Journal of Petroleum Science and Engineering 171 (2018) 558–569

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Kick tolerance calculations for drilling operations

Tuna Eren

Petroleum and Natural Gas Engineering Department, Izmir Katip Celebi University, Cigli Ana Yerleskesi, Merkezi Ofisler 1 Binasi, Oda:42, 35620, Cigli, Izmir, Turkey

ARTICLE INFO

Keywords:
Drilling engineering
Well engineering
Kick tolerance
Deep well design
High pressure
Well control

ABSTRACT

The future of oil and natural gas drilling is dependent on deep well drilling operations. Kick tolerance is a concept which is very important for the industry to ensure that the wells are drilled safely. Especially for natural gas wells one of the most important requirements in deep well engineering design is the kick tolerance calculations. The literature survey reveals that there is no global standard utilized for the kick tolerance calculations by any of the operators, drilling contractors or any other official institutions. It is obvious that the industry needs a reliable procedure for kick tolerance calculations not only for safer drilling but also optimized well plannings. In order to test the methodology a data acquisition process has been implemented to collect the data from the literature. A depth based novel kick tolerance calculation methodology that is based on iteration is introduced in this study, which easily identifies if any kick tolerance troubles are going to be encountered or not. The results indicate that with the introduced kick tolerance methodology the engineering teams can design the wells safely provided that the pore pressure and fracture gradient information belonging to the wells are accurate and available as needful. The study outputs the analysis for the well designers in regards to the depths that a well control incident can occur, which differentiates this research study from others by means of identifying the depth ranges for possible well control incidents. The utilization of the novel kick tolerance calculation approach provides an appropriate planning of drilling operations, safer drilling activities and improved capability of natural resource discoveries.

1. Introduction

Taking a kick while drilling or completion activities in a rig site is not something desired. The risk is greater in deep water environments due to the relatively lower fracture gradients and underlying overpressured formations. If the formation breaks or by other means fractures an underground blowout which can be very costly to control can be faced. Toop (2011) stated that correctly calculating kick tolerance is essential to safe well design and drilling. Loss of well control in a drilling campaign can result for an operator company to have both financial and reputation losses. Interestingly, neither the American Petroleum Institute (API) publications nor the International Association of Drilling Contractors (IADC) Drilling Manual seem to provide a method, Toop (2011). Many researches such as Fu et al. (2015), and Jin et al. (2016) stated that early kick detection is crucial for deep water well control. The introduced concept in this research study is based on a volume of kick fluid entering the well which causes the bottom hole pressure to increase with a closed wellhead. Therefore there is a tolerance that the well in subject can handle the kick without losing the control.

It is a requirement that each wells' kick tolerance has to be calculated beforehand. Failing to calculate correctly the kick tolerance as a function of the well design that is being constructed can have catastrophic consequences. A recent severe failure example within deep water oil and gas drilling industry to date is The Deepwater Horizon Disaster Cheng et al. (2013). Kick tolerance calculation is based on accurately knowing the wells' pore pressure and fracture gradients. Personnel working in an area of drilling engineering closely know that each and every one single well is unique in itself. What has been encountered in one well is not necessarily going to be the case for a near proximity well. However, it must be kept in mind that the formation pressures in a field is not going to change in a short time frame. For this reason due to having many factors in consideration while drilling a well; the kick tolerance concept for the wells is a point that has to be carefully taken into consideration. For each well a post well analysis should be run and its respective pore pressure and fracture gradient data shall be made available hence to be used for the pre-drill pore pressure and fracture pressure predictions of the future wells.

Aadnoy (2009) presented the main geometric variables for a directional well to derive a kick tolerance equation based on an influx of single gas bubble in a wellbore. Fig. 1 depicts a kick influx (gas bubble) which has entered into a wellbore. If it is assumed that the fracture is going to occur at the shoe, because it is the weakest formation throughout the open hole interval; the following expression of pressure

E-mail addresses: tunaeren@yahoo.com, tuna.eren@ikc.edu.tr.

https://doi.org/10.1016/j.petrol.2018.07.077
Received 3 July 2018; Received in revised form 26 July 2018; Accepted 30 July 2018
Available online 31 July 2018

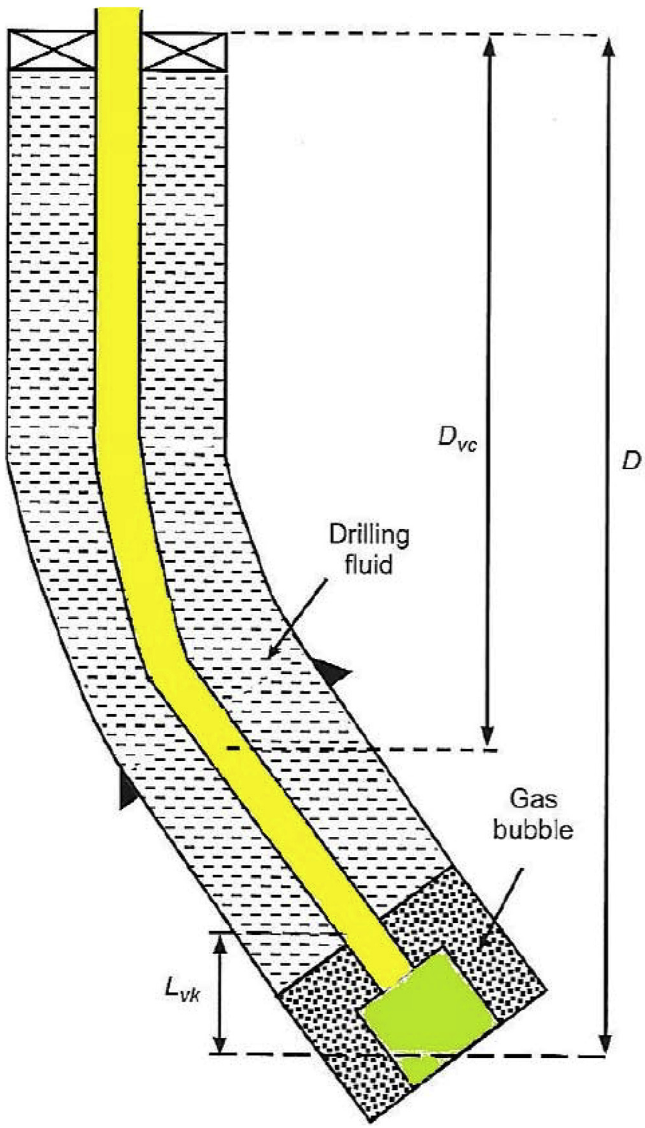

Fig. 1. Well geometry to derive a kick tolerance equation Aadnoy (2009).

balance can be obtained, Eq (1).

$$\rho_{kt} D_{vbh} 0.052 - \rho_g L_{vk} 0.052 - \rho_m (D - D_{vcs} - L_{vk}) 0.052 = \rho_f D_{vcs} 0.052 \quad (1)$$

where; ρ_{kt} is the kick tolerance expressing the pore pressure in terms of fluid density, ppg, D is the true vertical depth of the bottom of the hole, ft, ρ_g is the mass density of the influx which is supposed to be gas, ppg, L_{vk} is the vertical projection of the gas bubble length, ft, ρ_m is the mass density of the drilling fluid, ppg, D_{vcs} is the true vertical depth of the casing shoe, ft, ρ_f is the formation fracture or absorption pressure expressed in terms of the equivalent mass density, ppg. The equation for a kick tolerance can be derived basically simplifying Eq-1, as shown below in Eq (2).

$$\rho_{kt} = \rho_{df} + \frac{D_{vcs}}{D_{vbh}} (\rho_f - \rho_m) - \frac{L_{vk}}{D_{vcs}} (\rho_{df} - \rho_g) \quad (2)$$

One of the most important steps in well planning for a wildcat well is the preparation of the pore pressure and fracture gradient (PPFG) chart. The numerical data containing in this PPFG chart is the finger print of the well. It identifies the technical details of the well to be drilled as it is assumed. The actual PPFG of a well can only accurately be determined once the drilling tasks of the well are entirely accomplished. Optimum casing setting depths can be determined when lithological columns, predicted PPFG are available. Many of the aspects presented in this paragraph can be achieved by means of calculating the kick tolerance. Hence, the question to be answered at this point is "What is kick tolerance?" Kick tolerance is defined as the maximum amount of kick volume which can be circulated out of the well without breaking the formation down at the previous casing shoe depth (presuming that it is the weakest formation interval along the open hole section). The assumption that the casing shoe depth is the weakest formation section along the whole open hole section is not always true, e.g.: the weakest formation interval is not always the previous casing shoe depth.

In order to validate the results a rigorous data collection study was conducted during the data collection process the data points of pore pressure and facture pressure gradients are digitized from the publications which had pore pressure and fracture pressure gradient information. Pore Pressure and Fracture Gradient data from three main literature references are used. Zhang (2011), Salehi and Nygaard (2011) and Sanad et al. (2004) had pressure and fracture gradient data in their manuscripts.

Since the present research is investigating to propose a general convention regarding the handing of the kick tolerance related aspects not only during drilling but also in the well planning phases; the approach needs basic well data to be implemented. It should be kept in mind that the wells can be drilled safely by means of drilling by means of a sound manner. The chances to ascertain that a well is not going to kick is through ensuring that appropriate equipment and personnel with enough skills are present. With this present research study it is once more emphasized that having a reliable pore pressure and fracture gradient data is very important in designing wells.

2. Literature review

There are a significant number of studies in the literature which investigated the kick tolerance concept. With very basic terms; kick tolerance is the maximum kick volume that can be taken into the well and circulated out without causing formation damage. Watson et al. (2003) gave the definition of kick tolerance as the maximum kick intensity that a well can tolerate before the lost circulation is experienced at the last casing seat. Safety vise the present research is investigating how well control situations can be handled. Because of the possibility as mentioned by Avelar et al. (2009) blowout occurrence needs to be mitigated in order to avoid human casualties, financial losses and environmental pollution.

The importance of kick tolerance was stated by Ohara et al. (2004). In the technical report that was prepared the kick tolerance concept was stated to have shown to be a powerful parameter to use in well designs during drilling operations. They concluded that especially for deepwater drilling operations kick tolerance should be frequently used, and its use should be facilitated by a computer program.

One of the early studies on mathematical modeling of gas kicks was conducted by Leblanc and Lewis (1968). In their research they presented an analysis of annular backpressure variations associated with controlled gas kicks and subsequent occurrences. Their findings indicated that a successful drilling venture can be achieved by appropriate formulation of minimum equivalent fluid density, annular back pressure profile, and increased efficiency in the control of threatened blowout.

Kick tolerance is a function of formation pressure and formation breakdown pressure. The kick tolerance for a fixed rig is given to be