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A model for extended-reach limit analysis in offshore horizontal drilling based on formation fracture pressure

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ABSTRACT

In order to solve the problem that how far the offshore extended-reach well (ERW) can extend, the open hole extended-reach limit theory is used to establish the open hole extended-reach limit model for three offshore drilling modes including offshore conventional drilling and two dual gradient-drilling (DGD) modes, and the corresponding case study is analyzed. The results show that, water depth has great influence on the open hole extended-reach limit of ERW due to the particularity of offshore drilling; there is a decrease of the open hole extended-reach limit as the water depth is increased, and in general, the open hole extended-reach limit adopted two kinds of DGD modes are greater than that of offshore conventional drilling mode. Specifically, under the condition given by this article, the horizontal section limit of offshore conventional drilling is 4318 m, while both the two limits of DGD modes are close to 4500 m; as a contrast, the limit of onshore drilling is 7157 m. According to the sensitivity analysis of parameters in above models, the open hole extended-reach limit is decreased with the increase of mud density and mud flow rate, and the mud weight window of DGD mode is wider than that of offshore conventional drilling, which is one of the advantages of DGD; at the same time, there is an optimal eccentricity which can be used to improve the open hole extended-reach limit.

1. Introduction

In order to meet the world's increasing demand for oil and gas, the field of petroleum exploration and development has been gradually extended to cover the ocean. Since the high cost of operation, oil operators have also been compelled to invest in new technologies to optimize their production processes and cut operating costs (Silva et al., 2015), and then extended-reach well (ERW) has been applied to the development of offshore oil and gas (Talkington et al., 1998; Martins et al., 2001; Arukhe et al., 2014). There are many issues associated with extended-reach drilling (ERD), including Directional Well Design, Torque and Drag Limitations, Hydraulics and Hole Cleaning, etc (Agbaji, 2009); in fact, the criterion for ERD limit in this paper is the formation fracture pressure. The open hole extended-reach limit is the maximum measured depth (MD) of ERW and the horizontal section limit is the maximum MD of horizontal section, both of them can be used to measure the extension ability of ERW; moreover, the longer open extended-reach limit is required in order to achieve greater oil and gas production and improve economic efficiency. However, there is no answer about how far the offshore ERW can extend, therefore, the open hole extended-reach limit theory has been adopted to explain this problem in this paper.

The open hole extended-reach limit theory has experienced the following development process. Mason (1998) pointed out that limits of ERW can be divided into mechanical and formation-related limits; moreover, the latter one involves borehole stability and the fracture gradient. Rocha et al. (2003a, 2003b) discussed that the annular pressure drop is increased with MD of ERW; however, the fracture pressure cannot increase in step with the annular pressure drop, which means that ERW cannot extend without limitation.

The above research contents are mainly focused on the fundamental principle of the open hole extended-reach limit but without detailed model and calculation method. Deli et al. (2009) proposed the primary concept of open hole extended-reach limit firstly, which is the MD of ERW when the bottom hole pressure equals the fracture pressure; besides, the corresponding calculation model is derived, which is mainly depended on the fracture pressure of drilled formation, mud density as well as the annular pressure drop. Tengfei (2013) also carried out the relevant research work, and several factors are put into his model.

Although lots of research findings about the open hole extended-reach limit have been achieved by previous researchers,

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Nomenclature

a, b friction factor constants, dimensionless
D_w water depth, m
D_{fw} the depth between drill floor and the surface of water, m
D_v true vertical depth, namely TVD, m
D_i the casing inter diameter or wellbore diameter, mm
D_{dp} the pipe outer diameter, mm
e eccentricity, $e = \left(D_i - D_{dp}\right)/2$, mm
f_a the annular friction factor, dimensionless
K consistency coefficient, $Pa \cdot s^n$
L_t the open hole extended-reach limit, m
L_{tCD} the open hole extended-reach limit of offshore conventional drilling, m
L_{tSMD} the open hole extended-reach limit of the SMD mode, m
L_{tHGS} the open hole extended-reach limit of the HGS mode, m
$\sum_{i=1}^{n} L_{di}$ length of several deviated sections, m
L_{d1} length of the small inclination section, m
L_{d2} length of the large inclination section, m
L_h horizontal section limit, m
L_{hCD} the horizontal section limit of offshore conventional drilling, m
L_{hSMD} the horizontal section limit of the SMD mode, m
L_{hHGS} the horizontal section limit of the HGS mode, m
L_v length of vertical section, m
m flow behavior index, dimensionless
p_{bhCD} bottom hole pressure of offshore conventional drilling, MPa
p_{bhSMD} bottom hole pressure of SMD mode, MPa
p_{bhHGS} bottom hole pressure of HGS mode, MPa
p_{spin} submarine pump inlet pressure, MPa
p_f fracture pressure, MPa
p_p pore pressure, MPa
Q mud flow rate, L/s
Q' flow rate of the mixture, L/s
R eccentric coefficient, dimensionless
R_{lam} laminar eccentric coefficient, dimensionless
R_{turb} turbulent eccentric coefficient, dimensionless
Re_g generalized Reynolds number, dimensionless
v_a average annular fluid velocity, m/s
v_r average annular fluid velocity in riser of HGS mode, m/s

Greek

ν poisson's ratio, dimensionless
α biot's parameter, dimensionless
ε dimensionless eccentricity, dimensionless
ΔL represents incremental length, m
Δp pressure drop, MPa
Δp_{aCD} annular pressure drop of offshore conventional drilling, MPa
Δp_{aBML} annular pressure drop below the mudline, MPa
$a_n = \frac{1}{\pi}\sum_{\theta=0}^{2\pi} f(\theta)\cos(n\theta)\Delta\theta$ annular pressure drop of several deviated sections, MPa
Δp_{d1} annular pressure drop of the small inclination section, MPa
Δp_{d2} annular pressure drop of the large inclination section, MPa
Δp_h annular pressure drop of horizontal section, MPa
Δp_v annular pressure drop of vertical section, MPa
Δp_r annular pressure drop of riser, MPa
Δp_s safety margin, MPa
$\left(\frac{\Delta p}{\Delta L}\right)_h$ pressure loss gradients in horizontal section, MPa/m
$\left(\frac{\Delta p}{\Delta L}\right)_{friction}$ friction pressure loss gradients, MPa/m
ρ_b bulk density, g/cm^3
ρ_f the equivalent density of the formation fracture pressure, g/cm^3
ρ_m mud density, g/cm^3
ρ_{mix} mixture density, g/cm^3
ρ_w seawater density, g/cm^3
ρ_g grain density, g/cm^3
ρ_p pore pressure equivalent density, g/cm^3
ρ_{fl} fluid density, g/cm^3
ϕ porosity, dimensionless
σ_H maximum horizontal principal stress, MPa
σ_h minimum horizontal principal stress, MPa
σ_v the overburden pressure, MPa
ω_1, ω_2 tectonic stress coefficient, dimensionless

however, they did not do much research on offshore drilling by using the open hole extended-reach limit theory. Generally speaking, the cost of offshore operations is higher than that of onshore drilling, and better economic benefits can be obtained by using ERW. At the same time, since the existence of long water column, the mud weight window (MWW) is relatively narrower than onshore drilling, which also put forward higher requirements on the operation process of offshore drilling.

The main objective of this paper is to establish the open hole extended-reach limit model for conventional offshore drilling and two DGD modes including subsea mudlift drilling (SMD) mode and hollow glass spheres (HGS) mode respectively; moreover, the corresponding calculation methods of these three models should be derived; finally, a case study was given and the horizontal section limit of these three offshore drilling modes were compared with that of onshore drilling; in the meantime, the method to optimize the operation parameters of offshore ERW is also put forward.

2. The difference between offshore and onshore drilling

There are many differences between offshore and onshore drilling, and the differences between offshore conventional drilling and DGD also exist, these differences will inevitably influence the open hole extended-reach limit greatly.

2.1. Differences in rock mechanics

Due to the complexity of the marine environment, offshore drilling is confronted with lots of problems, which are different from onshore drilling, and the narrower MWW is one of the prominent problems. Compared with the terrestrial environment, the deposition rate in the ocean formation is faster, and the abnormal pressure of the formation is generally developed (Willson et al., 2003); therefore, the overburden pressure is usually lower due to the long water column. In addition, offshore drilling tend to have much lower fracture pressure (Rocha et al., 2003a, 2003b), leading to a narrower MWW (Zhiming et al., 2006), which is not