TECHNICAL SCIENCES

SELECTİON OF BEST FİTTİNG RHEOLOGİCAL MODEL FOR DRİLLİNG FLUİDS

Gulubayli A.
Doctoral student, department of Oil and Gas,
Azerbaijan State Oil and Industry University
16/21 Azadlig Avenue, Baku
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Abstract

The rheological parameters of drilling fluids play a vital role in cleaning the drilled rock particles and keeping the rock particles and weighting agent in suspension. If the correct rheological parameters are not selected, various complications may arise in the oil well drilling. In addition to the selection of the rheological parameters of the drilling fluid, the selection of the model for expressing the rheological parameters is also one of the important issues. Different models are used to determine rheological parameters during various calculations. Bingham plastic model for expressing rheological parameters during drilling, power law and modified power law model during hydraulic calculations, etc. To investigate which of these models determines the parameters of the drilling fluid accurately 2 different oil-based drilling fluid samples were prepared.

A 6-speed viscometer was used to measure the shear stress of the prepared drilling fluid samples. The obtained shear stresses were expressed in Pa, and calculations were made by building models. Mean absolute percentage error was used to determine which of the obtained results was more accurate. As a result of the calculations, it was determined that the most suitable model for expressing the rheological parameters of the drilling fluid is the Herschel-Bulkley model.

Keywords: Bingham Plastic model, Power Law model, Herschel-Bulkley model, drilling fluids, rheological parameters, logarithmic regression.

Introduction

Drilling fluids are one of the most important parameters of drilling. Regardless of the fact that different drilling fluids exist, they all perform the same functions. The drilling fluid has important functions such as controlloing formation pressure, remove cuttings form well to surface, and keeping the solid particles in the mud suspended when the circulation stops [1]. Each function is defined by a parameter corresponding to it. Controlling formotion pressure is determined by the specific gravity of the drilling fluids and rheological parameters used to clean the cuttings and keep the solid particles in suspension.

In general, there are two types of fluids, Newtonian and non-Newtonian [2]. Which types of fluid they belong to is determined by the relationship between shear rate and shear stress. In Newtonian fluids, the shear rate is directly proportional to the shear stress. Non-Newtonian fluids can be thixotropic, dilatant, etc. In thixotropic fluids, the viscosity decreases as the applied stress increases, while in dilatant fluids, the viscosity increases. Drilling fluids should be thixotropic to keep the cuttings and weightning agent particles suspended [3]. Therefore, they are classified as non-Newtonian fluids and various models are used to express their rheological parameters. As an example of those models, Ostwald-de Waele (Power law model), Herschel-Bulkley (yield power model), Bingham Plastic model [4] can be used.

Bingham-plastic model is used to determine the rheological parameters of drilling fluids during drilling. In the Bingham-plastic model, the solution parameters are yield point and plastic viscosity [5]. During hydraulic calculations, the drilling fluid is expressed by the power law model and the Herschel-Bulkley model [6]. The drilling mud parameters in the power law model are flow behavior index and consistency coefficient. However, the calculations revealed that these models do not fully represent the drilling fluids. Therefore, in this article, it was investigated which model fully expresses the parameters of the drilling fluid.

Various models have been proposed to determine the rheological parameters of drilling fluids. The flow parameters of drilling fluids are determined using models. Let's look at the use of the Newtonian model as the first model. In the Newtonian model, the shear stress and the shear rate are directly proportional to each other, and the parameter that determines this dependence is called viscosity. Viscosity is determined by the following expression:

$$\mu = \frac{\tau}{\dot{\gamma}}$$

Here, τ – shear stress (lb/100ft^2 or Pa), $\dot{\gamma}$ – shear rate (s^{-1}).

The viscosity profile for the Newtonian model is shown by line 1 in Figure 1.

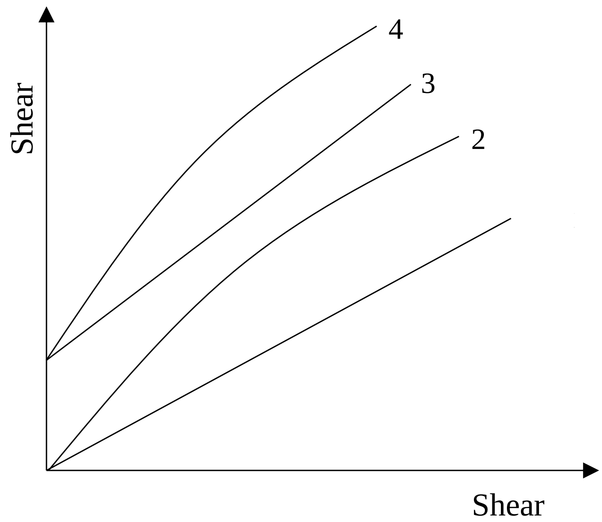

Figure 1. Flow behavior models

During the conducted studies, it was determined that the drilling fluids have an initial shear stress. Therefore, using the Newtonian model when dealing with solutions is inappropriate. Another model for expressing solutions is the bingham-plastic model. This model is shown as follows [5]:

$$\tau = \tau_0 + PV * \dot{\gamma} \quad (1)$$

Burada, τ – shear stress (lb/100ft^2 or Pa), τ_0 – yield point (lb/100ft^2 or Pa), PV – plastic viscosity (cP və ya Pa*s).

Plastic viscosity and yield point are determined by 600RPM and 300RPM viscometer readings:

$$PV = \theta_{600} - \theta_{300} \quad (2)$$

$$YP = 2 * \theta_{300} - \theta_{600} \quad (3)$$

The yield point characterizes the electrochemical attraction forces in the solution. Plastic viscosity depends on the size, amount and shape of the solid phase in the solution. Since the water phase behaves as a solid in oil-based solutions, increasing the amount of water leads to an increase in plastic viscosity. The expression form of Bingham plastic model is shown by line 3 in Figure 1.

The initial shear stress is not taken into account in the power law model. The expression form of the power model is as follows [7]:

$$\tau = K\dot{\gamma}^n \quad (4)$$

Here, K is consistency index (cP or Pa*s), n is flow behaviour index (dimensionless). K and n are calculated with 600RPM and 300RPM viscometer readings. The unit of K is the same as that of plastic viscosity - cP or Pa*s.

$$n = \log\frac{\tau_2/\tau_1}{\dot{\gamma}_2/\dot{\gamma}_1} = 3.32\log\frac{\theta_{600}}{\theta_{300}}$$

$$K = \frac{\tau_2}{\dot{\gamma}_2{}^n} = \frac{\theta_{300}}{511^n}$$

Here, θ_{600} and θ_{300} are viscometer readings at 600RPM and 300RPM, respectively. The correction factor to convert the RPM of the viscometer to the shear rate is 1.7033, to convert readingsto lb/100ft^2 is 1.067.

When using the power law model, its logarithm is used to find the values of K and n.

$$\log\tau = \log K + n\log\dot{\gamma}$$

Unlike the power law model, the Herschel–Bulkley model takes into account yiels stress. The expression form of the model is as follows [8]:

$$\tau = \tau_y + K\dot{\gamma}^n \quad (5)$$

Here, τ_y is yiled stress (Pa). In some sources, the viscometer reading at 3RPM is used as yield stress [9]. However, during this calculation, τ_y was calculated as follows [10]:

$$\tau_y = 2 * \theta_3 - \theta_6 \quad (6)$$

Here, θ_6 və θ_3 are viscosimeter reading at 6RPM and 3RPM, respectively.

The logarithm of the Herschel-Bulkley model is used in the calculations, as in the power law model.

$$\log(\tau - \tau_y) = \log K + n\log\dot{\gamma}$$

The power model is shown by line 2, and the Herschel-Bulkley model by line 4 in Figure 2. Figure 2 shows logarithmic representation of power law and Herschel-Bulkley model.

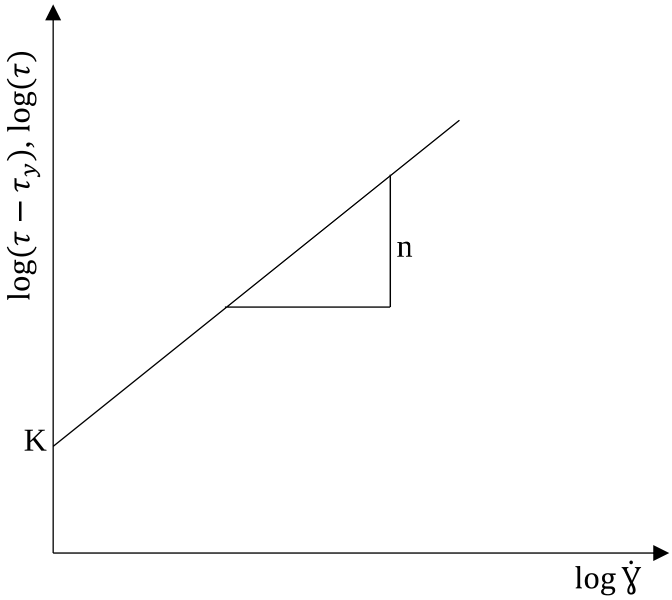

Figure 2. logarithmic representation of power law and Herschel-Bulkley model

Tabel 1.

Composition of drilling fluid samples

Composition	1th mud sample	2nd mud sample
Base oil	245ml	245ml
OBM VİS	3.2ppb	2.2ppb
OBM RM	1.6ppb	1.1ppb
Lime	6ppb	7.5ppb
EMUL P	6.5ppb	7.5ppb
Water	105ml	105ml
$CaCl_2$	40.37g	40.37g
Barite	230g	230g
OBM FLC	5ppb	5ppb

Fluid samples for model comparison were prepared in the Caspian Drilling Fluids laboratory. Prepared drilling fluids samples are oil-based drilling fluids. OBM VIS as a viscosifier, OBM RM to increase low shear rheology, OBM FLC to reduce fluid loss, EMUL P as an emulsifier, Barite as a weightning agent, CaCl2 salt as a brine, and Lime to give alcalinity to drilling fluids were used in the sample preparation. Two different drilling mud samples were prepared. The composition of the prepared mud samples is shown in table 1. A 30% CaCl2 salt solution (384.5 kg per 1 m3) was prepared.

Viscometer readings for prepared drilling mud samples are shown in table 2.

Table 2.

Viscometer readings for prepared drilling mud samples

	1st mud sample		2nd mud sample	
	$lb/100ft^2$	Pa	$lb/100ft^2$	Pa
R600	75	38.25	50	25,5
R300	47	23.97	31	15,81
R200	35	17.85	21	10,71
R100	22	11.22	13	6,63
R6	9	4.59	6	3,06
R3	8	4.08	5	2,55

First, let's look at the expressions of the sample 1 over the models. In Bingham-plastic model, the yield point (YP) and plastic viscosity (PV) should be calculated using equations (2) and (3). Correction factor to convert yield point to Pa is 0.51 (0.51*lb/100ft2 = Pa) and to convert plastic viscosity to Pa*s is 0.001 (cP = 0.001Pa*s). Plastic viscosity for sample 1is 28 and yield point is 19. According to the obtained results and using equation (1), the following expression is obtained for the bingham plastic model:

$$\tau = 9.69 + 0.01428\dot{\gamma} \quad (7)$$

Equation (4) and the regression model used to calculate K and n using the power law model. The logarithmic regression of power law model is shown in Figure 3.

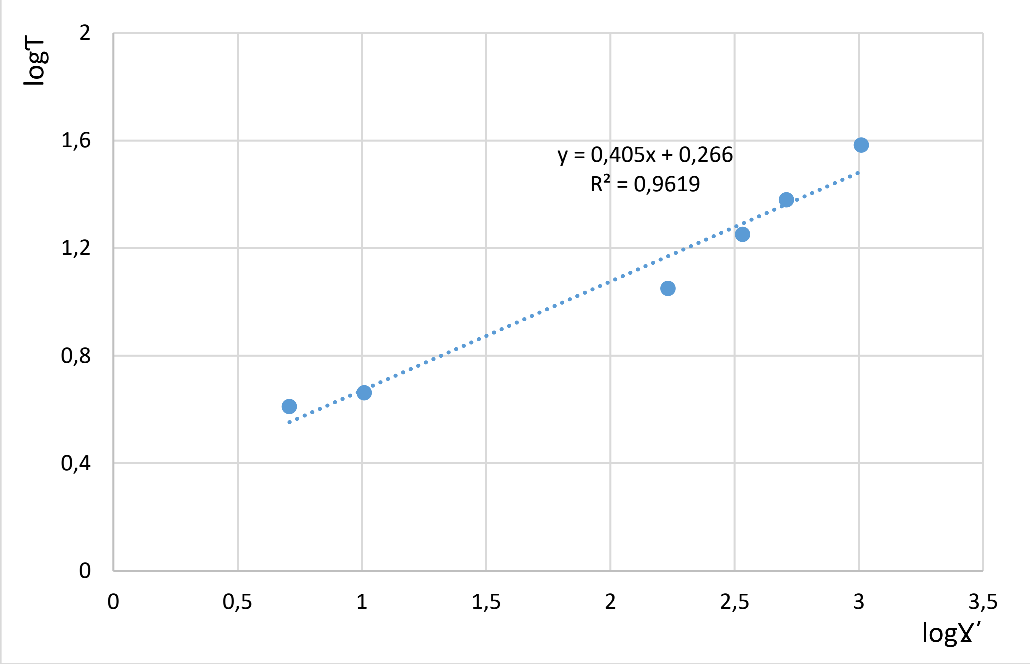

Figure 3. logarithmic regression of the power law model

As can be seen from Figure 3, the expression of the power law model for drilling fluid 1 is as follows:

$$\log\tau = 0.405\log\dot{\gamma} + 0.266 \quad (8)$$

The following expression for the power law model was obtained from the equation (8) (logarithmic regression equation):

$$\tau = 1.845 * \dot{\gamma}^{0.405} \quad (9)$$

To calculate K and n using the Herschel–Bulkley model, τ_y must first be calculated. τ_y is calculated by using equation (6). During calculation, τ_y= 7. After calculating τ_y, equation (5) and the regression model should be used to calculate K and n using the Herschel-Bulkley model. A logarithmic regression of Herschel-Bulkley model is shown in Figure 4.

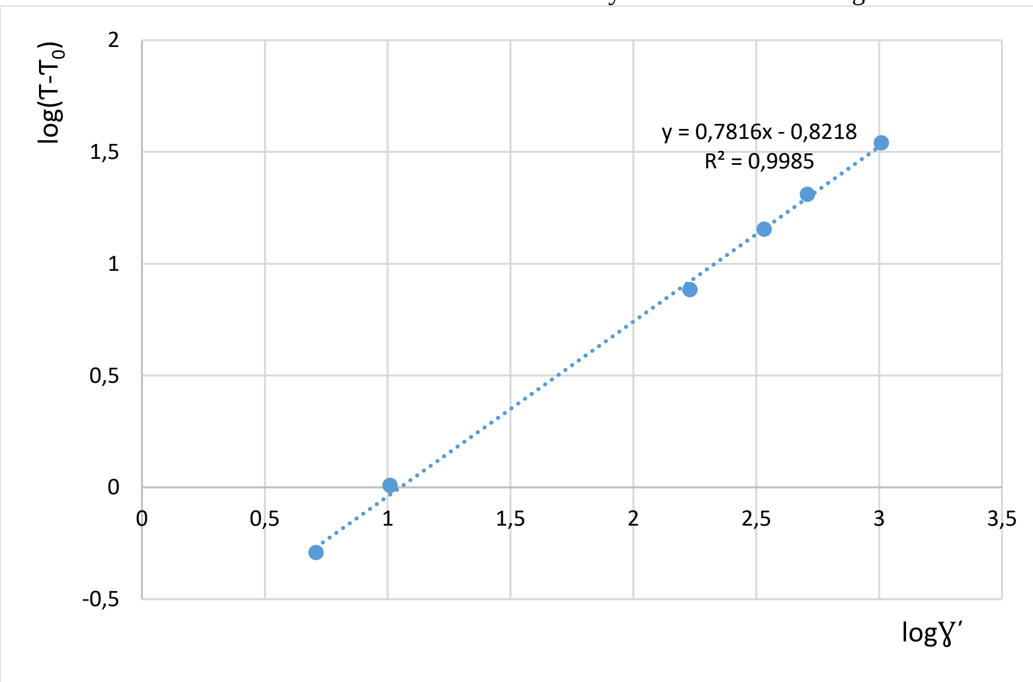

Figure 4. logarithmic regression of Herschel-Bulkley model

As can be seen from Figure 4, the expression of the Herschel-Bulkley model for drilling fluid 1 is as follows:

$$\log(\tau - \tau_y) = 0.7816\log\dot{\gamma} - 0.8218 \quad (10)$$

The following expression for the Herschel-Bulkley model was obtained from the equation (10) (logarithmic regression equation):

$$\tau = 3.57 + 0.1573 * \dot{\gamma}^{0.7816} \quad (11)$$

Values corresponding to the models for the different RPM of the viscometer were calculated from the models obtained for the 1st drilling fluid. The same calculations were made for the 2nd drilling fluid. Results of both calculations are shown in Table 3.

Table 3.

Shear stress for the RPM according to the models

	Shear rate	Real data	Bingham plastic	Power law	Herschel-Bulkley
1th mud sample	$1022s^{-1}$	38.25	24,284	30,537	38,963
	$511s^{-1}$	23.97	16,987	23,063	24,159
	$340.6s^{-1}$	17.85	14,554	19,568	18,564
	$170.3s^{-1}$	11.22	12,122	14,779	12,293
	$10.22s^{-1}$	4.59	9,836	4,730	4,538
	$5.11s^{-1}$	4.08	9,763	3,572	4,133
2nd mud sample	$1022s^{-1}$	25,5	16,023	19,370	22,302
	$511s^{-1}$	15,81	11,072	14,627	14,639
	$340.6s^{-1}$	10,71	9,420	12,410	11,581
	$170.3s^{-1}$	6,63	7,770	9,371	7,973
	$10.22s^{-1}$	3,06	6,219	2,997	2,903
	$5.11s^{-1}$	2,55	6,170	2,263	2,576

The mean absolute percentage error method was used to check the accuracy of the results of the calculations. The mean absolute percentage error is determined by the following expression:

$$MPE = \frac{1}{N}\sum\left|\frac{M-H}{H}\right|$$

Here, N is the number of values, M is the values obtained from the model, and H is the actual values.

The error results of the obtained models for both drilling fluids sample are shown in Table 4.

Table 4.

error of different models

Models	1st mud sample	2nd mud sample
Bingham-plastic	57.62	56.925
Power law	13.464	17.005
Herschel-Bulkley	3.108	9.086

Conclusion

It is clear from the calculations the Herschel-Bulkley model is the most suitable model for the expression of the drilling fluid. The reason of this is that the results obtained by the Herschel-Bulkley model correspond to the readings of viscometer. From the calculated errors, it is clear that the Herschel-Bulkley model has the least error. The worst model for drilling fluid expression is the Bingham plastic model. The error was above 50% for both solution samples. The power law model shows better results (error is between 10-20%) than the Bingham plastic model but worse than Herschel-Bulkley model.

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