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An advanced Driller's Method simulator for deepwater well control

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A B S T R A C T

Deepwater hydrocarbon reserves play an important role in the global energy industry. The safety issue which is associated with deepwater well control is one of the most crucial aspects during the well design and construction in a drilling scenario. Limited by the narrow drilling window and the long but small choke line, accurate prediction of the wellbore pressure is required to ensure a successful well control operation in deepwater. This paper focuses on the deepwater Driller's Method, developing an advanced simulator to predict the standpipe and choke pressures in deepwater horizontal well killing on the basis of "dynamic" bottom hole pressure. In order to improve the precision of the simulator, circulation temperature, gas expansion and choke line friction loss have been considered in the model. According to the data of a planned horizontal well X-2, the simulation and analysis of the behaviors of the standpipe and choke pressures during the deepwater Driller's Method well killing operation were performed with the proposed simulator. For further understanding the characteristics of the deepwater Driller's Method, it investigated the influence of some engineering parameters on the surface pressures, including seawater depth, horizontal section length, gas kick volume and killing rate. The results demonstrate that the standpipe pressure increases with seawater depth and killing rate; the peak choke pressure increases with seawater depth and gas kick volume; and the horizontal section length has a little impact on the standpipe and choke pressures. In addition, the application of the well killing case in BY-3 well, which is located in the South China Sea, has proved the validity of the simulator.

1. Introduction

It is well known that oil and gas exploration activity in deepwater scenario is characterized by high risk, especially when it involves well control operation in the drilling practice. When a gas kick is detected in the wellbore during the drilling, effective measures should be taken to cope with the kick immediately. Once it fails to control this issue, a well blowout accident will happen, leading to serious human casualties and property damage. The "Deepwater Horizon Accident", which occurred at the Gulf of Mexico in 2010, is the largest accidental marine oil spill in the history of the petroleum industry (Dadashzadeh et al., 2013; Skogdalen and Vinnem, 2012). A well control event allowed hydrocarbons to escape from the Macondo well onto the rig, resulting in explosions and sinking of the rig. Eleven people lost their lives, and millions of barrels of oil was leaked into the marine, causing an ecological disaster in this area. The direct and indirect economic losses of this blowout hazard amounted to billions of dollars. This accident again reminds us that the safety issues associated with well control should be given the first priority throughout the whole of the design and construction process.

To prevent the losses caused by the well blowout after a kick is confirmed in deepwater, it is critical to conduct a successful well killing operation. However, due to the influence of seawater depth and marine environment, deepwater well killing has posed much more scientific and technological challenges (Fossil and Sangesland, 2004; Nunes et al., 2002). On the one hand, the overburden formation in submarine experienced an insufficient compaction, resulting in a narrow drilling window between a formation's pore pressure and fracture pressure, which causes difficulties for well killing operation. On the other hand, there is a long but small choke line connecting the subsea with drilling rig, generating a considerable friction loss while circulating out a kick (Rezmer-Cooper and Lindsay, 1994; Santos, 2001). As a consequence, efforts to keep the bottom hole pressure above formation

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pressure may inadvertently result in fracturing the "narrow window" formation during deepwater well killing operation, inducing more complex downhole accidents.

Given these factors, in order to realize loss prevention in the deepwater well killing operation, efforts should be made in two aspects. The first is to choose rational well killing engineering parameters and develop a more precise Well Killing Sheet for construction. The second is to get a more accurately predicted surface pressures behaviors, which are crucial for guiding the operation of the choke valve in a "narrow drilling window" during the killing process.

In the recent years, several kick simulators have been developed to address the well control problems during deepwater drilling. D. Bertin developed a newly model to keep the deepwater killing process under control while never exceeding the fracture pressure at the shoe (Bertin et al., 1999). It optimized slow circulating rate according to the pressure loss induced in the choke line. C.S. Avelar presented a mathematical model of well killing in deepwater and introduced a finite difference formulation to solve the transient two-phase flow (Avelar et al., 2009). Z. Zhang proposed a well kill calculation model for deepwater Wait and Weight Method, which takes into account the influence of the choke line friction loss and gas expansion (Zhang et al., 2012). Z. G. Yuan considered the effect of frictional pressure losses, U-tube effect and fluid density, conducting dynamic simulations of operational parameters during the kill process under worst case blowout scenario in deepwater (Yuan et al., 2014). Z. Y. Wang developed a simulation model for deepwater gas kicks with the consideration of gas hydrate phase transition. The deepwater gas kick hydraulics were investigated with numerical calculations (Wang and Sun, 2014). y. Bhandari presented a Bayesian Network modeling for deepwater drilling risk analysis, which can be applied to predict failure analysis in blowout scenario (Bhandari et al., 2015).

As mentioned before, tracking the surface pressures behaviors of killing method has a significant importance to realize safe well control operation in deepwater (Avignon and Simondin, 2002; Yang et al., 2013). Generally, there are two common methods available to kill a well: the Driller's Method and the Wait and Weight Method (Carlsena et al., 2013; Leblanc and Lewis, 1968). The Wait and Weight Method requires one circulation to deal with the kick issue, and it has the least time the equipment is exposed to excess pressure. In some circumstances, it will generate the lowest pressure on the formation near the casing shoe. However, it requires a longer waiting time prior to circulating the influx from the wellbore. The Driller's Method is by far the most simple, and for most part the safest, since it gets the influx out in a simple manner (Skogdalen et al., 2011). The Driller's Method involves two successive (rather than concurrent) circulations (Nickens, 1987):

- In the first circulation, the influx is circulated out with the original drilling fluid;
- In the second circulation, balance of the wellbore pressure system is re-established by pumping the killing mud as a substitute for the original drilling fluid.

In this study, the Driller's Method was selected as the target to investigate the deepwater well killing operation. Combined with the special submarine formation conditions and deepwater well control characteristics, this paper presents an advanced deepwater Driller's Method simulator on the basis of "dynamic" bottom hole pressure. During the circulation, the annulus pressure loss cannot be ignored, and it is regarded as the difference between the "dynamic" bottom hole pressure and formation pressure. In the model, some critical factors have been considered for ensuring the accuracy of simulation results, including the circulation temperature, gas expansion and choke line friction loss. In order to illustrate the simulator, calculation of standpipe and choke pressures in deepwater Driller's Method were conducted with the data of a planned horizontal well X-2. Then, it investigated the impact of some engineering parameters on well control operation, such as seawater depth, horizontal section length, gas kick volume and killing rate. To evaluate the simulator, a well killing case of BY-3 well in South China Sea was applied to validate it.

2. Physical model

According to the characteristics of deepwater well killing operation, a physical model has been established (Fig. 1), and several hypotheses are listed as follows:

- A gas column comes into being at the bottom hole due to the gas kick, and its expansion is complying with the Real Gas Law during the raise process in the annulus;
- The drill stem structure is modeled as drill pipe;
- The whole annulus below mud line, including casing section and open hole section, has a uniform size;
- Effect of gas column on the annulus pressure loss is negligible during the calculation of standpipe pressure.

In Fig. 1, H_{sea} represents the seawater depth, H_{kop} is the depth from the wellhead to the kickoff point (KOP), H_c represents the choke line length, H_w is the vertical depth of the wellbore below the mud line, and H_t is the total vertical depth of the well. L_t is the total well depth, L_w is the wellbore length from the mud line to the bottom hole, and L_h is the wellbore length from the wellhead to the landing point.

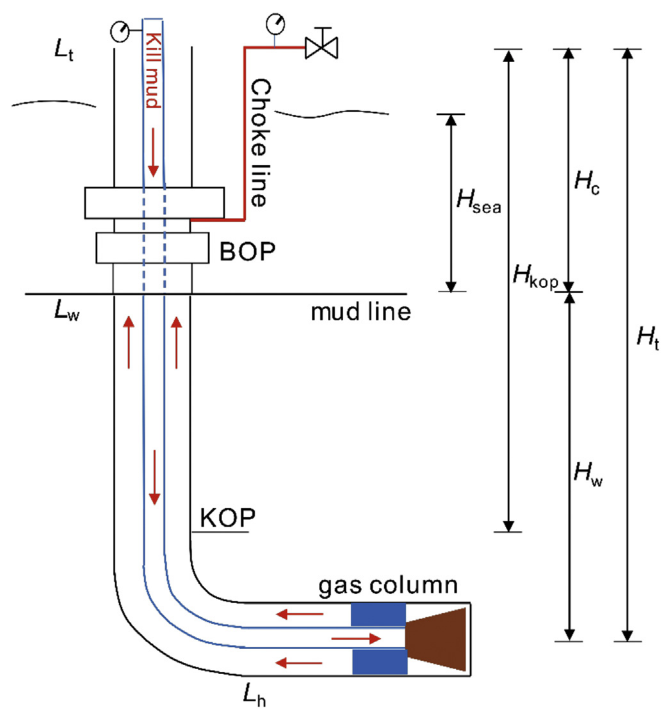

Fig. 1. Physical model of the wellbore in deepwater well killing.