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Natural bridging as a tertiary well control method in deep-water wells: A case study from Caspian Sea

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ABSTRACT

Blowout is the uncontrolled flow of reservoir fluids into the well, which can cause different types of problems during the drilling operations. In high-pressure formations with low rock strengths, it is more likely to occur self-killing through bridging mechanisms. The underbalanced conditions that are induced during developing a kick, leading into sufficient instability in exposed formations such that the borehole bridges over and kick kills itself. In this research, the potential of natural bridging is studied in one of the deep-water wells in the Caspian Sea to figure out whether this natural phenomenon is able to terminate the uncontrolled influxes of formation fluids into the borehole. For the reason, a series of semi-integrated numerical simulators are employed to evaluate wellbore pressure profile and wellbore instability as a function of time under blowout conditions. Applied analyses to a particular blowout scenario indicated that rock fragments falling off the wellbore wall are suspended in the two-phase flow (a mixture of gas and drilling mud) during developing the kick. As a result, cavings settlement is less not probable to plug the wellbore. On the other hand, suspension of rock fragments gradually increases the solid concentration of fluid phase until it hits a critical value at a certain time after the beginning of the kick, thereby bridging occurs before developing the kick into a blowout.

1. Introduction

A blowout is a sudden, accidental, uncontrolled phenomena that is initiated by personal inadvertently mistake or some unpredictable operational situations which can be intensified to large amounts of damage with a probability of rising into an expulsion of drilling fluid towards the surface in an oil/gas well, allocating to a continuous and uncontrolled flow of oil, gas or water leading the well to approach a complete loss of control (Nesheli, 2006) as far as being restrained.

Complete displacement of drilling fluid in the borehole leads to development of the uncontrolled influxes of formation fluid into the blowout. Skalle, Jinjun et al. (1999) introduced five blowout controlling methods to act as an intervention to involved factors naming: Blowout Preventer (BOP) implementation, pumping cement slurry, new equipment installation, pumping additional mud and also drilling relief wells. However, some beside aspects such as natural depletion, well collapse, bridging and water breakthrough are included indeed. With exception of bridging, other suggested methods are not proven to be a robust self-killing technique during a reasonably long time scale in deep-water wells (Willson, 2012).

Well control operation is mainly discussed in three phases of primary, secondary and tertiary well control. In the situations in which the kick is gained due to primary well control failure, and secondary well control methods are not applicable to prevent blowout either, it is indispensable to employ tertiary well control methods in order to treat the condition (Al-Qattan and Alam, 2014). Natural bridging can be considered as one of tertiary well control methods at which the exposed formations collapse around the wellbore to build up blockage in flow path or the produced solids bridge inside the wellbore (Willson, 2012). The blowout will be under control without any operational intervention within this process (Babalola, 2015). The main reason of natural bridging is wellbore pressure reduction during developing a kick. This pressure drop associated by kick, will provide noticeable changes in stress concentration around the wellbore and may induce a shear failure in exposed formations. If unconsolidated formations are exposed then the size of this shear failure and breakouts may be large enough to produce sufficient materials to satisfy plugging in the wellbore. As a result, these formations are serious candidates for bridging and self-killing (Willson et al., 2013).

There are two evaluation mechanisms presented in natural bridging (Adams and Kuhlman, 1990). According to the first mechanism, when exposed rocks or formation be not potent to support the pressure

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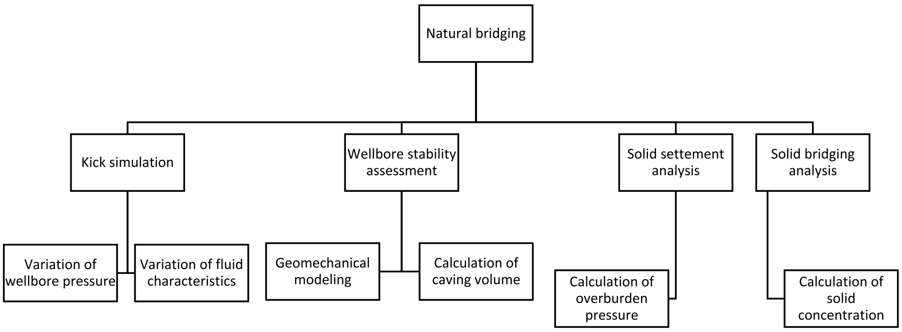

Fig. 1. All processes required to assess the natural bridging.

differentials caused by a rapid and dramatic change in the fluid pressure, the formation caves into the open hole and prohibits the fluid flow (Nesheli, 2006). In the second mechanism, the most important parameter to stop kick is the volume of solids which are producing from exposed formations via the kick progression. If the solid concentration reaches the critical value -that is called critical concentration-the effective viscosity of fluid column tends to infinity and the flow becomes stagnant (Frankel and Acrivos, 1967).

Flak (1997) explained that in deep-water wells, in the presence of low strength formations; wellbore bridging halts the risk of the prolonged blowout while Adams and Kuhlman (1990) affirmed the fact of natural formation bridging capability to stop many blowouts. The statistical analysis of killing methods by Skalle et al. (1999) for cased wells drilled in Texas and Outer Continental Shelf (OCS) between 1960 and 1996 delineated the fact that most blowouts occurred at shallow depths and were ceased due to collapsing or bridging of unconsolidated formations in open hole section. However, experiences from deep-water wells blowout came up the struggle of whether natural bridging can be reflected as a reliable mechanism to attenuate the blowouts duration in most of deep-water wells. For instance, the recent blowout data regarding deep-water wells in Gulf of Mexico shows that thirty five wells with shallow water flows undergoing for prolonged periods, do not support the idea of being killed through bridging mechanisms (Eaton, 1999). Furthermore, after the blowout of Macondo well in the Gulf of Mexico in 2010, obligators from worldwide decided imposition of more rigorous well-permitting qualifications. For instance, department of Bureau of Safety and Environmental Enforcement (BSEE) Notice to Lessees (NTL) takes the worst case discharge calculations as a demanding factor for every one of each upcoming well permit considerations. As a part of these new regulations, the information regarding to the potential for the well to bridge over are required for worst-case discharge calculations (Willson et al., 2013). Therefore, it seems imperative to address the potential of self-killing along with other killing options as a part of blowout contingency planning.

There are only a few literature studies published on analysis of self-killing blowouts. Akbarnejad-Nesheli and Schubert (2006) evaluated the bridging tendency of deep-water wells using wellbore breakout approach leading into this deduction that the depth in which collapse occurs and bridging tendency depends on both the water depth and magnitude of maximum horizontal stress. As a noticeable hint, they employed a simplistic approach in simulations without taking cavings volume quantification or caving transport into account. Willson (2012) and Willson et al. (2013) implemented a series of semi-analytical analysis to investigate possibility of natural bridging by considering different kick scenarios. This task involved four major analysis modules as kick development, borehole collapse, caving transport and caving bridging analysis. Finally, the conclusion came up suggesting that bridging and self-killing are more likely to happen during the progression of kick resulting from loss of riser margin when drill pipe is in the open-hole interval of the wellbore.

In this study, the same approach introduced by Willson et al. (2013) and Willson (2012) is applied to assess the potential of wellbore bridging in one of Caspian Sea wells by employing semi-integrated numerical simulators. The main objective of this study is introducing a series of semi-coupled analysis, which make it possible to assess the natural bridging in wells (especially in deep-water wells) where possibility of bridging seems to be high, and its information are required for other analysis. This approach can help other researchers in future to make this natural phenomenon more applicable and acceptable in terms of HSE. In addition, the proposed strategy for analyzing the natural bridging is declared as a convenient solution to the engineers in order to appraise the transient wellbore pressure profile, influx rate and wellbore stability under various blowout scenarios to generate a comprehensive blowout contingency plan and achieve a better risk management.

Here is the scheme of all processes required to assess the natural bridging shown in Fig. 1.

2. Natural bridging analysis methodology

2.1. Kick development analysis

Simulation of the kick is the first step to natural bridging analysis. When formation pressure is higher than the hydrostatic pressure of drilling fluid, gas will find a way into the wellbore and become mixed with it. Within the gas kick period of development, the well can be divided into three regions including over-pressured gas-bearing formation, two phase-flow and single phase flow (Starrett et al., 1990) illustrated in Fig. 2. A kick simulator coding developed in MATLAB to model and couple the different well regions to obtain the wellbore pressure profile and flow characteristics as a function of time.

Darcy equation for radial flow was attended in the case of modeling the formation fluid influx into the well (Ahmed, 2006):

$$q_g = \frac{kh(p_r^2 - p_w^2)}{1424\mu_g ZT \ln\left(\frac{r_e}{r_w}\right)} \tag{1}$$

Where q_g is gas flow rate (Mscf/day), r_w is well bore radius (ft), r_e is reservoir radius (ft), p_w is well bore pressure (psi), p_r is reservoir pressure (psi), k is permeability (md), h is reservoir zone height (ft), Z is gas deviation factor and μ_g is gas viscosity (cp).

For modeling the two-phase flow region, Hasan and Kabir (1988) mechanistic model is executed which is able to calculate the gas void fraction for five types of flow regimes: bubble flow, slug flow, dispersed bubble flow, churn flow and annular flow. The former objective is gained using the following equation for gas void fraction (Hasan and Kabir, 1992):