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# A novel mitigation on deepwater annular pressure buildup: Unidirectional control strategy

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ABSTRACT

When completing deepwater wells, a significant portion of the completion fluid is often trapped in the casing annuli because of widespread use of multi-layer casing technology. When transferred into testing or production, the temperature field in the immediate vicinity of the wellbore is redistributed by any present thermally conductive fluids. Raising trapped completion fluid to a high temperature can trigger high thermal stress, and this stress has been proven to present a grave threat to the safety of deepwater wells. In this paper, a thermal conductivity model of fluid-filled annuli based on a typical well structure used in the South China Sea is established to determine the effect of different production parameters during the well production or testing process on pressure behavior. A numerical simulation of the effects of fluid trapped in the casing annuli on temperature distribution was conducted. Based on this simulation, a novel method for mitigating the pressure of the trapped fluid by a way of a unidirectional control strategy was studied, and a unidirectional pressure control casing nipple tool was developed. Laboratory simulations were then conducted using a prototype tool to determine the technical feasibility of the unidirectional control strategy. The change in trapped fluid pressure with time was obtained for different release pressures and tool valve orifice diameters, showing the effects of different valve orifice diameters and volumetric injection rates on the pressure release performance. Experimental results demonstrate that the pressure envelope decreases quadratically with the increase in the pressure grade, while the valve working duration decreases linearly with the increase in valve orifice diameter. The increase in the volumetric injection rate was found to have little effect on the cumulative volume displacement. The proposed unidirectional pressure control strategy for controlling the accumulation of pressure in the annuli of deepwater wellbore casings can effectively eliminate the fatal dangers presented by thermal stress. It can also reduce the risk of casing deformation due to thermal stress within trapped annuli and reduce occurrences of wellhead sealing damage.

## 1. Introduction

The subsea well completion method is commonly applied to deepwater oil and gas wells. In the process of subsea well completion, the cement sheath forming the top surface of the multi-layer technical casing is typically located a certain depth below the mudline. As a result, a certain amount of completion fluid can become trapped in the technical casing annulus between the wellhead sealing ring and the cement sheath top surface. Importantly, there is a twin-stage temperature gradient profile along the axis of a deepwater well affected by the water depth. The wellbore temperature near the mudline is generally 2–4 °C, while the formation temperatures at the end of the wellbore often exceed 100 °C. During production well testing, high-pressure and high-temperature (HPHT) oil or gas will flow in the oil tube, heating the fluid that is trapped in the casing annuli. The temperature of the trapped fluid will increase, then expand, increasing its volume and with that, its pressure (Kan et al., 2016). This phenomenon is referred to as Annular Pressure Buildup (APB).

Vargo et al. (2003) has performed research on several deepwater oil and gas wells in the Marlin oilfield of the British Petroleum Company in the Gulf of Mexico. This research indicated that the temperature of trapped fluid in the casing annuli increases sharply as a result of deepwater well production tests. This temperature and subsequent pressure increase was observed to seriously damage well casings within a few hours of the commencement of the deepwater well production test in several wells. Azzola et al. (2004) have also performed research on the

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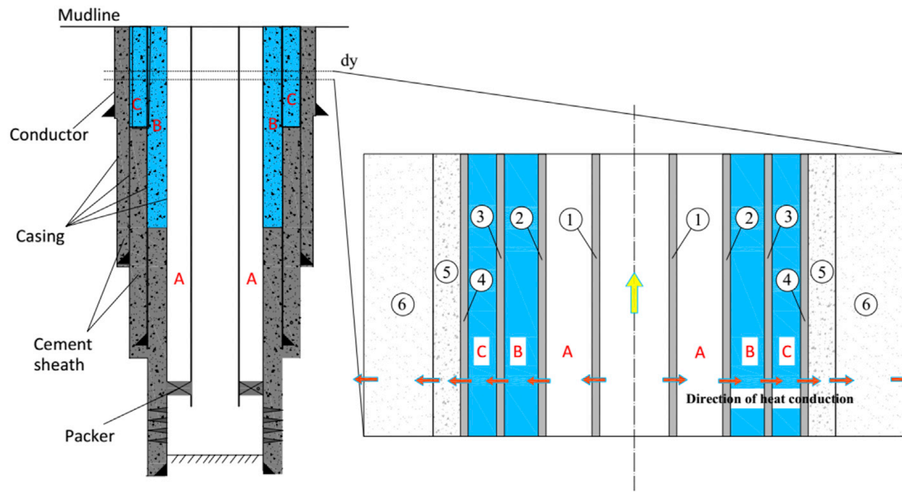


**Fig. 1.** Diagram of the heat transfer process in a deepwater wellbore.

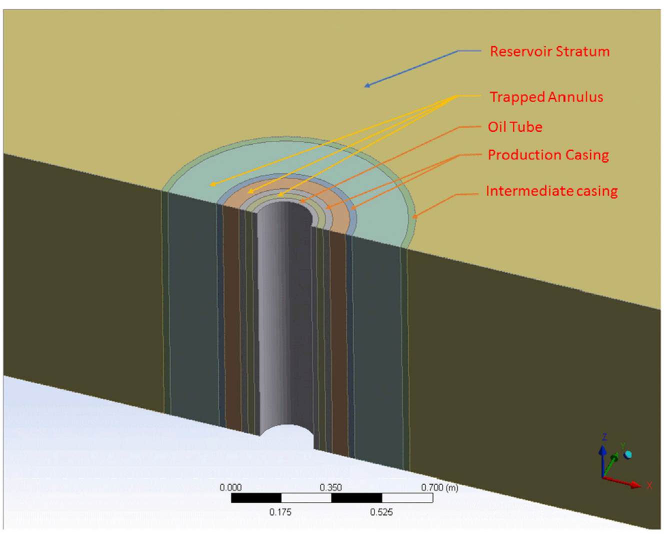


**Fig. 2.** Partial geometric model of wellbore heat transfer.

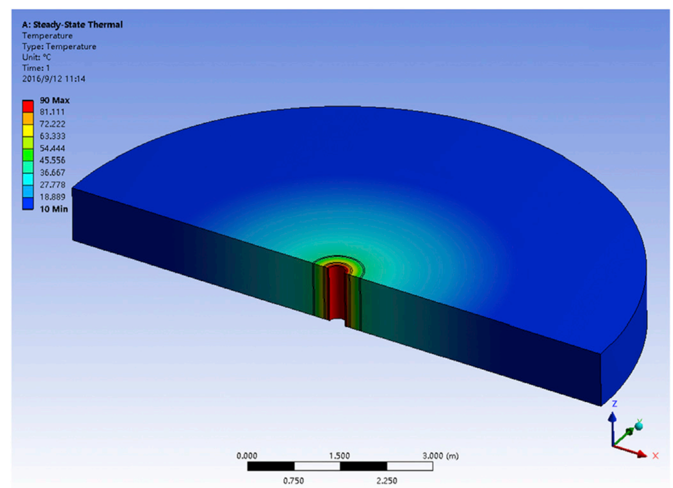


**Fig. 3.** Temperature contours of wellbore heat transfer as determined by numerical simulation (integral).

trapped pressure and temperature increases in casing annuli, investigating the performance of deepwater wells located in the Gulf of Mexico, Brazil, and West African offshore regions, respectively. Their research also indicates that the temperature and volume of trapped fluid present in deepwater well annuli will increase when the wellbore is heated by the hot formation fluid flowing through the oil tube. The additional pressure is generated as a result of the fluid expansion phenomenon, which then leads to potential safety incidents in the downhole, such as casing collapse, subsea wellhead failure, casing cracking, wellhead sealing failure, and so on. All of these incidents pose a serious threat to safe deepwater oil production.

Hasan et al. (2010) proposed a calculation method to determine casing annulus pressure and temperature. By applying heat transfer theory to the deepwater wellbore, a flow-rate estimate was also conducted in the calculation method. Jin et al. (2013) and Huang (2014) all studied the theoretical calculation of annular pressure and annular temperature, which each then used to propose a series of predictive analysis models to determine the annular pressure and annular temperature of deepwater wells. Wang et al. (2011) studied the wellbore temperature during the drilling process, including the variation of wellbore temperature along the longitudinal axis of the wellbore, included to capture the effects of drilling fluid circulation, in which the wellbore temperature was calculated using a coupling model.

Based on theoretical analysis and calculation, Azzola et al. (2004) conducted research on vacuum-insulated tubing technology in an effort to mitigate annular pressure buildup, providing both a theoretical calculation method and experimental results (Zhou et al., 2015). Bo et al. (2015) conducted research on the injection of nitrogen in order to control annular pressure buildup, demonstrating that the annular pressure could be controlled effectively by injecting a 5–20% nitrogen volume fraction into the entrapped annulus via a nitrogen-foam completion fluid when completing a deepwater well. Rizkiaputra (2016) conducted research into a proposed deepwater wellbore design based on the use of a sacrificial low-intensity casing included to mitigate the impact of pressure buildup in the casing annulus and provided both numerical and experimental simulations for deepwater wellbore design. On the basis of theoretical analysis and calculation.

In the past, the study of annular pressure control technology has been largely based on the theoretical calculation of the distribution of pressure and temperature in the annuli. At the same time, feasibility evaluations of the most applicable pressure control technologies have been conducted.