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Analysis of the hydraulic characteristics of flushing fluid when gas enters wells drilled from semi-submersible drilling rigs

Analiza charakterystyki hydraulicznej płynu przemywającego, gdy gaz dostaje się do odwiertów, które wykonano z półzanurzalnych platform wiertniczych

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ABSTRACT: The article considers how in recent years the study of hydraulics and hydrodynamics have been successfully used in the qualitative analysis of complications arising during the drilling of wells. One of the main factors determining the success of well drilling is hydrodynamic pressure. Also a boundary layer forms both on the wall of the casings and on the walls of the well has important means. One potential complication is the appearance of gas when a well is drilled from a semi-submersible drilling rig. The article deals with issues of clarifying the nature and eliminating gas, as well as preventive measures and their consequences. However, in order to take a final decision it is necessary to analyse the nature of the pressure change at the blowout preventer on a semi-submersible drilling rig. A number of works have been devoted to determining hydraulic pressure and hydraulic resistance in the circulation system of wells, on the basis of both stationary and non-stationary processes. Gas was observed in well no. 28 of the Sangachal-Sea field (Caspian Sea, Azerbaijan) at a depth of 3819 m and with a specific gravity of the flushing fluid of 2.25–2.27 g/cm^3. When the blowout preventer was closed, the pressure increased to 10 MPa for 2–3 hours, before decreasing to 2.5 MPa and stabilising. The conclusion from this is that if the flow rate, the angle of deviation of the installation and contact time of the surfaces are constant, the influence of the flushing fluid decreases as the pressure drop increases. As the fluid filtration rate increases, the friction force between the drill pipe and the borehole wall increases. The friction force between the surfaces of the column and the filter cake is inversely proportional to the fillet velocity.

Key words: hydrodynamic pressure in the well, drilling hydraulics, drilling fluid parameters, offshore drilling, drill pipes, blowout prevention, reservoir fluids, resistance coefficients.

STRESZCZENIE: W artykule wskazano w jaki sposób w ostatnich latach badania hydrauliczne i hydrodynamiczne zostały z powodzeniem wykorzystane do analizy jakościowej problemów powstających w procesie wiercenia otworów. Jednym z głównych czynników decydujących o powodzeniu wiercenia otworów jest ciśnienie hydrodynamiczne. Istotne znaczenie ma również tworzenie się warstwy przyściennej, zarówno na ściance rur okładzinowych, jak również na ścianie odwiertu. Jednym z problemów jest pojawienie się gazu podczas wiercenia odwiertu z platform półzanurzalnych. W artykule rozważane są zagadnienia związane z wyjaśnieniem charakteru i eliminacją przypadków pojawienia się gazu, ze środkami zapobiegawczymi i ich konsekwencjami. Jednak do podjęcia ostatecznej decyzji konieczne jest przeanalizowanie charakteru zmiany ciśnienia na głowicy przeciwerupcyjnej (BOP) na platformie półzanurzalnej. Szereg prac poświęcono wyznaczaniu ciśnienia hydrodynamicznego i oporu hydraulicznego w układzie obiegu płynu w odwiercie na podstawie procesów stacjonarnych i niestacjonarnych. W odwiercie nr 28 na polu Sangachal-Sea (Morze Kaspijskie, Azerbejdżan) zaobserwowano gaz na głębokości 3819 m, przy płynie przemywającym o gęstości 2,25–2,27 g/cm^3. Po zamknięciu głowicy przeciwerupcyjnej (BOP) ciśnienie wzrosło do 10 MPa na 2–3 godziny, a następnie spadło do 2,5 MPa i ustabilizowało się. Wynika z tego, że jeżeli natężenie przepływu, kąt odchylenia instalacji od pionu oraz czas kontaktu powierzchni są stałe, to czas płukania odwiertu maleje wraz ze wzrostem „spadku ciśnienia". Wraz ze wzrostem szybkości filtracji płuczki wzrasta siła tarcia między rurą wiertniczą a ścianą odwiertu. Siła tarcia między powierzchnią kolumny rur a osadem filtracyjnym jest odwrotnie proporcjonalna do prędkości usuwania gazu z odwiertu.

Słowa kluczowe: ciśnienie hydrodynamiczne w odwiercie, hydraulika wiertnicza, parametry płynu wiertniczego, wiertnictwo morskie, rury płuczkowe, profilaktyka przeciwerupcyjna, płyny złożowe, współczynniki oporu przepływu.

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Introduction and problem statement

Studying the difficulties encountered when drilling oil and gas wells and developing measures to prevent them will improve the technical and economic indicators of drilling. Until recently, hydraulics was used in drilling to calculate the circulation system. In recent years, the studies of hydraulics and hydrodynamics have been successfully used in the qualitative analysis of difficulties arising during the drilling of wells. One of the main factors determining the success of well drilling is hydrodynamic pressure. Also a boundary layer forms both on the wall of the casings and on the walls of the well significantly effects the hydraulic characteristics of movement.

Many problems can occur whilst drilling wells in geologically complicated areas. Numerous articles have been dedicated to research on the topic (Mirzajanzade and Seid-Rza, 1966; Movsumov et al., 1972). One such complication is the appearance of gas during the drilling of a well from a semi--submersible rig. The issues of clarifying the nature and elimination of gas occurrences, as well as preventive measures and their consequences, are discussed in the work of Movsumov (1976). However, in order to take a final decision, it is necessary to analyse the nature of the pressure change at the blowout preventer (BOP) on a semi-submersible drilling rig (SSDR).

A number of works have been dedicated to determining the hydraulic pressure and hydraulic resistance in the circulation system of a well, on the basis of both stationary and non-stationary processes (Malevanisky, 1976). However, they do not take into account the influence of reservoir fluids entering the well, which changes the hydraulic characteristics of the drilling fluid in the annular space. Therefore, we have proposed a method for determining the hydraulic resistance coefficient based on wellhead information about changes in pressure and flow rate over time when reservoir fluids enter the annular space of the well (Seid-Rza, 1963).

Methodology of research and factual material

Usually, a preventer unit is installed at wellheads in complicated areas (for an SSDR, the wellhead is located at the bottom of the sea); on the outlet of such units there are pressure gauges to monitor pressure changes in the annular space. Numerous observations have shown that pressure increases sharply to a maximum, then gradually decreases and stabilises at a certain value.

Gas was observed in well no. 28 of the Sangachal-Sea field (Caspian Sea, Azerbaijan), at a depth of 3819 m and with a specific gravity of the flushing fluid of 2.25–2.27 g/cm^3. After the preventer was closed, the pressure increased to 10 MPa for 2–3 hours, before falling to 2.5 MPa and stabilising. In well no. 38, at a depth of 2784 m and with a specific gravity of the drilling mud of 2.20–2.25 g/cm^3, a gas phenomenon occurred. After the preventer was closed, the pressure increased to 5.0 MPa for 1.5–2 hours, then fell to 1.0 MPa and stabilised.

The study of phenomenon occurring during gas observation is a practical and theoretical interest. It was assumed that in the process of flushing through the BOP before the fluid from the reservoir enters the flushing solution in the drill pipes and in the annular space, the pressure losses were P_{01} and P_{02}, respectively (stationary distributions), and that the average volume velocities and pressure losses in the drill pipes remain constant and change in the annular space, respectively, according to the law $\psi(t)$, $\varphi(t)$ (Safarov, 1972; Walker, 1976a).

For the pipe and the annular space of the system of differential equations have the form:

$$\left.\begin{aligned} \frac{dP_1}{dx} &= \frac{d(\rho W)_1}{dt} + 2a_1\rho W_1 + b_1 \\ \frac{dP_1}{dt} &= C_1^2 \frac{d(\rho W)_1}{dx} \end{aligned}\right\} \tag{1}$$

$$\left.\begin{aligned} -\frac{dP_2}{dx} &= \frac{d(\rho W)_2}{dt} + 2a_2\rho W_2 + b_2 \\ -\frac{dP_2}{dt} &= C_2^2 \frac{d(\rho W)_2}{dx} \end{aligned}\right\} \tag{2}$$

where P_1 is the average pressure, W_1 is the average volume velocity, ρ is the density of the drilling mud, $2a_2$ is the coefficient of resistance, C_1 is the speed of sound, b_1 is the value characterizing the plastic properties of the liquid and t is time. The initial and boundary conditions have the following form:

$$\text{when } x = 1$$

$$P_1(x, 0) = P_{01},\ \ P_2(x, 0) = P_{02},\ \ \frac{(\rho W)_1}{t=0} = A,\ \ \frac{(\rho W)_2}{t=0} = B$$

$$P_1(l, t) = \varphi(t),\ \ P_1(0, t) = P_2(0, t)$$

$$Q_1(0, t) = Q_2(0, t)$$

$$\frac{(\rho W)_1}{x=t} = \psi(t) \tag{3}$$

Additional conditions are given as $P_1(l, t) = f(t)$ and $(\rho, W)_2 = \xi(t)$.

Following (Walker, 1976b) and solving the inverse problem using the Laplace transform, a system of equations is determined for deriving the coefficients of hydraulic resistances in the pipe and in the annular space, respectively:

$$\Phi_1(t_0) = \left\{\frac{F_1}{F_2}\left[1 - \frac{\bar{\varphi}(t_0)}{t_0} - \bar{\psi}[0]\right] - \right.$$

$$\left. - \frac{C_1^2}{C_2^2}\left[\frac{b_2 l}{AC_1} - \frac{1}{t_0} - \frac{\bar{\varphi}(t_0)}{t_0} - \bar{\psi}[0] - f^*(t_0)\right]\right\} : \tag{4}$$

$$: \frac{C_1}{C_2^2} = 2a_1 \frac{1}{t_0}$$

$$\Phi_2(t_0) =$$
$$= \left\{ \frac{1}{t_0} 2a_1 \frac{l}{C_2} + \frac{2b_2 l}{AC_1} \frac{1}{t_0} \left(\frac{B}{A} + 1 \right) - \frac{\bar{\varphi}(t_0)}{t_0} - \bar{\psi}[0] - f^*(t_0) \right\} :$$
$$: \frac{F_1}{F_2} \left[\frac{\bar{\varphi}(t_0)}{t_0} - 1 + \bar{\psi}[0] \right] = 2a_1 t_0 \quad (5)$$

$$\bar{\varphi}(t_0) = \int_0^\infty \varphi(\bar{t}) \bar{e}^{st} dt \quad (6)$$

$$\bar{f}(t_0) = \int_0^\infty f(\bar{t}) \bar{e}^{st} dt \quad (7)$$

where F_1 and F_2 are the cross-sectional areas of the pipe and the annular space, t_0 is the pressure relaxation time, C_1 and C_2 are the velocities of sound, $2a_1$ and $2a_2$ are the resistance coefficients in the pipe and the annular space, b_1 and b_2 are the value characterizing the plastic properties of the liquid and l is the depth of the well.

$$A = \rho W, B = \rho W_2$$

where ρ is the density of the drilling mud.

Results and discussion

From formulas (4) and (5) above, it can be seen that the dependency between $\Phi_1(t_0)$ and $\Phi_2(t_0)$ from $1/t_0$ is expressed as a straight line. Calculating $\bar{\varphi}(t_0)$ and $\bar{f}(t_0)$ for the cases under study, we construct the dependencies $\Phi_1(t_0)$ and $\Phi_2(t_0)$ from $1/t_0$. Using the angular coefficient and following formulas (4) and (5), we determine the coefficients of hydraulic resistance in the pipe and the annular space. According to formulas (4) and (5) from the approximating function, the values of the coefficients of hydraulic resistance can be found: λ_1 in the pipe and λ_2 in the annular space, respectively (Table 1).

Having calculated the values of the hydraulic resistance in the drill pipe and the annular space, it is possible to determine the hydrodynamic pressure using known formulas (Walker, 1976b). In order to check the method, a scheme has been developed to measure the pressure and flow changes over time at the inlet of the drilling riser and the outlet along the throttled lines of the preventer block when drilling fluid circulates through the manifold block on an adjustable fitting with the die closed at the wellhead block of preventers installed in a well drilled from an SSDR at the bottom of the sea.

Table 1. Values of hydraulic resistance coefficients: λ_1 in the pipe and λ_2 in the annular space

Tabela 1. Wartości współczynników oporu hydraulicznego, odpowiednio w rurze, λ_1, i w przestrzeni pierścieniowej, λ_2

Approximating functions	λ_1	λ_2
$Q_1(t) = -0.0000$	0.031	0.28
$P_1(t) = -0.0003169t^2 + 0.53041t + 28.2782$		
$Q_2(t) = -0.014t^2 + 0.3067t + 4.15564$	0.03	0.31
$P_2(t) = -0.0001111t^2 + 0.005537t + 4.659$		
$Q_3(t) = -0.05468t^2 + 0.22098t + 23.1237745$	0.03	0.24
$P_3(t) = -0.00468t^2 + 0.6878t + 63.2904$		
$Q_4(t) = -0.000448t^2 + 0.0961t + 0.600858$	0.028	0.27
$P_4(t) = -0.002047t^2 + 0.40698t + 11.84927$		

An induction pressure sensor of types D or D-1 and an RGR-7-2 flow meter are installed on the riser. Such devices are installed at the outlet via throttled preventer lines in front of the fitting. Pressure and flow are simultaneously recorded by recorders mounted on the remote control. In addition, devices are installed on the remote control that show the flow rate of the flushing fluid at the inlet and outlet. The devices were installed on the Shelf-2 well No. 4 pl. Intermediate. The diameter of the through hole of the fitting was 0.020 m; the depth of the well was 2400 m. A casing string with a diameter of 339.7 mm is lowered to this depth and an annular space is formed in the well from circles measuring 0.317 m (inner diameter of the casing string) and 0.127 m (outer diameter of drill pipes).

The density of the drilling mud is 1840 kg/m^3, the conditional viscosity according to SPV-40 s, the maximum shear stress τ_0 is 0.65 Pa and the structural viscosity η is 0.014 Pa·s. A preliminary test of the devices and an initial series of experiments were carried out. Figure 1 presents diagrams of pressure changes and the flow rate of the flushing fluid over time at the inlet and outlet during operation of 1 pump and simultaneously 1 and 2 pumps. The curves were processed on a computer using the least squares method, then approximating functions were found in the form:

$$Q_i(t) = A_{1i}t^2 + B_{1i}t + C_{1i} \quad (8)$$
$$P_i(t) = A_{2i}t^2 + B_{2i}t + C_{2i} \quad (9)$$

Conclusion

1. Based on the processed experimental curves and the constant coefficients A and B, with approximate integration the values $\bar{\varphi}(t_0)$ and $\bar{\varphi}(t)$ are determined. Then the dependences between $\bar{\varphi}(t_0)$, t are constructed; using the angular coefficients of these lines, the coefficients of hydraulic resistance in the pipe and annular space are calculated according to the dependence of the pressure and flow of drilling fluid at the wellhead and at the outlet along the throttled lines of the preventer block, which can simulate the flow of fluid into the well with the preventer closed.
2. If the flow rate, angle of deviation of the installation from the vertical and contact time of the surfaces are constant, the time of indentation of the flushing fluid decreases as the drop in pressure increases.

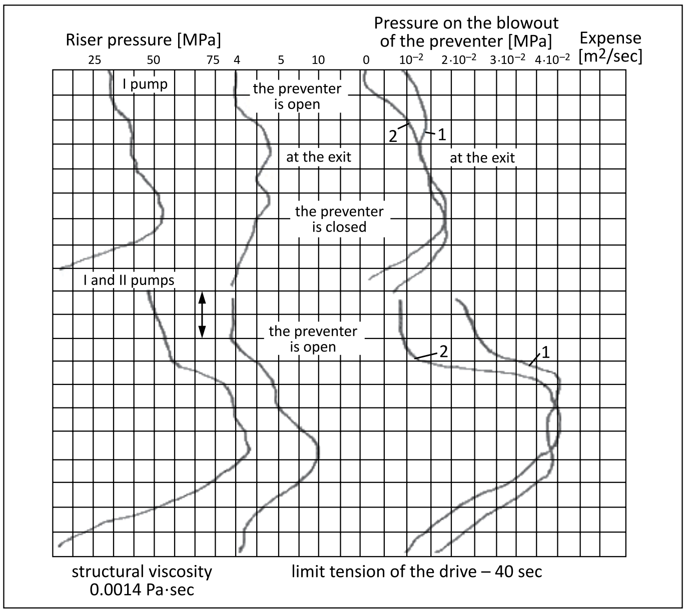

Figure 1. Changes in pressure and flow of the flushing fluid

Rysunek 1. Zmiany ciśnienia i przepływu płynu przemywającego

3. As the fluid filtration rate increases, the friction force between the drill pipe and the borehole wall increases.
4. The friction force between the surfaces of the column and the filter cake is inversely proportional to the velocity of the fillet.

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