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Calculation of Pressure Loss of Two Drilling Muds in Noor Oil Field

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ABSTRACT

In this work, calculation of pressure losses in circulating system for two drilling muds is evaluated in Noor oil field. Two types of drilling muds that were used for drilling section 12 1/4" and 8 3/4" which are Salt saturated mud and Ferro Chrome Lignosulfonate-Chrome Lignite mud. These calculations are based on field data that were gathered from the drilling site of well Noor-15, which are included, rheological data, flow data and specification of drill string. Based on the obtained results, the best rheological model that fit their data is the Herschel-Bulkley model according to correlation coefficient value for their two drilling mud. Also, the difference between the calculated pressure loss by Herschel-Bulkley model and standpipe pressure value are very convergence.

Keywords: pressure losses, Salt saturated mud, FCL-CL mud.

حساب فقدان الضغط لنوعين من أطيان الحفر في حقل نور النفطي

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الخلاصة

خلال هذا البحث تم حساب فقدان الضغط في منظومة دوران طين الحفر لنوعين من الأطيان المستخدمة في حقل نور النفطي. إن هذه الأطيان هي الطين المشبع بالملح المستخدم في حفر التجويف ذو قطر "12 1/4 و طين FCL-CL المستخدم في حفر التجويف ذو قطر "8 3/4 . هذه الحسابات تمت بالاعتماد على البيانات الحقلية المأخوذة أثناء حفر بئر نور-15 و التي تشمل الخواص التيارية لطين الحفر و بيانات الجريان و موصفات خيط الحفر. من النتائج المستحصلة من هذا البحث يمكن الاستنتاج إن أفضل موديل يمكن أن يمثل الخواص التيارية لكلا نوعي طين الحفر هو موديل هيرشل-بلكلي و ذلك بالاعتماد على قيمة معامل الارتباط بالإضافة إلى أن هذا الموديل يعطي اقل فرق بين فقدان الضغط المحسوب و الضغط الحقيقي المقاس على برج الحفرمقارنة مع باقي الموديلات المستخدمة بالبحث.

الكلمات الرئيسية: فقدان الضغط، الطين المشبع بالملح، طين FCL-CL.

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1. INTRODUCTION

Noor Oilfield is located in the southeast of Iraq, about 15 km northeast of Amara city, Missan Governorate. The field is NW- SE trending anticline and is about 18.9 km long and 5.9 Km wide**, (Midhat, et al., 2014)**. Fifteen oil wells have been drilled in Noor oilfield and this research is made on the last. Oil is produced from Mishrif formation. Many problems face drilling in Noor oil field, so it became more important to make studies that can prevent these difficulties or reduce them, especially when drilling 12 1/4" and 8 3/4" holes. A lithology and drilling parameters of these holes are shown in **Fig.1** and **Fig. 2**. The 12 1/4" hole is characterized by abnormal high formation pressure, high temperature and contains layers of salt rock. Salt-saturated mud is used to drill this hole. One of the problems that occur is the flow of fluids into the well after the process of cementing, which leads to pollution of the new drilling fluid that used in the next hole with salt. Therefore, it is important to calculate the loss of pressure inside the well to see if there is a flow of fluid or not before replacing SSM by FCL-CL. 8 3/4" hole is the last, and FCL-CL mud is used in it. It's the production hole and drilling fluid losses may happen in addition to pipe sticking, therefore; rheological model of drilling fluid must be detected, and pressure losses must be calculated accurately.

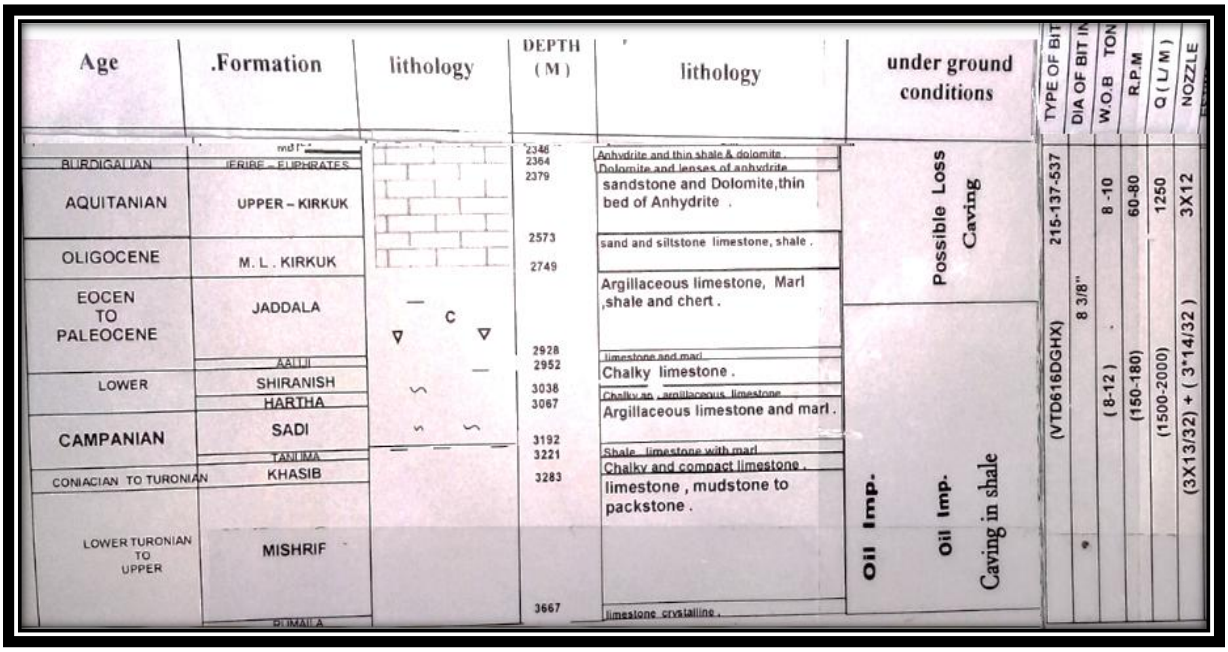

Figure 1. Lithology and drilling parameters of 8 3/4" hole.

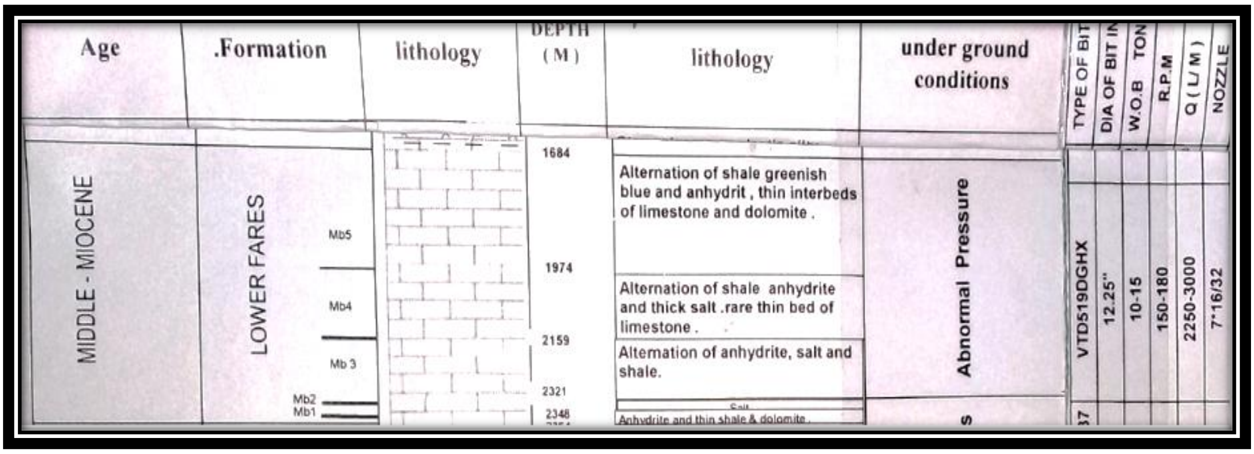

Figure 2. Lithology and drilling parameters of 12 1/4" hole.

2. PROPERTIES OF DRILLING MUDS

There are many types of drilling mud used in oil field. A classification of it is given by **(Caenn, et al., 2011)** is shown in **Table 1**. Drilling fluids studied in these researches are salt-saturated mud and FCL-CL mud. First one is used for drilling hole of 12 1/4". The length of hole is about 700 m, and it contains a salt rock. Salt formations are distinctive. Porosity and permeability of salt are very little. It can flow plastically through other geological rock beds under stress with "salt creep" and that leads to reducing in wellbore size and collapse in casing. Also, salt dissolves in water, therefore; the salinity of a water-based mud must be kept near or at saturation to prevent or minimize wellbore enlargement that can lead to bad cementing of the casing and incomplete zonal isolation, **(Amer, et al., 2016)**. Boreholes in salt layers tend to be overbalanced, **(Weijermars, et al., 2013)**. After completing the drilling of this hole, casing is placed and then the process of cementing is done. Float shoe and float collar are drilled as well excess cement by using the same drilling fluid, which specifications may be affected by these successive processes. The specifications of SSM are shown in **Table 2.** The second type of drilling fluid is used for drilling hole of 8 3/4". FCL-CL mud has been used because of its resistant to contamination. A ferrochrome lignosulfonate called Q-BROXIN had the unusual property of thinning gyp muds and salty muds. In 1955, Roy Dawson introduced Q-BROXIN to oil field drilling. Chrome lignite (CL) with chrome lignosulfonate afforded a simple chemical system that was widely applicable. This system supplied control on both filtration and flow properties over a wide range in pH, salinity, and solids content**, (Caenn, et al., 2011)**. The length of hole is about 1300 m. Drilling fluid specifications are shown in **Table 3.** All tests of drilling muds are made according to, (**API RP 13B-1, 2003)**. The devices used are shown in **Fig.3.**

Table 1. Classification of Drilling Muds.

Class	Common Subclasses
Fresh-water muds[d]	pH 7-9.5
	Spud muds
	Bentonite muds
	Phosphate muds
	Lignite muds
	Lignosulfonate muds
	Organic colloid muds
Inhibited muds[d]	Lime muds
	Gypsum muds
	Sea-water muds
	Saturated salt-water muds
Low-solids muds[n]	Less than 3%-6% of solids
Emulsions	Oil in water
	Water in oil
	Reversed-phase
Oil-based muds	Less than 5% water
	A mixture of diesel fuel and asphalt

d Dispersed systems.
n Nondispersed systems.

Table 2. SSM properties.

Fluid Type		SSM
Density	g/cm^3	2.10
Filtrate	mL/30min	7
pH		11.5
Total Hardness	mg/l	4000
NaCl	mg/l	234300
Viscosity	sec	42
Water/ Oil / Solid	%	69/0/31
Gel 0/10	$lbs/100ft^2$	14/57
Φ 600	$lbs/100ft^2$	71
Φ 300	$lbs/100ft^2$	46
Φ 200	$lbs/100ft^2$	39
Φ 100	$lbs/100ft^2$	27
Φ 60	$lbs/100ft^2$	23
Φ 30	$lbs/100ft^2$	21
Φ 6	$lbs/100ft^2$	16
Φ 3	$lbs/100ft^2$	14

Table 3. FCI-CL properties.

Fluid Type		FCL-CL
Density	g/ cm^3	1.25
Filtrate	mL/30min	3
pH		9.5
Total Hardness	mg/l	120
NaCl	mg/l	25575
Viscosity	sec	56
Water/ Oil / Solid	%	83/8/9
Gel 0/10	$lbs/100ft^2$	12/19
Φ 600	$lbs/100ft^2$	77
Φ 300	$lbs/100ft^2$	51
Φ 200	$lbs/100ft^2$	41
Φ 100	$lbs/100ft^2$	29
Φ 60	$lbs/100ft^2$	23
Φ 30	$lbs/100ft^2$	18
Φ 6	$lbs/100ft^2$	12
Φ 3	$lbs/100ft^2$	11

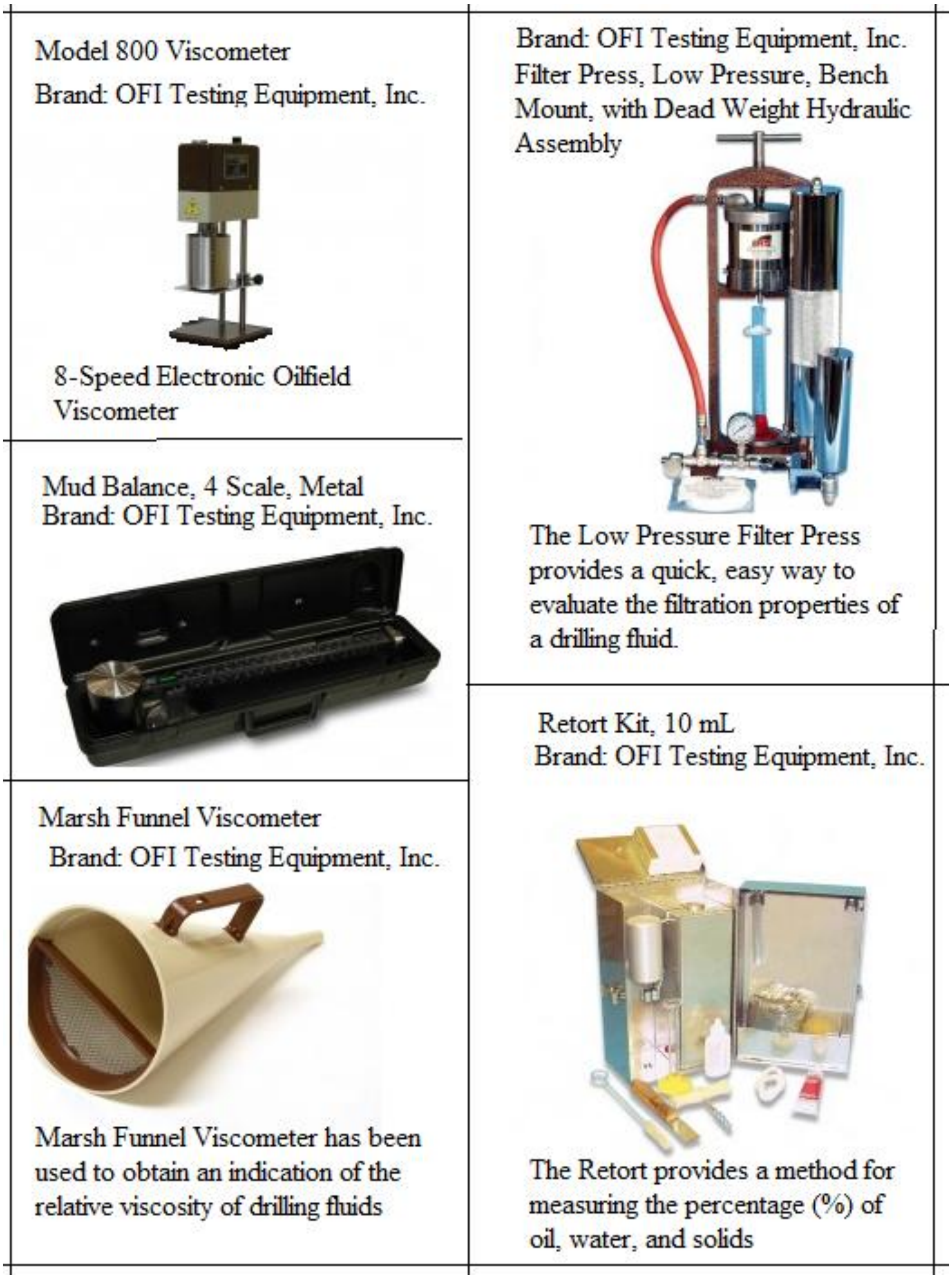

Figure 3. Instruments for testing drilling mud Specifications.

3. RHEOLOGICAL MODELS

Rheology is the study of the deformity and flow of materials. Fluid motion might be consisted of a number of plates moving parallel to one another at various speeds**, (Guillot, 2006)**. The velocity gradient (shear rate) of the fluid particles can be mathematically represented as:

Shear rate =velocity difference between 2 platelets /distance between 2 platelets (1)

Shear stresses are caused by force F that has an effect on element. The following equation expresses that.

$$\tau = F/A \qquad (2)$$

There are many models that represent the relationship between shear rate and shear stress. In this research, three models: Bingham plastic, **(Ian, et al., 2017 and Bingham, 1922)**, Power law, **(Munawar, et al., 2011),** and Herschel-Bulkley**, (Munawar, et al., 2011),** are used and the pressure loss is measured by these models.

3.1Bingham Plastic Model

Bingham model can be known through two parameters: plastic viscosity and yield point. The plastic viscosity depends on the size, concentration, shape of solids and the viscosity of the liquid phase. Te yield point is formed by the power of attraction between solid particles as a result of the existing charge on their surfaces.
It can be represented mathematically as follows:

$$\tau = \mu p * \gamma + \tau y \qquad (3)$$

Type of the flow of the drilling fluid is determined by Reynolds number. If flow is laminar, the pressure loss is calculated by the following equation**, Rabia, 1985**:

Inside drill pipe,

$$\Delta p = \frac{\mu p\, L\, v}{1500\, d^2} + \frac{L\, Yb}{225\, d} \qquad (4)$$

In annulus

$$\Delta p = \frac{\mu p\, L\, v}{1000\, (dh - de)^2} + \frac{L\, Yb}{200\, (dh - de)} \qquad (5)$$

Pressure loss equation of turbulent flow is**, Rabia, 1985**:

Inside dill pipe,

$$\Delta p = \frac{f\, \rho\, L\, v^2}{25.8\, d} \qquad (6)$$

In annulus

$$\Delta p = \frac{f\, \rho\, L\, v^2}{25.8\, (dh - de)} \qquad (7)$$

3.2 Power Law Model, (API 13D, 1980).

Power-law model can be known through two variables: consistency index (k) and power-law index (n) (dimensionless). It can be represented mathematically as follows:

$$\tau = k * \gamma^n \qquad (8)$$

Since drilling fluids are shear-thinning to some degree, the viscosity of the fluid changes with a change in the shear rate. In order to calculate pressure loss, the effective viscosity at a given rate of shear must be known, therefore, effective viscosity is calculated by using **Eq.(9)** and by using Reynolds Number Eq**.(10)** the flow regime is determined. Based on the flow regime; friction factor is calculated by using **Eq.(11)(12)(13)(14)(15)** and by **Eq.(6) and (7)** pressure loss is measured.

$$\mu e = K * \gamma^{n-1} \quad (9) \qquad\qquad R = \frac{987 * V * d * \rho}{\mu e} \quad (10)$$

Laminar flow
Re< 3470 - 1370n

$$f = \frac{a}{R^b} \quad (11)$$

where b=1 and a= 16 inside pipe and 24 inside the annulus

Turbulent flow
Re > 4270 - 1370n

$$f = \frac{a}{R^b} \quad (11) \qquad \text{where} \quad b = \frac{(1.75-\log n)}{7} \quad (12)$$

$$\text{and} \qquad a = \frac{(\log n + 3.39)}{50} \quad (13)$$

Transitional Flow
3470 - 1370 n <Re< 4270 - 1370n
inside annulus

$$f = \frac{R}{800} * \left[\frac{a}{(4270-1370*n)^b}\right] + \left(\frac{24}{3470-1370*n}\right)\left(1-\frac{R}{800}\right) \quad (14)$$

inside pipe

$$f = \frac{R}{800} * \left[\frac{a}{(4270-1370*n)}\right] + \left(\frac{16}{3470-1370*n}\right)\left(1-\frac{R}{800}\right) \quad (15)$$

3.3 Herschel-Bulkley Model

The yield-power law (Herschel-Bulkley) fluid combines Power-law and Bingham plastic behaviours of fluids. It can be represented mathematically as follows, **(Hemphill, et al., 1993)**:

$$\tau = \tau_y + k * \gamma^n \quad (16)$$

Pressure loss is estimated by using the same equation of Power-law model, but Φ600 and Φ300 is calculated from **Eq.(16).** Power law exponent and Consistency index in Eq.(16) are obtained from **Fig.6** in the case of SSM and **Fig.9** in the case of FCL-CL.

4. EXPERIMENTAL WORK

For two type of drilling fluid, their properties are measured and listed in **Table 2** and **Table 3.** Rheological data are obtained from Fann V-G Meter readings. Linear regression analysis is run for the experimental data to select the model closest to the actual flow curve. This is done for Cartesian coordinates for the Bingham model and logarithmic coordinates for the Power Law and Herschel-Bulkley models. The model with squared correlation coefficient closest to unity will be chosen. R squared formula is given by, **(Lenschow, 1992)**:

$$R^2 = \left(\frac{p*\sum X*Y - \sum X*\sum Y}{\sqrt{(P*\sum X^2 - \sum X^2)((P*\sum Y^2 - \sum Y^2))}}\right)^2 \quad (17)$$

The flow data, wellbore specifications and the specifications of drill string consisting from drill pipe, heavyweight drill pipe, drill collar and drilling bit are shown in **Table 4** and **Table 5.** By using all these parameters, pressure loss inside wellbore for the three rheological models can be calculated and make a comparison between them.

Table 4. Drill string and flow data specification of FCL-CL.

Standpipe pressure psi		1975
SPM		90
Liner diameter of the pump in		6.5
The linear length of the pump in		12
Depth (m)		3075
Bit size (in)		8 3/8
number of nozzle * size of nozzle (in)		2*12/32+ 6*13/32
Drill pipe		
ID (in)	OD (in)	L (m)
4.276	5	718
4	5	2125.65
Drill Collar		
ID (in)	OD (in)	L (m)
2.875	6.75	178.35
Casing		
ID (in)	OD (in)	L (m)
8.535	9.625	3343
Heavy weight drill pipe		
ID (in)	OD (in)	L (m)
3	5	53

Table 5. Drill string and flow data specification of SSM.

Standpipe pressure psi		829
SPM		55
Liner diameter of the pump in		6.5
The linear length of the pump in		12
Depth (m)		2341
Bit size (in)		8 3/8
number of nozzles		3
size of the nozzle (in) (without nozzle)		1.3
Drill pipe		
ID (in)	OD (in)	L (m)
4.276	5	718
4	5	1404
Drill Collar		
ID (in)	OD (in)	L (m)
2.875	6.75	163
Casing		
ID (in)	OD (in)	L (m)
8.535	9.625	3343
Heavy weight drill pipe		
ID (in)	OD (in)	L (m)
3	5	53.84

5. RESULTS

The three models (Bingham plastic, Power law, and Herschel-Bulkley) of rheological data of SSM with its R^2 are shown in **Fig.4**, **Fig.5** and **Fig.6** respectively and in **Fig.7**, **Fig.8** and **Fig.9** for FCL-CL mud. According to R^2 results, Herschel-Bulkley model is the best one that represents the relationship between shear stress and shear rate for two types of drilling mud.

Pressure loss in each part is measured according to the three models and the results are listed in **Table 6** for SSM and in **Table 7** for FCL-CL mud. Herschel-Bulkley model gives the minimum difference in pressure between standpipe pressure and total pressure loss. There is a difference (about 93 psi) in pressure between standpipe pressure and total pressure loss in the case of FCL-CL mud. This is because the efficiency of mud pumps is assumed to be 90% but in fact, it is constantly changing due to drilling operations and continuous change of damaged parts of mud pumps so assuming the efficiency to be 93.5%, the difference in pressure reduces to 3 psi only. In this way we can roughly measure the efficiency of mud pumps easily and quickly.

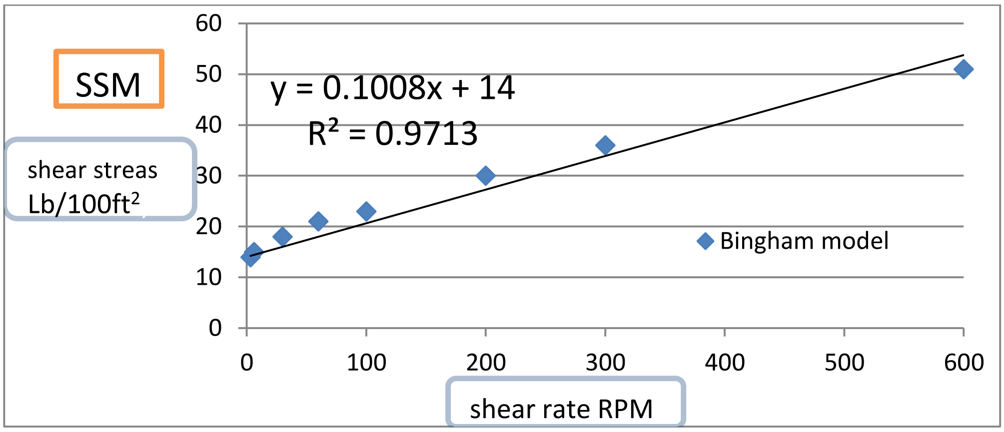

Figure 4. Bingham model of SSM.

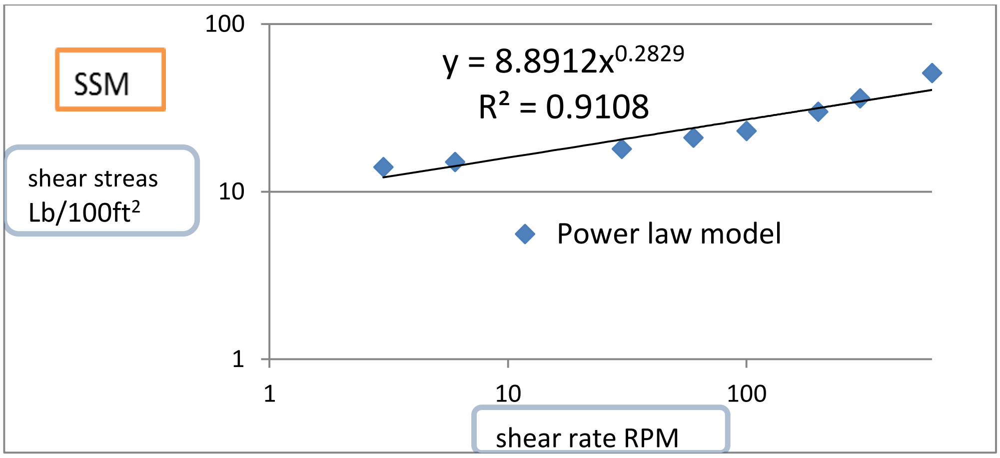

Figure 5. Power law model of SSM

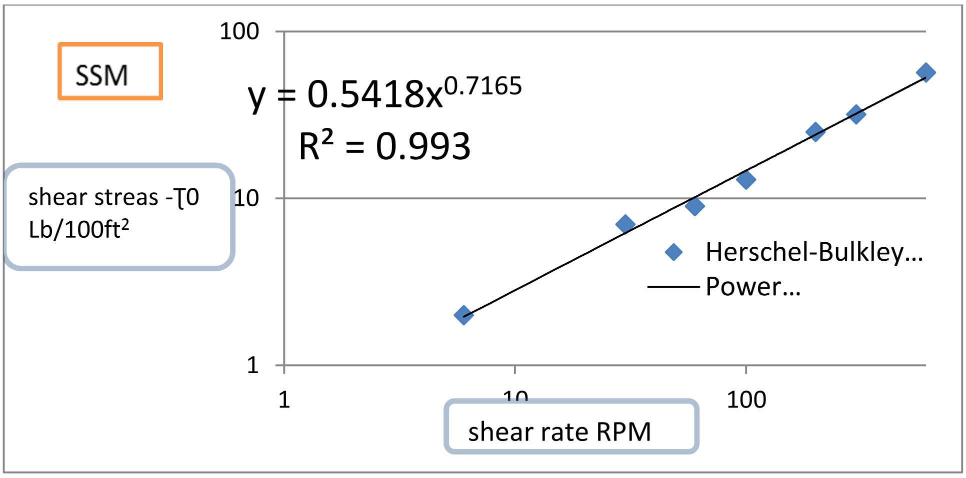

Figure 6. Herschel-Bulkley model of SSM.

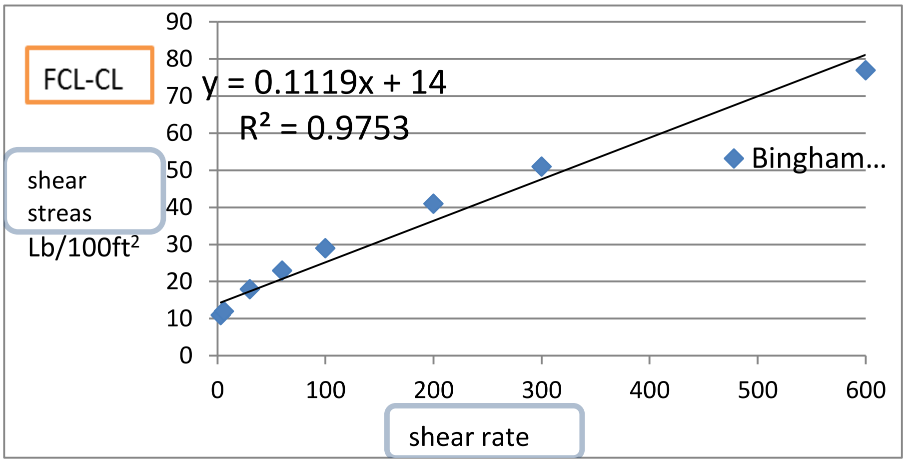

Figure 7. Bingham model of FCL-CL.

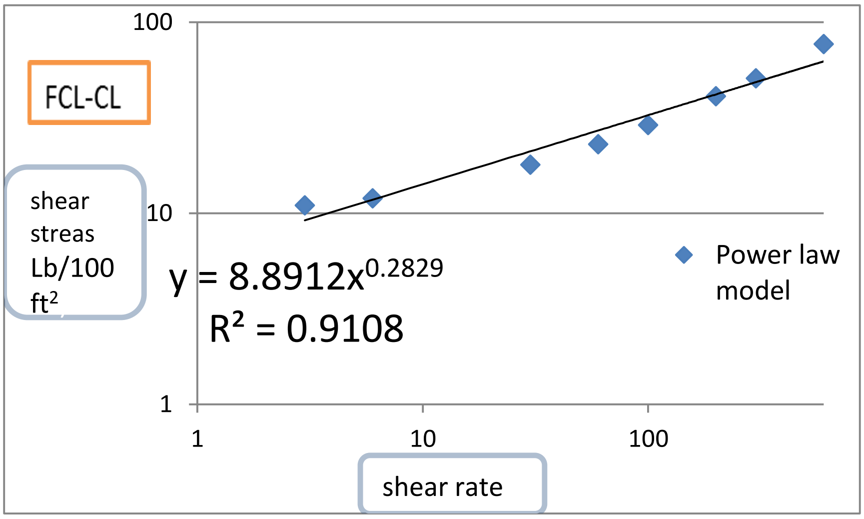

Figure 8. Power law model of FCL-CL.

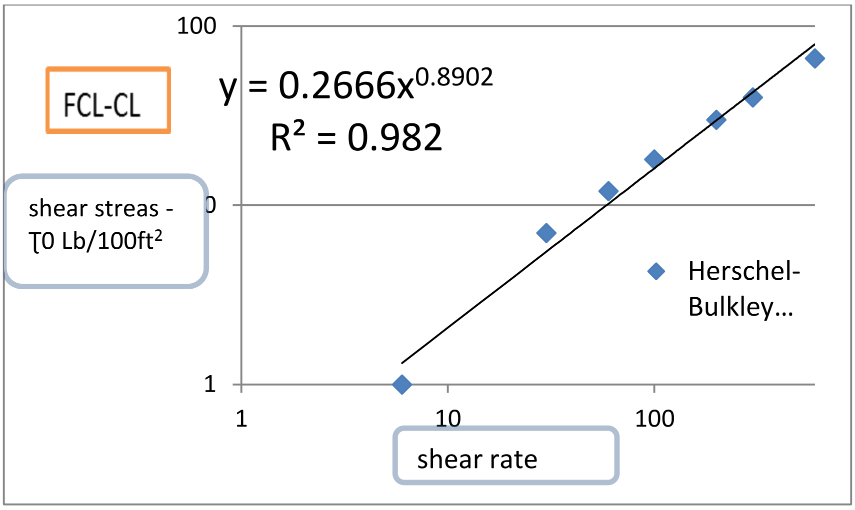

Figure 9. Herschel-Bulkley model of FCL-CL.

Table 6. Pressure loss by using SSM.

Model of SSM drilling mud	Δps (psi)	Δpp (psi)	Δpc (psi)	Δpap (psi)	Δpac (psi)	Δpb (psi)	Δpt (psi)	Spp-Δpt (psi)
Bingham	11	328	122	258	48	7	772	58
Power Law	10	337	112	262	112	7	851	-22
Herschel-Bulkley	10	316	115	272	116	7	836	-7

Table 7. Pressure loss by using FCL-Cl.

Model of FCL-Cl drilling mud	Δps (psi)	Δpp (psi)	Δpc (psi)	Δpap (psi)	Δpac (psi)	Δpb (psi)	Δpt (psi)	Spp-Δpt (psi)
Bingham	27	707	447	215	85	168	1650	325
Power Law	27	688	435	205	189	168	1712	263
Herschel-Bulkley	29	787	464	233	200	168	1882	93

7. CONCLUSIONS

Based on this experimental study and field data, several conclusions can be derived:

1- According to R^2 for two types of drilling muds, the best model that reflects the relationship between shear stress and shear rate is Herschel-Bulkley model.
2- According to the difference between standpipe pressure and total pressure loss for two types of muds, Herschel-Bulkley model is the best one.
3- When Float Shoe, Float collar and excessive cement inside 9 5/8" casing are drilled we can predict if there is a flow of salt fluid from formation or not. That is done if there is a reduction in standpipe pressure compare with total pressure loss that calculated by using the Herschel-Bulkley model.

4- In the case of FCL-CL mud, it can be predicted that if there is a loss in drilling mud inside formation or not. That is done if there is a reduction in standpipe pressure compare with total pressure loss that calculated by using Herschel-Bulkley model.
5- From the obtained results, there is a slight difference of R^2 between Bingham and Herschel-Bulkley models, therefore more study should be done for other drilling muds used for drilling wells in the same field.

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NOMENCLATURE

d = pipe diameter, in.

f = friction factor, dimensionless.

FCL-CL =ferro chrome lignosulfonate- chrome lignite.

K= consistency index,Ibf-s ^{n}/100 f^2.

L = pipe length, ft.

n = flow behavior index, dimensionless.

P = number of fann readings made.

q = flow rate, gal/min.

R= Reynolds number, dimensionless.

R^2= (Correlation Coefficient)^2.

SSM=salt saturated mud.

SSP= stand pipe pressure, psi.

v = velocity, ft/s.

x = shear rate or its logarithm.

y = shear stress or its logarithm.

Δpac = pressure loss inside annuals around drill collar, Ibf/in^2.

Δpap = pressure loss inside annuals around drill pipe, Ibf/in^2.

Δpb = pressure loss inside bit, Ibf/in^2.

Δpc = pressure loss inside drill collar, Ibf/in^2.

Δpp = pressure loss inside drill pipe, Ibf/in^2.

Δps = surface pressure loss, Ibf/in^2.

Δpt = total pressure loss, Ibf/in^2.

Ʈ = shear stress, Ibf/l00ft^2.

Ʈy: yield stress, Ibf/l00ft^2.

γ = shear rate, S^{-1}.

μp = plastic viscosity of Bingham fluid, cp.

ρ = fluid density, Ibm/gal.

μe = effective viscosity, cp.