SOCAR Proceedings No.4 (2024) 048-050

SOCAR

SOCAR Proceedings

Drilling & Completion

journal home page: http://proceedings.socar.az

EMERGING SOURCES CITATION INDEX

Scopus

EVALUATION OF THE EFFECT OF BERNOULLI FORCE ON STUCK PIPE DURING DRILLING

R. H. Veliyev

«SOCAR, Baku, Azerbaijan

A B S T R A C T

Stuck pipe is one of the biggest problems that can occur during drilling. Stuck pipe leads to drilling of sidetrack, and re-drilling of that interval. In order to eliminate the stuck of the instrument, it is necessary to know the cause of its occurrence. It is necessary to eliminate the stuck of the instrument as quickly as possible, as the time for elimination increases, the severity of the stuck increases. Seizure of the tool can occur in two ways: mechanical and differential. During the drilling of oil and gas wells, drilling fluids with different basic and rheological properties are used. Experience shows that drilled rock particles, which are mixed with water-based or oil-based drilling fluids (clay based drilling fluids, polymer based drilling fluids, oil-based drilling fluids) and brought to the surface, have a significant effect on the rheodynamics of the solution, and turn it into a more active multiphase flow. Rock particles of different diameters, which play the role of mechanical particles, play the role of dispersed phase. Based on the interaction of the phases, it is possible for the drilling tool to be stuck because of Bernoulli force which is result of the migration of the rock particles to drilling tool, which is caused by the pressure gradient that changes along the cross-section and is directed towards the center of the cylindrical flow. In the article, the occurrence of stuck is justified and the evaluation of the Bernoulli force, which is the main reason, is considered. As a result of calculation it was determined that Bernoulli force is a function of drilling fluids and drilled rock particles densities, diameter of the drilled rock particles.

Keywords: drilling fluids; Bernoulli forces; static pressure; phiysical model; pressure gradient.

Date submitted: 17.08.2024 **Date accepted:** 28.10.2024

Introduction

The structure of multiphase flows (gas-liquid, oil-water-gas, oil-gas-mechanical particles, drilling fluids, etc.) depends greatly on the orientation of the channel (pipe) and the direction of movement [1, 2]. So, during the movement of these flows in a vertical pipe from top to bottom and vice versa from bottom to top, as well as in horizontal direction, their characteristics differ significantly from each other. Since the gradient-velocity field is formed not only along the length, but also along the cross-section of the flow according to the law of conservation of energy [1-3], the carrier dispersion medium is able to transport dispersed phase particles along the axis of the flow, in its core. Due to the Bernoulli force, which is directed from the edges of the cylindrical flow towards the center, those particles move (mechanical, gas, water, etc.) very easily in the core of the carrier medium, moving along the axis of the flow [4-7].

It is known that during such flows mainly gravity, Archimedes, and Bernoulli forces (if we do not consider friction and inertia forces) are active forces, which cause sedimentation and migration events. It is clear that although the direction of these forces is known, their effect will be different depending on the direction of the multiphase flow [5]. So, in vertical downward and upward flows, Archimedean and gravitational forces will be opposite to each other, and Bernoulli›s force will be perpendicular to them. In the case of horizontal flows, although the direction of all three forces is perpendicular to the flow, the Bernoulli force will be perpendicular to the axis of the flow from the edges, and the Archimedean and gravitational forces will be opposite to each other. Schematically, the directions of these forces in different directional flows are shown in figure 1.

The evaluation and effect in stuck pipe effect of the Bernoulli force which forms as a result of static pressure gradient (dP/dr) and intensifies along the cross-section with increasing flow rate is discussed below [6,7].

Problem of research

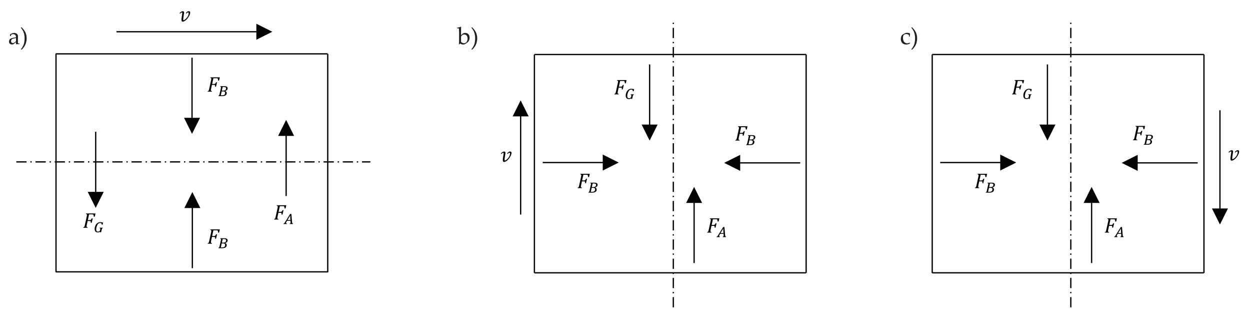
Let express the substitute for the forces acting on a particle in a liquid flowing in a cylindrical tube by Newton›s second law:

$$F=ma$$

Here, F – substitute for the forces acting on the object (particle) (N); m – the mass of the particle (kq), a – accelaration of the particle movement (m/s^2).

E-mail: racu.veliyev@socar.az

http://dx.doi.org/10.5510/OGP20240401016



a) horizontal, b) bottom up, c) up bottom

F_B – Bernoulli force, F_A – Archimedean force, F_G – Gravitational force

Fig. 1. Direction of active forces in multiphase flows with different directions

Since acceleration characterizes the rate of change of velocity, it can be replaced by (dv/dt). It is possible to write the mass of a particle as the product of its density (ρ) and its volume (V). If we assume that the particle is spherical, its mass can be determined by the following expression:

$$m=0.167\,\pi d^3\times\rho \tag{2}$$

Here, d – is diameter of partciles (m).

If we consider the expression (2) and the expression (dv/dt) in the expression (1) above, we get the following expression:

$$F=0.167\pi d^3\times\rho\times\frac{dv}{dt} \tag{3}$$

Here, dv/dt – It characterizes the rate of change of speed and the acceleration of the particle (m/s^2).

If we multiply and divide the last expression by the expression dr, then we get:

$$F_B=0.167\pi d^3\rho\frac{dv}{dr}\times\frac{dr}{dt}=0.167\pi d^3\rho v\frac{dv}{dr} \tag{4}$$

Here, v – flow velocity of drilling fluids (m/s); dv/dr – is the velocity gradient along the cross section (s^{-1}).

The last expression thus obtained characterizes the variation of the Benoulli force directed towards the center of the flow along the cross-section. The expression of the Bernoulli force can be determined based on the Bernoulli equation. It is known that if we do not take into account the geometric pressure, the stability of the energy can be expressed as follow:

$$P+\frac{1}{2}\rho v^2=const \tag{5}$$

Here, v – velocity (m/s); P – pressure at a given point (Pa); ρ – density of drilling fluids (kq/m^3); g – gravitational acceleration (m/s^2);

Solution of problem

A new physical model of flow according to Bernoulli›s law is shown in figure 2 [8]. According to the new flow model, the static pressure changes along the cross-section, while the sum of the static and velocity pressures, i.e., the total pressure, remains constant. For comparison, let›s note that the graphs representing the change of static and velocity pressures along the cross-section according to the old physical model of the flow are shown in figure 3. According to this flow model, the static pressure is assumed to be constant along the cross-section, rather than the absolute pressure (P_0).

If we take into account that the sum of static and velocity pressures is unchanged according to the expression (5) in the cross section of the flow, then we can write [8, 9]:

$$\frac{d}{dr}\left(P+\frac{1}{2}\rho v^2\right)=0 \tag{6}$$

From the last expression, we get the following expression that characterizes the change of the pressure gradient along the cross-section:

$$-\frac{dP}{dr}=\rho v\frac{dv}{dr} \tag{7}$$

If we consider expression (7) in equation (4), we get the Bernoulli force as follow:

$$F_B=-0.167\pi d^3\frac{dP}{dr} \tag{8}$$

Here, d – the diameter of the particle moving in the drill-

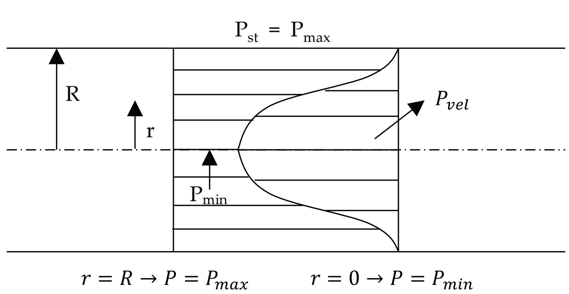


Fig. 2. New physical model of flow (static and velocity pressure variation)

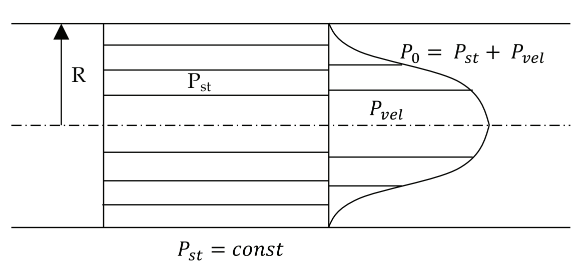


Fig. 3. Old physical model of flow

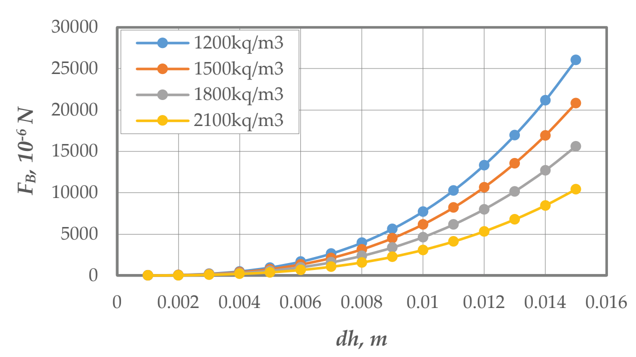


Fig. 4. Dependence of the Bernoulli force on the diameter of the mechanical particle (for drilling fluids with different specific gravity)

ing fluid (m); dP/dr – is the pressure gradient across the cross section (Pa/m).

The transfer movement of the flow along the cross-section occurs under the influence of the pressure gradient along the length (height), against the background of the movement of the medium. As the average flow rate increases, the flow turbulence also increases. Because, the pressure gradient across the cross-section increases more intensively with increasing speed. When the pressure gradient values are greater than the specific weights of the phases, i.e. $\left(\frac{dP}{dr}=(\rho_{m.h}-\rho_m)g\right)$, mechanical rock particles migrate towards the center of the flow, in other words, to the drill string under the influence of the Bernoulli force. Taking into account the mentioned condition, we get the following expression for the evaluation of the Bernoulli force:

$$F_B = 0.167\pi d^3\left(\rho_{m.h}-\rho_m\right)g$$

Here, $\rho_{m.h}$ – density of mechanical particle (kq/m^3); ρ_m – density of drilling fluids (kq/m^3); g – gravitational acceleration (m/s^2).

As can be seen from the last expression, the Bernoulli force which directed from the pipe wall to the center of the flow in the cylindrical flow increases significantly as the difference in densities of mechanical particles and fluid (drilling fluid) and the diameter of mechanical cuttings increases. Diameters of mechanical cuttings was taking into account in 1-15 mm (sometimes it is possible to see washout in borehole that's why diamter of cuttings became larger) [10]. The variation of this force with the increase in the diameter of the mechanical particles at constant values of the parameters $\rho_{m.h}$, ρ_m is given in figure 4.

As can be seen from the last statement and figure 4, even in small diameters of rock fragments, their migration to the center of the flow is inevitable despite the high degree of dispersion. As the diameter of the drilled rock particles increases due to the Bernoulli force created by the variable pressure gradient, it is possible that they significantly increase their frictional forces due to their intensive migration (transportation) to the center of the flow and cause the stuck pipe. In calculations, the density of excavated rock particles was assumed to be 2700 kq/m^3 (densities of rock particles changes between 2.22 and 3.12. that's why 2.7 was chosed as a avarage specific gravity) [11].

Conclusion

1. During the gravity flow of multiphase drilling fluids, result of the migration of the drilled rock particles towards the drill string due to the effect of the Bernoulli force which directed towards the center of the flow caused by the pressure gradient that forms along the cross-section can cause stuck pipe in oil well drilling.
2. As a result of the research, it was determined that as the diameter of the rock particles increases and the density of the drilling fluid decreases, the Bernoulli force increases significantly and the probability of the stuck pipe increases.

References

1. Suleimanov, B. A., Veliyev, E. F., Shovgenov, A. D. (2022). Well cementing: fundamentals and practices. *Moscow-Izhevsk: ICS.*

2. Suleimanov, B. A., Veliyev, E. F., Aliyev, A. A. (2023). Oil and gas well cementing for engineers. *John Wiley & Sons.*

3. Sitenkov, V. T. (2004). Theory of gradient-velocity field. *Moscow: JSC «VNIIOENG».*

4. Ismayilova, F. B. (2021). On the role of the Bernoulli force in the operation of multiphase pipelines. In: International Conference «Rassokhin Readings». Part 2. *Ukhta: USTU.*

5. Ismayilov, G. G., Iskandarov, E. Kh., Fataliyev, V. M. (2019). Investigating the impact of dissolved natural gas on the flow characteristics of multicomponent fluid in pipelines. *Open Physics*, 17(1), 206-213.

6. Suleimanov, B. A. (2011). Sand plug washing with gassy fluids. *SOCAR Proceedings*, 1, 30-36.

7. Issa, M. A., Alrazzaq, A. A. A. A., Mukthar, Y. (2023). Review of the mechanisms for preventing, diagnosing, and treatment of pipe sticking in drilling operations. *Iraqi Journal of Chemical and Petroleum Engineering*, 24(3), 133-140.

8. Oliveira, A.R.E. (2019). History of the Bernoulli principle. In: Uhl, T. (Eds) Advances in mechanism and machine science. *IFToMM WC 2019. Mechanisms and machine science. Vol 73. Springer, Cham.*

9. Ivanov, E., Klyuyev, A., Zharkovski, A., Borshchev, I. O. (2021). Numerical simulation of multiphase flow structures in openfoam software package. *E3S Web of Conferences*, 320, 04016.

10. Yi, S. L., Wang, Z. M., Yi, X. Z., Chang, W. (2013). The fundamental characteristics on particle size distribution of drilling rock-cuttings. *Applied Mechanics and Materials*, 275-277, 2411-2414.

11. Aghamelu, O. P. (2011). A geotechnical investigation on the structural failures of building projects in parts of Awka, Southeastern Nigeria. *Indian Journal of Science and Technology*, 4(9), 1119-1124.