.99	8.94	5.67	7.01
Yield point ,(1b/100Ft^2)	6.55	5.07	4.22	4.35	5.30
Gel 10 sec ,(1b/100Ft^2)	1.45	1.00	0.85	0.85	1.4
Gel 10 min ,(1b/100Ft^2)	8.46	6.51	4.95	4.33	7.72
n	0.596	0.643	0.553	0.478	0.438
K	0.532	0.353	0.403	0.477	0.793
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	101.72	110.69	92.8	94.55	65.75
Power Law	4.37	5.25	9.84	11.72	9.26
Modified Power Law	15.21	9.65	9.92	14.42	9.31
Robertson Stiff	4.80	2.24	4.38	5.43	2.46
Modified Robertson Stiff	25.34	13.55	3.44	5.83	1.99
Casson	8.02	8.67	2.69	5.11	3.07

Table (7) Effect of Gypsum on Gypsum Mud Rheology.

Mud wt. 9.50 ppg.	35ppb Bentonite+ 5 ppb Gypsum+0.7ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	17.76	16.24	10.33	7.78	8.54
Yield point ,(1b/100Ft^2)	8.11	5.67	4.68	4.68	5.86
Gel 10 sec ,(1b/100Ft^2)	1.8	1.0	1.01	0.95	2.04
Gel 10 min ,(1b/100Ft^2)	9.25	7.5	6.02	4.74	8.49
n	0.561	0.650	0.591	0.541	0.474
K	0.803	0.377	0.377	0.414	0.744
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	85.05	117.48	103.29	104.3	74.96
Power Law	5.25	5.54	6.74	9.18	8.26
Modified Power Law	8.25	7.2	10.74	10.68	-
Robertson Stiff	5.32	5.27	1.25	3.50	0.811
Modified Robertson Stiff	12.22	5.55	11.57	4.74	-
Casson	7.96	6.56	6.10	3.71	4.77

As indicated in figures (7, 8) and tables (8, 9) the increment in Caustic soda (NaOH) from 0.7 ppb (PH=9.65) to1.05 (PH=10.46) results in an decrease in the rheological properties values. At 150 ^{0} F ,due to the combination effect of both temperature (which tend to disperse mud particles) and Caustic soda dispersion, a continuous dispersion occurs resulting in more friction forces (high PV) and more flocculated particles(High YP).

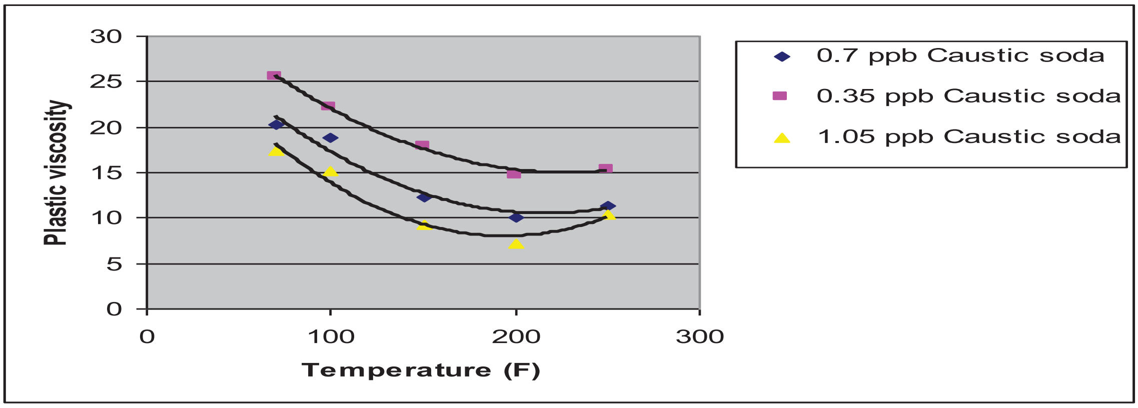

Fig. (7) Effect of Caustic soda on Plastic Viscosity at different temperatures.

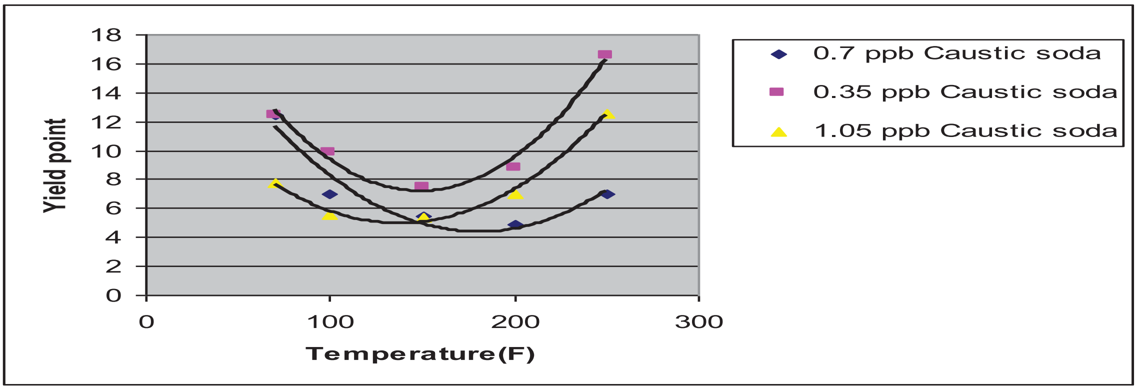

Fig. (8) Effect of Caustic soda on Yield point at different temperatures.

The decrement in NaOH concentration from 0.7 ppb (PH=9.65) to 0.35 ppb (PH=9.09) results in an increase in both yield point and plastic viscosity; this is due to the loss of OH^{-1} ions.

Table (8) Effect of Caustic Soda on Gypsum Mud Rheology.

Mud wt. 9.55 ppg.	35ppb Bentonite+ 6ppb Gypsum+0.35 ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	25.48	22.24	17.88	14.75	15.37
Yield point ,(1b/100Ft^2)	12.46	9.86	7.44	8.84	16.59
Gel 10 sec ,(1b/100Ft^2)	2.45	2.15	1.71	1.84	2.55
Gel 10 min ,(1b/100Ft^2)	12.02	10.57	9.25	9.19	11.55
n	0.505	0.508	0.536	0.499	0.340
K	1.682	0.881	0.941	1.095	3.88
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	62.01	92.33	64.65	71.66	42.51
Power Law	5.70	5.25	6.16	4.18	7.00
Modified Power Law	6.14	8.36	6.84	5.02	8.76
Robertson Stiff	4.26	3.28	9.34	5.91	2.58
Modified Robertson Stiff	4.21	10.85	6.22	6.40	3.00
Casson	6.37	8.45	9.74	9.89	3.54

Table (9) Effect of Caustic Soda on Gypsum Mud Rheology.

Mud wt. 9.58 ppg.	35ppb Bentonite+ 6ppb Gypsum+1.05 ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	17.35	15.14	9.26	7.11	10.41
Yield point ,(1b/100Ft^2)	7.76	5.58	5.39	7.02	12.55
Gel 10 sec ,(1b/100Ft^2)	1.25	1.00	0.82	1.42	2.55
Gel 10 min ,(1b/100Ft^2)	6.54	5.66	3.82	7.33	12.02
n	0.55	0.618	0.546	0.371	0.448
K	0.795	0.453	0.485	1.371	1.389
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	85.27	94.57	104.93	53.89	99.17
Power Law	9.11	10.04	10.24	10.14	4.63
Modified Power Law	9.92	12.59	11.29	11.92	7.86
Robertson Stiff	7.06	10.04	9.77	1.59	4.54
Modified Robertson Stiff	6.14	14.48	12.02	2.60	10.86
Casson	5.36	13.02	12.95	2.23	9.84

In figures (9, 10) and tables (10, 11), the effects of 81.88% and 80.88% of water ratio are presented. It is clearly shown that, as the ratio of water decreases to 80.88% much higher values of both plastic viscosity and yield point are obtained due to high value of solid content to the liquid content ratio. With 81.88% of water ratio, thermal flocculation is obtained at 150^0 F in which high gelation effect is shown clearly.

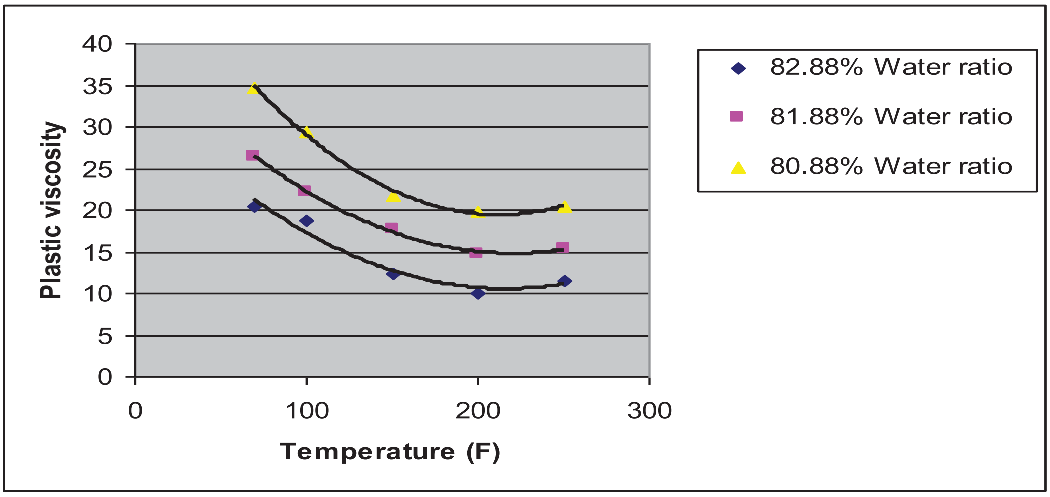

Fig. (9) Effect of Water ratio on Plastic Viscosity at different temperatures.

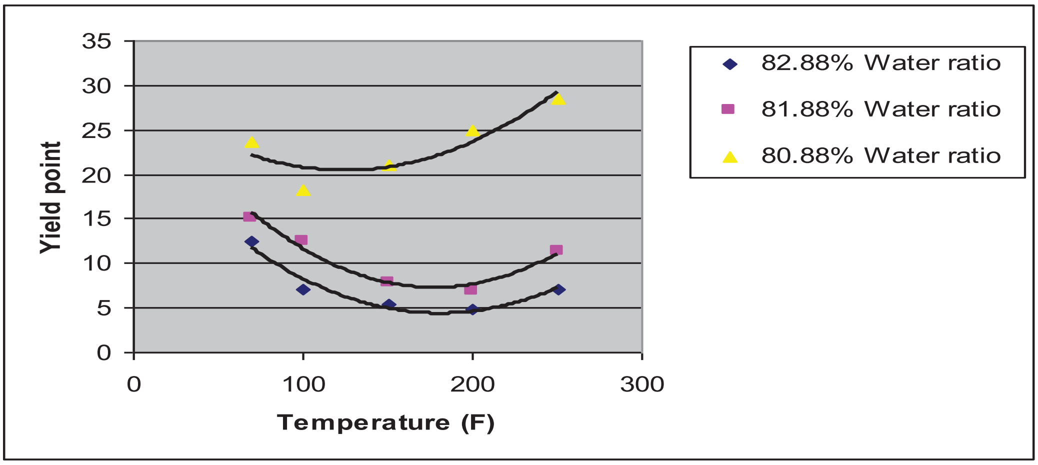

Fig. (10) Effect of Water ratio on Yield point at different temperatures.

Table (10) Effect of Water Ratio on Gypsum Mud Rheology.

Mud wt. 9.78 ppg.	81.88% Water ratio+35ppb Bentonite+ 6ppb Gypsum+0.7ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	26.42	22.15	17.67	14.58	15.29
Yield point ,(1b/100Ft^2)	15.17	12.52	7.82	6.98	11.37
Gel 10 sec ,(1b/100Ft^2)	3.70	3.15	2.55	2.41	3.60
Gel 10 min ,(1b/100Ft^2)	16.0	14.5	11.32	10.5	15.18
n	0.451	0.567	0.615	0.505	0.492
K	2.619	1.029	0.543	0.941	1.267
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	49.43	106.61	121.63	62.92	85.80
Power Law	6.74	4.90	8.15	7.01	4.11
Modified Power Law	7.16	-	-	-	-
Robertson Stiff	3.64	1.588	7.24	6.47	3.57
Modified Robertson Stiff	3.04	-	-	-	-
Casson	7.47	9.38	8.28	6.75	8.64

Table (11) Effect of Water Ratio on Gypsum Mud Rheology.

Mud wt. 9.91 ppg.	80.88% Water ratio +35ppb Bentonite+ 6ppb Gypsum+0.7ppbNaOH+3ppb Qbroxine +1 ppb CMC				
Test Temp, ^{0} F	70	100	150	200	250
Plastic viscosity,(c.p)	34.69	29.45	21.76	19.89	20.33
Yield point ,(1b/100Ft^2)	23.65	18.26	21.09	24.89	28.50
Gel 10 sec ,(1b/100Ft^2)	4.80	4.35	4.50	5.01	8.00
Gel 10 min ,(1b/100Ft^2)	24.21	22.50	24.28	26.47	32.82
n	0.344	0.569	0.577	0.582	0.388
K	6.858	1.302	1.140	1.134	4.17
Average Absolute Percentage Error For The Following Rheological Models At Certain Temperature					
Bingham Plastic	27.5	132.37	203.51	214.5	83.57
Power Law	10.72	9.42	3.57	4.06	6.75
Modified Power Law	13.54	-	-	-	-
Robertson Stiff	5.39	9.19	2.06	2.39	4.65
Modified Robertson Stiff	7.53	-	-	-	-
Casson	4.13	9.36	14.61	14.13	6.62

The effect of temperature reduces both the friction and attractive forces between solids particles due to the increase of distance between solids particles, thus the plastic viscosity and yield point reduce to almost 200 ^{o} F in which the evaporation of water occurs.

In all tested gypsum mud, due to the separation of the solid and liquid phase, the tested samples got unreasonable values of plastic viscosity and yield point at temperature above 250 ^{o} F.

Conclusions:

1 - In all tested mud, both the yield point and plastic viscosity have a trend of same behavior.

2 - The results show that the over treatment with thinner (Q Broxine) resulted in adverse action.

3 -Temperature has a great effect on Gypsum mud viscosity, in which at approximately 200^{0} F, due to the thermal flocculation the rheological properties tend to increase clearly.

4-At low concentration, NaoH act as dispersant decreasing the viscosity and improve thermal stability of the mud.

5 - Most of the tested muds show that both Robertson-stiff and Casson models represent the laboratory data accurately.

ABBREVIATIONS

PV: Plastic Viscosity

YP: Yield Point

PH: Mud Alkalinity

CMC: Carboxyl methyl cellulose.

Rpm: Revolution per minute.

^{0}F/min: Temperature gradient (Fahrenheit per minute).

Psi: Pound per square inch.

cc: Cubic centimeter.

H.V: High viscous.

N: Behavior index.

K: Consistency index.

Ppb: pound per barrel.

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