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Determination of pressure change during drilling a well from semi-submersible drilling platform

Określenie zmian ciśnienia podczas wiercenia otworu z półzanurzalnej platformy wiertniczej

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ABSTRACT: The article states that a ship in the open sea is in a complex oscillatory motion due to the aerodynamic force of water flow and hydrodynamic pressure. Among the lateral, keel, horizontal, and vertical vibrations, only the vertical vibration of the vessel primarily affects the technological process of drilling a well. The article determines the magnitude of the hydrodynamic pressure that arises in the wellbore from the oscillation of the semi-submersible drilling platform in the absence of well flushing and a telescopic string, a compensator for vertical movement. When formulating the problem accurately, one should take into account the presence of natural vibrations of both the drilling tool and the semi-submersible drilling platform from which the well is to be drilled. The semi-submersible drilling platform was awarded by Caspian Drilling Company to two subsidiaries of Keppel offshore & Marine Company with Caspian Rigbuilders and Caspian Shipyard Company. This platform, named after Heydar Aliyev, is the first and the only drilling platform in the world with a 1,400-atmosphere system technology. Its carrying capacity is 5,600 tons, and its displacement is 47,500 tons. Vertical vibrations of the semi-submersible platform, caused by hydrometeorological conditions, set in motion the drilling tool associated with the semi-submersible drilling platform, along with the flushing solution that fills the well during drilling without a riser. This leads to a change in the hydrodynamic pressure in the well. Therefore, the change in hydrodynamic pressure in the well must be checked using a special installation that simulates the vibrations of the vessel and drilling tool in a well filled with drilling fluid.

Key words: offshore drilling, floating vessels, semi-submersible drilling platform, well, hydrometeorological conditions, gas, oil and water leaks, drilling tools.

STRESZCZENIE: W artykule wskazano, że statek na otwartym morzu znajduje się w złożonym ruchu oscylacyjnym wywołanym siłą aerodynamiczną przepływu wody i ciśnieniem hydrodynamicznym. Spośród drgań bocznych, kołyszących, poziomych i pionowych tylko drgania pionowe statku mają zasadniczy wpływ na proces technologiczny wiercenia otworu. W artykule określono wielkość ciśnienia hydrodynamicznego, które powstaje w odwiercie w wyniku oscylacji półzanurzalnej platformy wiertniczej przy braku płukania odwiertu i przewodu teleskopowego - kompensatora ruchu pionowego. Przy dokładnym formułowaniu problemu należy wziąć pod uwagę występowanie drgań własnych zarówno narzędzia wiertniczego, jak i półzanurzalnej platformy wiertniczej, z której ma być wykonywany odwiert. Półzanurzalna platforma wiertnicza została zakupiona przez Caspian Drilling Company dla dwóch spółek zależnych Keppel Offshore & Marine Company z Caspian Rigbuilders i Caspian Shipyard Company. Platforma ta, nazwana imieniem Heydara Aliyeva, stała się pierwszą i jedyną platformą wiertniczą na świecie z technologią systemu 1400 atmosfer. Jej nośność wynosi 5600 ton, a wyporność 47500 ton. Pionowe wibracje platformy półzanurzalnej, spowodowane warunkami hydrometeorologicznymi, wprawiają w ruch narzędzie wiertnicze związane z platformą półzanurzalną, wraz z roztworem płuczącym, który wypełnia odwiert podczas wiercenia bez zastosowania kolumny rynnowej. Prowadzi to do zmiany ciśnienia hydrodynamicznego w odwiercie. W związku z tym zmiana ciśnienia hydrodynamicznego w odwiercie musi być sprawdzana za pomocą specjalnej instalacji, która symuluje drgania statku i narzędzia wiertniczego w odwiercie wypełnionym płuczką wiertniczą.

Słowa kluczowe: wiercenie na morzu, statki pływające, półzanurzalna platforma wiertnicza, odwiert, warunki hydrometeorologiczne, wycieki gazu, ropy i wody, narzędzia wiertnicze.

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Introduction

With intensive exploration and development of offshore oil fields taking place in all areas of the globe, it has been established that floating vessels represent the most economical option when drilling in relatively poorly explored deep-sea waters.

The unique challenges of offshore drilling necessitate organized research activities pertaining to the hydrometeorological conditions under which drilling operations are planned, as well as the technology employed for drilling wells in the context of continuous vessel vibration due to waves and potential complications (Aliev and Bondarenko, 2006.).

A ship in the open sea is subject to complex oscillatory motions caused by aerodynamic forces from water flow and hydrodynamic pressure. Nevertheless, of the various types of vibrations (lateral, keel, horizontal and vertical), it is only the vertical vibration that can affect the technological process of drilling a well. All other types of vibrations that affect the performance of the semi-submersible drilling platform (holding it at the point) have an insignificant effect on potential well complications and can be completely or partially eliminated when designing the vessel (Lyon and Stein, 2005.).

Vertical vibrations of the semi-submersible platform, induced by hydrometeorological conditions, set in motion the drilling tool associated with the semi-submersible platform, and with it the flushing solution that fills the well when drilling without a riser. This leads to a change in the hydrodynamic pressure in the well and, consequently, possible complications. Should the hydrodynamic pressure fluctuate in a manner that results in a value exceeding that of hydraulic fracturing, the well will either lose or absorb the flushing solution. Conversely, if pressure drops below the formation pressure, gas, oil, and water may leak into the well.

Many researchers have recently focused on determining hydrodynamic pressure during various drilling operations (Lyon and Stein, 2005). This article aims to determine the magnitude of hydrodynamic pressure generated in the wellbore due to oscillations of the semi-submersible drilling platform in the absence of well flushing and a telescopic string – a compensator for vertical movement.

In formulating the problem accurately, it is essential to consider the presence of natural vibrations of both the drilling tool and the semi-submersible drilling platform from which the well is to be drilled (Gritsenko et al., 1995).

The semi-submersible drilling platform was awarded by Caspian Drilling Company (CDC) to two subsidiaries of Keppel offshore & Marine Company with Caspian Rigbuilders and Caspian Shipyard Company (CSC) (Figure 1). The platform, named after Heydar Aliyev, is the first and the only drilling platform in the world with a 1400-atmosphere system technology. Its carrying capacity is 5,600, and displacement is 47,500 tons (Pelletier, 1996).

The principal objective of the article is to determine pressure changes during well drilling from a floating drilling platform.

Materials and methods

To simplify the solution, we assumed that the drilling tool, together with the vessel, performs an oscillatory motion following the cosine law, as expressed by the formula of Blagoveshchensky (Petrov, 2009):

$$Z = Z_m \cos(\omega_1 t + \beta_1 - \delta_1)$$
$$T_1 = \frac{2\pi}{\omega_1} \tag{1}$$

where:

Z_m – vibration amplitude,
ω_1 – wave frequency,
T_1 – wave period.

$$\mathrm{tg}\beta_1 = \frac{2\mu_1 x_1}{1 - q_1 x_1^2}$$
$$\mathrm{tg}\delta_1 = \frac{2\mu_1 x_1}{1 - x_1^2}$$
$$Z_m = \chi r_0 \sqrt{\frac{(1 - q_1 x_1^2)^2 + 4\mu_1^2 x_1^2}{(1 - x_1^2)^2 + 4\mu_1}}$$

where:

q_1 – abstract coefficient,
ω_2 – heave frequency,

$$\chi = \frac{\omega_1}{\omega_2};\ \mu_1 = \frac{h_1}{\omega_2}$$

$\chi = \omega_1/\omega_2$; $\mu_1 = h_1/\omega_2$
h_1 – heave resistance coefficient,
r_0 – half-wave height.

Hydrometeorological conditions represent the initial characteristic for which the semi-submersible platform is calculated. Consequently, prior to commencing drilling operations, it is necessary to collect comprehensive hydrometeorological data about the drilling area. In our case, the heave amplitude of the semi-submersible platform was calculated for the Gunashli region, located in the open sea.

In accordance with the safety regulations and conditions for ensuring the safety of the upper part of the drill string and casing, which are in the water and secured to the ship, it can be assumed that drilling without significant restrictions should be carried out at a sea state of 6 points, an average wave height of 3 m and a wave period of T_1 =7 sec.

Figure 1. Floating semi-submersible drilling platform "Heydar Aliyev"

Rysunek 1. Pływająca półzanurzalna platforma wiertnicza „Heydar Aliyev"

The calculations to determine the forced vertical oscillations of the vessel were conducted according to formula (1), utilizing the geometric dimensions of the vessel currently under design:

- main deck dimensions: 69.50 · 69.50 m,
- displacement: 47,500 t.

By employing the pattern of semi-submersible platform movement in waves over time and the Navier-Stokes differential equation of unsteady motion of an incompressible viscous fluid, it is possible to determine the hydrodynamic pressure in the well during semi-submersible platform oscillation from the tools (Croasdale et al., 1994; Mazo and Potashev, 2013).

When solving the problem, the Navier–Stokes equation take the following form:

$$\rho\frac{\partial u}{\partial t}=\eta\left(\frac{\partial u^2}{\partial r^2}+\frac{1}{r}\cdot\frac{\partial u}{\partial r}\right)-\frac{\partial p(t)}{\partial Z} \tag{2}$$

Let us denote:

$$-\frac{1}{\rho}\cdot\frac{\partial P}{\partial Z}=f(t)$$

$$L(t)=\int_0^t v(t)dt$$

The averaging method is the optimal approach for resolving this issue, as the precise solution obtained through operational calculus method does not yield viable formulas for calculation.

In this case, the initial and boundary conditions are:

$$u(R_2,\,t) = 0 \text{ for } r = R_2$$

$$u(R_1t)=\frac{dZ}{dt}\Big|_{r=R_1}=v(t)=-Z_m\omega_1\sin(\omega_1 t+\beta-\delta_1) \tag{3}$$

$$u(r,\,0) = A_k \text{ for } t = 0$$

$$Q=\int_{R_1}^{R_2}2\pi ru(r,t)dr=\pi R_1^2 v(t) \tag{4}$$

where:

k – ratio of drill pipe to annulus areas,

$$A = -Z_m\,\omega_1\,\sin(\beta_1 - \delta_1)$$

R_1 – drill pipe radius,

R_2 – well radius.

We average:

$$\varphi(t)=\frac{1}{R_2-R_1}\int_{R_1}^{R_2}\frac{du}{dt}dZ \tag{5}$$

Then equation (2) will take the form:

$$\varphi(t)-f(t)=v\frac{1}{r}\cdot\frac{d}{dr}\left(r\frac{du}{dr}\right)$$

Let us denote:

$$\varphi(t) - f(t) = \Phi(t)$$

Then:

$$u=\frac{\Phi(t)r^2}{4v}+c_1\ln r+c_2$$

Using boundary conditions, we determine the integral constants:

$$c_1=\frac{v(t)}{\ln\frac{R_2}{R_1}}-\frac{\Phi(t)(R_2^2-R_1^2)}{4v\ln\frac{R_2}{R_1}}$$

$$c_2=\frac{\Phi(t)(R_2^2-R_1^2)\ln R_2}{4v\ln\frac{R_2}{R_1}}-\frac{\Phi(t)R_2^2}{4v}-\frac{v(t)\ln R_2}{\ln\frac{R_2}{R_1}}$$

Then:

$$u(r,t)=\frac{\Phi(t)(R_2^2-R_1^2)\ln R_2}{4v\ln\frac{R_2}{R_1}}\ln\frac{R_2}{r}-\frac{\Phi(t)(R_2^2-R_1^2)}{4v}-\frac{v(t)}{\ln\frac{R_2}{R_1}}\ln\frac{R_2}{r}$$

Using boundary conditions (4) we determine:

$$\varphi(t)=\left(\frac{A_1W+DB)}{D}\right)\cos(\omega_1 t+\beta_1-\delta_1)$$

$$f(t)=\left(\frac{A_1W}{D}+B\right)\cos(\omega_1 t+\beta_1-\delta_1)-\frac{W}{D}\sin(\omega_1 t+\beta_1-\delta_1)$$

We designate:

$$D=\frac{1}{16v}\left[\frac{(R_2^2-R_1^2)}{n\frac{R_2}{R_1}}-(R_2^4-R_1^4)\right]$$

$$W=\frac{z_m\omega_1(R_2^2-R_1^2)}{4\ln\frac{R_2}{R_1}}-z_m\omega_1R_1^2$$

$$A_1=\frac{R_2^2-R_1^2}{4v\ln\frac{R_2}{R_1}}-\frac{R_2^2+R_1^2+R_2R_1}{6v}$$

$$B=\frac{z_m{\omega_1}^2R_1}{R_2-R_1}-\frac{z_m{\omega_1}^2}{\ln\frac{R_2}{R_1}}$$

Finally, the formula for hydrodynamic pressure over time becomes:

$$\Delta P = \rho L(t)\left[\left(\frac{A_1 W + BD}{D}\right)\cos(\omega_1 t + \beta_1 - \delta_1) - \right. \\ \left. - \frac{W}{D}\sin(\omega_1 t + \beta_1 - \delta_1)\right] \tag{6}$$

where:

v – kinematic viscosity,

ρ – solution density,

L – well depth.

Using formula (6), we determine the hydrodynamic pressure in a well drilled from a floating vessel (the parameters of which are given above), which undergoes vertical oscillatory motion under the influence of 6-point sea waves.

Results and discussion

The following data were used in the calculations: drill pipes with a diameter of 5 inches, a well with a diameter of $9^{3/4}$ inches, well depth of 4,500 m, $v = 10^{-6}$ m^2/s.

As a result, varying values of hydrodynamic pressure in the well were obtained, differing in sign, magnitude, and time. The maximum value of pressure change in the barrel during the oscillatory movement of the semi-submersible platform is ±5.2 MPa.

Given the reservoir pressure in a well at a depth of 4,500 m equal to 23.0 MPa, and the hydraulic fracturing pressure at this depth equal to 38.0 MPa (for the Gunashli region, the hydraulic fracturing gradient is 0.019 MPa/m), we can analyze how the hydrodynamic pressure in the well fluctuates in response to the vessel's oscillations under the influence of 6-point sea waves (if the hydrodynamic pressure exceeds the hydraulic fracturing pressure of the formation, it can result in either loss or absorption of the solution), or find out whether the formation pressure exceeds the hydrodynamic pressure (which in turn, can lead to water, gas or oil entering the well).

In general, it is necessary to find out whether the condition Ppl ≤ Pgd ≤ Pgr is met (where: Ppl – formation pressure, Pgd – hydrodynamic pressure, Pgr – hydraulic fracturing pressure), under which it is possible to avoid complications in the well.

In the case of drilling in the Gunashli region, there is a risk of water leaks into the well due to minimum value of hydrodynamic pressure being lower than reservoir pressure (2.30 MPa). However, the danger of hydraulic fracturing is not present under these conditions (Targ, 2010).

Conclusions

Since wells in all oil fields (with rare exceptions) are drilled with drilling fluid, which is a viscous-plastic fluid, the actual conditions in the Gunashli well may differ. Solving the problem of unsteady motion of a viscous-plastic fluid in the annular space of a well drilled from a floating vessel with its continuous oscillation along with the drilling tool is very complex and time-consuming, as it involves solving integral equations.

Therefore, the hydrodynamic pressure fluctuations in the well must be checked using a special installation that simulates the vibrations of the vessel and the drilling tool in a well filled with drilling fluid.

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