RHEOLOGICAL CHARACTERISTICS OF DRILLING FLUIDS

Solikhov Khasan
Student, the Branch of the Russian State University of Oil and Gas (NRU) named after I.M.Gubkin in Tashkent
e-mail: solixovxasan1@gmail.com
Sadullaeva Maftuna Abdujalilovna
Teacher, the Branch of Russian State University of Oil and Gas (NRU) named after I.M. Gubkin in Tashkent

ABSTRACT. The article discusses the rheological properties of a high-density, barite-free drilling mud developed on the basis of formats and polyacrylamide. A comparative analysis with a traditional barite solution is carried out, including an assessment of viscosity and shear stress at different shear rates. It has been established that the non-barite solution has pronounced pseudo-plastic properties, which makes it more effective when drilling horizontal and directional wells. Recommendations for the use and control of the parameters of such solutions under drilling conditions are presented.

KEYWORDS: Drilling fluid, viscosity, shear stress, shear rate, flushing, velocity, a barite-free fluid

АННОТАЦИЯ. В статье рассматриваются реологические свойства безбаритного бурового раствора повышенной плотности, разработанного на основе форматов и полиакриламида. Проведён сравнительный анализ с традиционным баритовым раствором, включающий оценку вязкости и напряжения сдвига при различных скоростях сдвига. Установлено, что безбаритный раствор обладает ярко выраженными псевдопластическими свойствами, что делает его более эффективным при бурении горизонтальных и

наклонно-направленных скважин. Представлены рекомендации по применению и контролю параметров таких растворов в условиях бурения.

КЛЮЧЕВЫЕ СЛОВА: Буровой раствор, вязкость, напряжение сдвига, скорость сдвига, промывка.

Introduction.

The rheological properties of a drilling fluid play a significant role in ensuring the efficiency of well drilling. They influence processes such as cuttings removal, borehole stabilization, hydraulic energy transfer, and development prevention. The article discusses parameters of non-saline salt-based drilling mud and compares them with traditional barite-based mud.

Non-Newtonian fluids without expressed plastic or thixotropic properties include emulsions (including invert emulsions), drilling fluids, solutions treated with water-reducing agents or viscosity reducers, polymer-based drilling fluids with low clay content, and foams. Suspensions containing polymer additives often exhibit viscoelastic properties.

The rheological characteristics of drilling fluids is more consistent with the Bingham model than the Newtonian model. However, most drilling fluids do not obey either of these two models. If rheological parameters are determined at two points within a specific range of shear rates on the flow curve (points 1 and 2 in Fig. 1), then outside this range, the calculated shear stress values may be higher (for the Bingham model) or lower (for the Ostwald model) than the actual values.

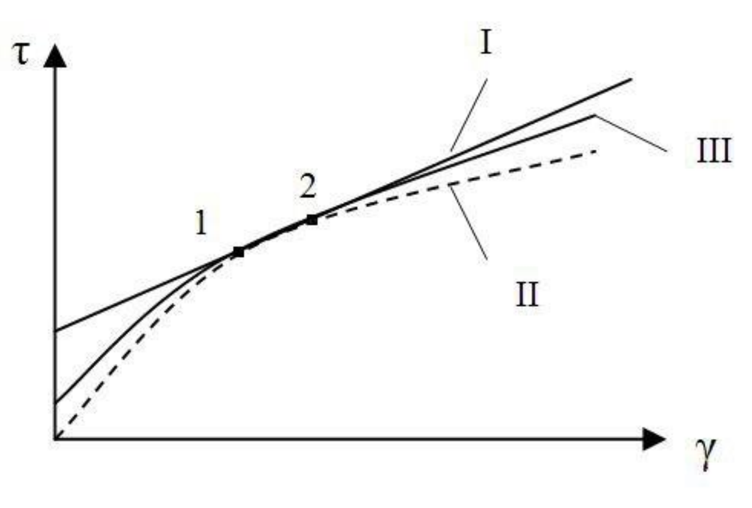

Fig.1. Approximation of the real flow curve of the liquid using Bingham and Ostwald-de Waele models:
I – Bingham model;
II – Real fluid;
III – Ostwald-de Waele model.

Much wider range of shear rates is covered by three-parameter models: the Herschel-Bulkley model for viscoplastic systems and the Bingham model for solutions exhibiting pseudoplastic properties. However, determining the rheological parameters of solutions for these models and integrating their motion equations is quite challenging.

The properties of the drilling fluid is determined by its flow regime. There are two flow regimes: laminar flow, which predominates at low flow velocities (the pressure-speed relationship is governed by the fluid's viscous properties), and turbulent flow, which predominates at high velocities and depends on the inertial properties of the fluid (viscosity influences it only indirectly) (Fig. 2).

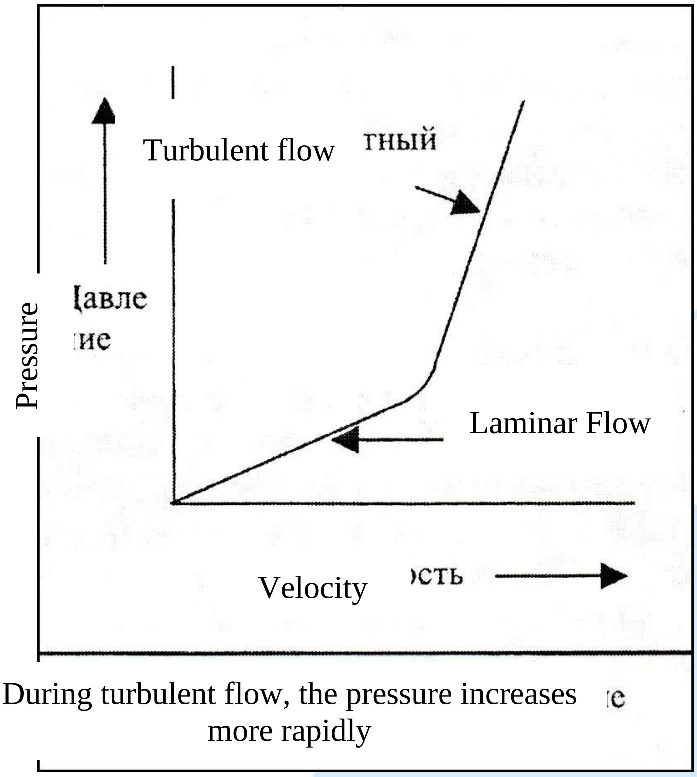

Fig.2. Flow regime of drilling fluids

Laminar flow in a circular pipe can be visually represented as the sliding of thin cylinder inside another (see Fig. 3). The velocity of the cylinders increases from zero at the pipe wall to a maximum along its axis. The ratio of the difference in velocities of adjacent layers, Du, to the distance between them Dr, is called the shear rate g = Du/Dr (4.30)

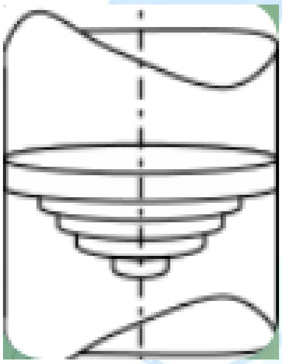

Fig.3. Schematic illustration of laminar flow of fluid in a pipe.

The strength of interaction between two adjacent layers moving relative to each other at a certain velocity depends on the type of fluid, the contact area of the sliding layers, and the shear velocity (Newton's law of internal friction).

F = ηSg

Where F – The frictional force between two adjacent layers of fluid;

η - dynamic viscosity, depending on the nature of the liquid;

S – contact area of layers;

g - shear rate.

If we divide both sides of the equation by S, then:

F / S = η g,

where F / S = t - shear stress causing shear of the layer.

[t] = F / S = Н/м2 = Pa.

Then in its final form we will obtain I. Newton's law t = η g.

[η] = t / g = Па/с-1 = Па×с

At a temperature of 20.5 °C and a pressure of 0.1 MPa, the viscosity of water is 1 mPa×s.

For Newtonian fluids, the dynamic viscosity remains constant at any shear rate (in pipes, in the post-pipe space, in the bit nozzles) and geometrically represents the

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tangent of the angle of inclination of the rheological curve to the shear rate axis (Fig. 4).

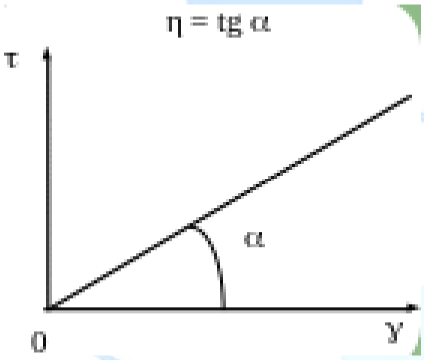

Fig. 4. Graph of the dependence t = f(g) of Newtonian (viscous) liquids

In a non-Newtonian fluid, the ratio of shear stress to shear rate (at any shear rate) is a quantitative characteristic of the effective, or apparent, viscosity. Figure 5 shows that effective viscosity decreases with increasing shear rate and is therefore a significant parameter for hydraulic calculations only at the shear rate at which it is measured. Figure 6 shows that effective viscosity cannot serve as a reliable parameter for comparing the behavior of two different drilling fluids.

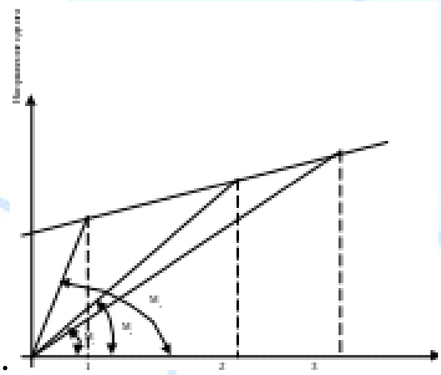

Fig. 5. Decrease in effective (apparent) viscosity with increasing shear rate

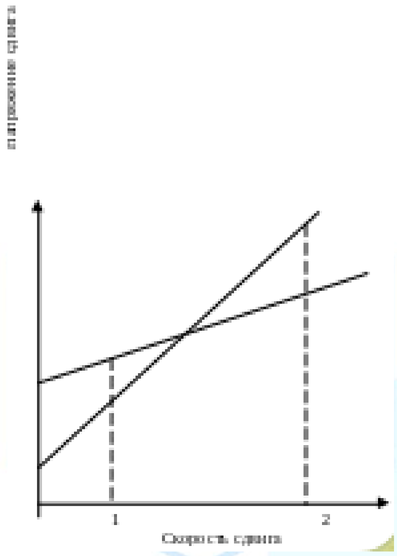

Fig. 6. Comparison of effective viscosity (apparent) at two shear rates for two different drilling fluids

The rheological behavior of certain drilling fluids, particularly those derived from clays and fresh water, is characterized by thixotropy. This means that after agitation is halted, their yield stress gradually increases over time. During a period of rest, the fluid's internal structure undergoes recovery. Subsequently, when subjected to shear at a constant rate, the viscosity of a thixotropic fluid decreases dynamically as its structure is progressively broken down until a stable state is attained. As a result, the apparent viscosity of these fluids is influenced by both the time elapsed

since agitation and the applied shear stress.

Research Objective

To analyze and evaluate the rheological characteristics of a high-density barite-free drilling fluid based on formates of formic acid and synthetic polymers, as well as to perform a comparative analysis with a barite-weighted drilling fluid.

Composition and methodology

Fluid 1: Barite-free — based on formats with the addition of polyacrylamide (PAM) (fig.7) (molecular weight ≈ 27 mln).

Fluid 2: classic barite solution with higher stable viscosity.

A rotational viscometer Fann 35A (Fig. 8) was used to analyze viscosity, velocity, and shear stress under various conditions.

The shear stress is calculated using the formula:

$$\tau = \eta \cdot \dot{\gamma} \cdot 0.001$$

Fig.7. Polyacrilamide (PAM)

Fig.8. Rotational viscometer Fann 35A

Results for a barite-free solution

Shear rate (1/s)	Viscosity (cP)	Shear voltage (Pa)
0.17	5000	0.85
5.10	2000	10.20
10.20	1000	10.20
51.00	150	7.65
102.10	80	8.17
255.30	60	15.32
511.00	50	25.55
1021.00	45	45.94

Conclusion: The solution exhibits pronounced pseudoplastic behavior. As the flow rate increases, the viscosity decreases, which facilitates both slurry retention (at low speeds) and easy circulation (at high speeds).Comparative analysis with barite solution

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Shear rate	Voltage (Pa) – none-barite	Voltage (Pa) – barite
0.17	0.85	0.20
5.10	10.20	5.10
10.20	10.20	9.69
51.00	7.65	45.90
102.10	8.17	86.78
255.30	15.32	204.24
511.00	25.55	398.58
1021.00	45.94	765.75

Interpretation:

The barite fluid exhibits a nearly linear increase in shear stress, which is characteristic of a Newtonian fluid.

The non-barite fluid is a pronounced non-Newtonian type: the viscosity decreases sharply with increasing speed. This reduces the load on the pumps, reduces pressure losses and increases flushing efficiency.

Additional properties of non-barite fluid

Thermal stability: withstands temperatures up to 450°F without structural degradation.

Filtration: reduced to ~5.4 ml/30 min.

Formation compatibility: easily removed with acidic reagents, does not clog pores.

Conclusion:

1. Barite-free drilling mud has pseudoplastic rheological behavior, which makes it more flexible in controlling flushing.

2. Compared to barite solution, it requires less energy for pumping and has better filtration properties.

3. The use of PAM (polyacrylamide) allows maintaining viscosity at high temperatures and reduces contamination of the productive formation.

4. Comparison shows that at high circulation rates, the barite-free solution creates a load 3–5 times lower than the barite solution.

Recommendations

Use barite-free muds when horizontal and directional drilling of the wells.

Use high molecular weight PAA to maintain rheological properties.

Conduct regular monitoring of viscosity and shear stress at different speeds to adapt to specific geological and technical conditions.

When designing a drilling fluid, it is important to consider not only the density but also the impact on formation productivity and filtration requirements.

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