Rheology of drilling muds

G Kudaikulova

1 Kazakh National Technical University, Almaty, Kazakhstan

kgulzhanabd@mail.ru

Abstract. Therheological properties of drilling muds were studied. It is shown that for receiving pseudo-plastic liquids with an indicator of nonlinearity of N<0.3 use of polymers with a high molecular weight or a combination of polymers to various influence on water structure is most expedient.

1. Introduction

In the process of drilling wells drilling muds prevent possible technological complications, minimize layer pollution by components of drilling muds, provide the fullest carrying out of drilling cutting and let us achieve the highest the technician – economic indicators.

The hydraulic program of washing of wells, which is realized by regulation of rheological indicators of drilling muds plays an important role in the solution of most of these problems.

Rheological properties of drilling muds have considerable impact on carrying out of drilling cutting on a day surface, creation of hydrodynamic pressure in well. The major factor in defining the efficiency of carrying out of cutting is a ratio of plastic viscosity of drilling mud with a dynamic resistance to shift in the course of a current. Hydrodynamic pressure, in turn, defines possibility of complications in the course of construction of wells: manifestation or absorption of drilling mud, hydraulic fracturing of rocks, and also layer pollution [1, 2]. Therefore there is a problem of management of rheological characteristics of drilling muds in a well occurs which can be solved by chemical processing of drilling muds by various polymers.

2. Theory

All existing rheological models reflect the ideal behavior of real bodies. A number of complex models which are used in various rheological systems were introduced by a combination of three main models.

Drillers are interested inthose models, received by an experimental or semi-empirical way, only if they are applicable for the liquids with non-Newtonian behavior.

In order to describe the behavior of drilling muds with the low maintenance of the solid phase, processed by polymeric reagents (developed by us and considered in present work), Gershel – Balkli's model is commonly used, which in its turn was achieved by a combination of viscoplastic model of Bingham with Ostvald – de Vaale's model. Bingam's viscoplastic model describes substances which have the yield point, below which substances aren't deformed, whereas above – they flow like viscous liquids. There are two rheological parameters at this model – yield point ($\tau_0$) and plastic viscosity ($\eta_p$):

$$\tau = \tau_0 + \eta_p\gamma,$$

(1)

where $\tau$– stress of shear, $\gamma$ – rate of shear.

In Ostvald– de Vaale's model there are two rheological parameters – experimental constants $K$ and $N$; $K$ – consistence and $N$ – nonlinearity indicator:

$$\tau = K\gamma^N,$$

(2)

It is possible to calculate apparent viscositycomparing this equation to Newton’s law:
\[
\eta = \frac{\gamma}{N-1}
\]

As at the drilling muds developed by us N < 1, that points to degree of non-Newtonian behavior of liquid, so \( \eta = K \). Thus, Gershel – Balkli's model will look as follows:

\[
\tau = \tau_0 + K \gamma^N
\]

Researches of the processes proceeding in a well, show that as drilling muds, it is most expedient to use the pseudo-plastic liquids possessing size of an indicator of nonlinearity of N<0.3 [2 – 4]. Such liquids provide effective cleaning a hole of well of drilling cutting and minimum possible losses of pressure in a well.

3. Experimental

Unfortunately, provisions on management of a nonlinearity indicator at drilling muds aren't developed yet. It is caused by that studies of properties of drilling muds and their analytical description in the course of movement carry out from a position of classical mechanics of continuous mediums[5, 6]. Thus it isn't considered that drilling mud is the continuous medium at rest which properties are defined by properties of bonds in it.

We suggest considering of drilling mud as the discrete system consisting of the discrete dispersive medium and a disperse phase. Thus it is necessary to consider that in drilling mud on an interface between two phases of disperse system there is a double electric layer (DEL) which charge on the separate centers is presented by discrete ions.

The indicator of nonlinearity N will depend on ability of hydrogen bonds to form new bonds in mud and is an indicator estimating its internal continuity, and a consistence indicator K – the size of durability of hydrogen bonds. According to it for pseudo-plastic liquid it will be fair that than more size N especially solution is discrete, and than it is more K, that bigger durability hydrogen bonds in volume of mud possess.

From practice of drilling it is known that at drilling mud have size N<0.3 it keeps a continuity of the structure, and at values N>0.3 costs of energy of overcoming of internal resistance of liquid sharply increase that testifies about bigger discrete of drilling mud and fast destruction of bonds in its structure.

Research of rheological parameters of the drilling muds developed was made by FANN – viscometer, model 35 SA (USA) and the VSN-3 rotational viscometer (Russia).

In this research two types montmorillonite clays – clay of the Taunkent field of South Kazakhstan and the Tagansky field of East Kazakhstan are used. The polymers of French “Promafor” (Polycol 60S, Polycol 60SM, Polyfor 30, Polyfor 50), German “Bayer” (Antisol 100, Antisol 30000), USA “M-I Swaco” (EZ MUD, Barazan, Modivis) and Kazakh polymer SOP – threefold copolymer of an acrylic row are used. For each type of drilling mud, polymers are added in different weight concentrations ranging between 0.03 % to 0.7 %.

Consistence (K) and an indicator of nonlinearity (N) were calculated on formulas (5) and (6) [3]:

\[
K = \frac{\tau}{\gamma^N} = \frac{\gamma^N}{0.511/511}
\]

\[
N = 3.32 \log \frac{\gamma}{\gamma^3_600/\gamma_300}
\]

In present work we discuss results of the received values of rheological parameters of drilling muds, as major practical parameters connected with speed of a stream of drilling mud in a well and sharp fluctuations of pressure at lowering-hoisting operations and also at start-up or a stop of drilling pumps.

4. Results and Discussion

Rheograms of the developed drilling muds testify that they aren't ideal viscoplastic liquids as shear stress at zero stress above viscometer indications at low speeds of rotation. In Figure 1 are presented developed rheograms such drilling muds. Rheological parameters of drilling muds processed by various reagents are specified in Table 1.
In the course of a current of drilling mud owing to deformation of DEL there is an effect of braking of particles. The more concentration of clay particles (in a case with Taukentsky clay), the more electrically loaded covers of particles interact by means of attraction or pushing away forces.

Addition of polymers in clay suspension leads to destabilization and decrease in degree of dispersion of system at the expense of aggregation of particles. This process happens owing to reduction of thickness of DEL and increase in forces of an attraction of Van der Waals and adsorption of chains of polymer by surfaces of clay particles. These processes considerably influence viscosity of system, as is observed at increase in concentration of polymers.

The yield point ($\tau_0$) characterizes resistance at a current, caused by the electric forces of an attraction pushing away existing between solvated particles. Value $\tau_0$ depends on concentration of a disperse phase, extent of ionization, thickness of DEL, the nature of ions, concentration and the nature of ions in the dispersive medium and concentration of polymer in system. Change of $\tau_0$ is caused mainly by change of concentration of polymers and their adsorption, displacing balance of forces of an attraction and pushing away.

Apparently from Table 1 values of an indicator of nonlinearity are influenced by structure, concentration and the nature of reagents. Big values $N$ as it was already specified, testify about bigger discrete of drilling mud because bonds between reagents and particles of clay are less strong, than their bonds with water molecules. The hydrated compounds in the course of movement of liquid will represent a separate phase, similar to a firm phase of mud. Such mud is more similar to viscoplastic liquid and have nonlinearity indicator more than 0.3. In this way reagents with the increased concentration in mud – Polycol 60S, Polycol 60SM, Polyfor 50 proved.

Other option when durability of hydrogen bonds in volume of mud is distributed evenly and as a whole increases not at so considerable value. It conducts to deficient rigidity and the increased plasticity of communications. According to it solution in the course of mechanical movement doesn't break the microstructure at the expense of fast restoration of the destroyed bonds. Such reagents give to mud of property of pseudo-plastic liquids. In this way showed reagents with higher molecular weight such, as Antizol 30000, EZ MUD, Barazan and Modivis. It is connected with that molecules with a high weight owing to the size make more uniform changes to water structure in comparison with molecules of smaller weight and respectively provide more uniform distribution of durability of hydrogen bonds in volume of mud. Because the number of single contacts at molecules with high weight above, than at molecules with a low weight, and liquid durability on destruction of structure of solution is higher also, as well as the speed of formation of single contacts.
Bar combinations Antisol with Barazan or Modivis biopolymers, and also Polyfor 30 reagents with sodium acrylates. Antisol with the Polycol 60S and Polycol 60SM reagents representing a mix of polyacrylamides and similar combinations are combinations Antisol (improved cellulose) and the SOP acrylic copolymer, or of strongly differing on molecular weight, promotes obtaining optimum properties of bonds. Example of for example, the combination in drilling mud of reagents with the various nature of dissolution, or comparison with the mud processed only by Polyfor 30 reagent.

In case of combination use reagent Polyfor 30 with Antisol arises strong synergetic increase of durability of bonds in mud (high value K), but without change of an indicator of nonlinearity in comparison with the mud processed only by Polyfor 30 reagent.

| №  | Composition of mud (clay suspension on CS + polymer) | Plastic Viscosity mPa·s | Yield Point τ₀ Pa | Consistency K Pa·s | Nonlinearity indicator N |
|----|---------------------------------------------------|------------------------|------------------|------------------|-------------------------|
| 1  | CS 1 (Taukan clay 10 % + H₂O)                     | 6.0                    | 28.73            | 9.34             | 0.22                    |
| 2  | CS 2 (Tagansky clay 5 % + H₂O)                    | 1.0                    | 30.24            | 28.51            | 0.022                   |
| 3  | CS 2 + 0.03 % SOP                                 | 0.5                    | 53.52            | 37.1             | 0.006                   |
| 4  | CS 2 + 0.04% SOP                                  | 0.0                    | 64.32            | 68.47            | 0                       |
| 5  | CS 2 + 0.05 % SOP                                 | 2.0                    | 56.64            | 53.14            | 0.023                   |
| 6  | CS 2 + 0.03 % Polyfor 30                         | 6.0                    | 100.60           | 75.96            | 0.063                   |
| 7  | CS 2 + 0.04 % Polyfor 30                         | 7.5                    | 107.75           | 88.2             | 0.048                   |
| 8  | CS 2 + 0.05 % Polyfor 30                         | 8.5                    | 129.54           | 111.86           | 0.038                   |
| 9  | CS 2 + 0.06 % Polyfor 30                         | 17.0                   | 115.65           | 63.28            | 0.122                   |
| 10 | CS 2 + 0.07 % Polyfor 30                         | 23.0                   | 115.89           | 58.5             | 0.137                   |
| 11 | CS 1 + 0.1 % Polycol 60S                         | 6.0                    | 28.73            | 9.33             | 0.22                    |
| 12 | CS 1 + 0.3 % Polycol 60S                         | 8.0                    | 16.28            | 5.35             | 0.30                    |
| 13 | CS 1 + 0.5 % Polycol 60S                         | 8.5                    | 22.51            | 3.92             | 0.34                    |
| 14 | CS 1 + 0.7 % Polycol 60S                         | 13.0                   | 16.76            | 1.08             | 0.53                    |
| 15 | CS 1 + 0.1 % Pol. 60SM                           | 6.5                    | 29.21            | 9.00             | 0.23                    |
| 16 | CS 1 + 0.3 % Pol. 60SM                           | 9.0                    | 18.67            | 4.11             | 0.34                    |
| 17 | CS 1 + 0.5 % Pol. 60SM                           | 10.0                   | 22.03            | 3.57             | 0.38                    |
| 18 | CS 1 + 0.7 % Pol. 60SM                           | 15.0                   | 12.93            | 0.65             | 0.61                    |
| 19 | CS 1 + 0.1 % Polyfor 50                          | 3.5                    | 28.25            | 17.03            | 0.13                    |
| 20 | CS 1 + 0.2 % Polyfor 50                          | 7.0                    | 26.34            | 6.24             | 0.28                    |
| 21 | CS 1 + 0.3 % Polyfor 50                          | 7.5                    | 27.30            | 6.84             | 0.27                    |
| 22 | CS 1 + 0.5 % Polyfor 50                          | 9.5                    | 22.03            | 3.30             | 0.37                    |
| 23 | CS 2 + 0.04% Antisol 100                          | 1.9                    | 31.13            | 12.48            | 0.18                    |
| 24 | CS 2 + 0.04% Antisol 300000                      | 4.8                    | 35.92            | 23.36            | 0.09                    |
| 25 | CS 2 + 0.04 % EZ MUD                             | 6.0                    | 31.60            | 10.76            | 0.21                    |
| 26 | CS 2 + 0.04 % Barazan                            | 7.0                    | 34.48            | 19.35            | 0.12                    |
| 27 | CS 2 + 0.04 % Modivis                           | 3.5                    | 34.96            | 19.35            | 0.12                    |

In order to receive the drilling muds being pseudo-plastic liquid with value N less than 0.3 was of interest to find combinations of the reagents, capable to provide uniform distribution of durability of hydrogen bonds in structure of water of a drilling mud. For this purpose we developed recipes of the drilling muds containing mutually compatible reagents, allowing to operate durability of hydrogen bonds in volume of mud. Drilling muds were prepared with Tagansky clay. Results of the carried-out researches are given in Table 2.

The mechanism of action of binary composition of reagents such is. At introduction of composition of reagents in clay suspension one reagents will create an initial grid on the basis of hydrogen bonds, to set thereby mud structure, others at the expense of the hydration will redistribute it among themselves, with simultaneous alignment of durability of hydrogen bonds on mud volume. Therefore, for example, the combination in drilling mud of reagents with the various nature of dissolution, or strongly differing on molecular weight, promotes obtaining optimum properties of bonds. Example of similar combinations are combinations Antisol (improved cellulose) and the SOP acrylic copolymer, or Antisol with the Polycol 60S and Polycol 60SM reagents representing a mix of polyacrylamides and sodium acrylates.

Combinations Antisol with Barazan or Modivis biopolymers, and also Polyfor 30 reagents with Barazan or Modivis allow to receive muds with a nonlinearity indicator N <0.3 where biopolymer plays the priming role, focusing original structure of mud.

In case of combination use reagent Polyfor 30 with Antisol arises strong synergetic increase of durability of bonds in mud (high value K), but without change of an indicator of nonlinearity in comparison with the mud processed only by Polyfor 30 reagent.
Table 2. Influence binary composition of reagents on rheological parameters drilling muds

| №  | Composition of mud (clays suspension CS + polymer 1 + polymer 2) | Plastic Viscosity mПа·s | Shear Strength 1 | Shear Strength 10 | Consistency K Па·s | Nonlinearity indicator N |
|----|---------------------------------------------------------------|-------------------------|------------------|-------------------|-------------------|------------------------|
| 1  | CS + 0.04 % SOP + 0.04 % Antisol                              | 30.0                    | 19.68            | 20.16             | 50.32             | 0.154                  |
| 2  | CS + 0.04 % SOP + 0.05 % Antisol                              | 33.5                    | 21.60            | 22.56             | 44.58             | 0.175                  |
| 3  | CS + 0.04 % SOP + 0.06 % Antisol                              | 26.5                    | 22.08            | 23.04             | 55.50             | 0.140                  |
| 4  | CS + 0.04 % SOP + 0.07 % Antisol                              | 22.0                    | 33.12            | 33.60             | 50.45             | 0.129                  |
| 5  | CS + 0.04 % SOP + 0.08 % Antisol                              | 22.5                    | 32.64            | 36.00             | 58.13             | 0.125                  |
| 6  | CS + 0.04 % SOP + 0.04 % Polyfor30                            | 12.0                    | 17.28            | 19.44             | 63.11             | 0.081                  |
| 7  | CS + 0.04 % SOP + 0.05 % Polyfor30                            | 14.5                    | 17.76            | 20.40             | 58.96             | 0.096                  |
| 8  | CS + 0.04 % SOP + 0.06 % Polyfor30                            | 22.0                    | 18.48            | 19.44             | 46.98             | 0.138                  |
| 9  | CS + 0.04 % Polyfor30 + 0.07 % Polyfor30                       | 26.8                    | 17.28            | 20.88             | 45.47             | 0.155                  |
| 1  | CS + 0.04 % Polyfor30 + 0.08 % Antisol                         | 10.5                    | 41.76            | 45.60             | 107.42            | 0.051                  |
| 2  | CS + 0.04 % Polycol 60S + 0.04 % Antisol 30000                 | 10.0                    | 2.85             | 9.56              | 13.66             | 0.17                   |
| 3  | CS + 0.04 % Polycol60SM + 0.04 % Antisol100                    | 8.0                     | 4.86             | 6.04              | 5.83              | 0.30                   |
| 4  | CS + 0.04 % Antisol 30000 + 0.04 % Barazan                      | 5.5                     | 4.2              | 4.7               | 11.01             | 0.20                   |
| 5  | CS + 0.04 % Antisol 30000 + 0.04 % Modivis                     | 4.5                     | 7.05             | 7.55              | 14.7              | 0.16                   |
| 6  | CS + 0.04 % Polyfor30 + 0.04 % Barazan                         | 5.5                     | 1.01             | 5.03              | 12.03             | 0.19                   |
| 7  | CS + 0.04 % Polyfor30 + 0.04 % Modivis                         | 4.5                     | 4.86             | 5.03              | 16.03             | 0.15                   |

5. Conclusion

Thus, proceeding from specification of ideas of interaction of reagents in volume of drilling muds and the given experimental results, follows that for receiving pseudo-plastic liquids with an indicator of nonlinearity of N<0.3 use of polymers with a high molecular weight or a combination of reagents to various influence on water structure is most expedient.

References
[1] Kister E.G. 1972 Chemical processing of drilling muds. M: "Nedra", 392
[2] Gray G.R., Darley H.C.H. 1985 Composition and Properties of Oil Well Drilling Fluids Transl. Engl. M: “Nedra”, 509
[3] Makovey N. 1986 Hydraulics of drilling. M:“Nedra”, 536
[4] Ogibalov P. M., Mirzadzhanzade A. Kh. 1970 Non-stationary movements viscously-plastic mediums. M: Moscow State University Publishing, 415
[5] Krasnov K.S. 1984 Molecules and chemical bond. M: “Vyssh. Sh.”, 295
[6] Rabinovich N.R. 1989 Engineering problems of mechanics of the continuous medium in drilling. M:“Nedra”, 270