Failure Modes of Oil Well Cement During Service Life

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Abstract

This study was focused on characterizing the potential failure modes for cemented oil wells, composite of metal-cement-geomaterial, during the service life based on the information in the literature. The three basic modes of failures have been identified and include rock-cement debonding, cement-casing debonding and cement failure. Also mixed modes of failures are possible in the composite configuration.

1. Introduction

The composite nature of the oil well configuration raises many challenges during the service life of the production well. There are more than 141,000 active oil wells in Texas by 2009 according to the U.S. Energy Information Administration. Primary cementing is critical in providing effective zonal isolation to prevent foundation fluids from migrating into annulus for the life of the well. Cement failure is not uncommon for oil wells. The cement must completely fill the annular space between the casing and the rock. Sometimes caves in the ground can consume the cement, and makes the annular space not full filled with the cement. Also, water from the ground water zone may migrate into the cement. The poor slurry design and poor management of hydrostatic head pressure can also cause low bond strength of the cement (Hetrick 2011). During service life, debounding, cracking and plastic deformation have occurred in lots of oil wells. Survey of 142 oil wells in Alberta, Canada showed that only 19% of the cement did fair to excellent cement job, and the problems came from poor cement bond and cement degradation, which increased the potential for well failure leading to well leakage (Alberta Energy and Utilities Workshop 2007). Cement shrinkage experiment by exposing the cement to water desaturation showed that the bulk shrinkage can lead to the debonding of the cement from the bore hole wall (Saidin et al. 2008). Besides, incomplete mud displacement by cement can form mud channel across the zones of interest and lead to interzonal communication. A well can be temporarily or permanently abandoned by sealing with cement. Improperly applied or aging cement can crack or shrink lead to fluid leakage (Mainguy et al. 2007). Blowout of Macondo well which was temporarily abandoned was probably due to swapping of cement and drilling mud in the shoe track (the section of casing near the bottom of the well) and contamination of the shoe track cement (Report Regarding the Causes of the April 20, 2010 Macondo Well Blowout).

2. Objective

Characterize the potential failure modes for cemented oil wells during the service life of the oil wells. This will also help with identifying the causes of failures.

3. Failure Modes during Service

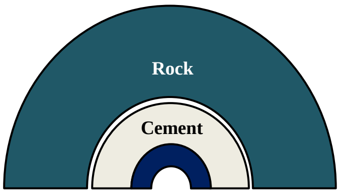
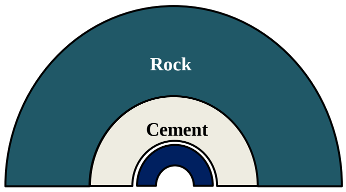
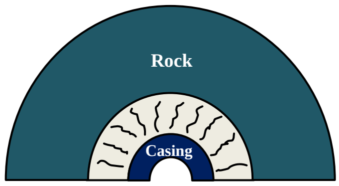
Mode 1: Rock-Cement Debonding. The cement sheath could debond at the rock-cement interface related to the stiffness contrast or pressure and temperature change inside the casing (Ravi et al. 2002). The debonding could also be caused by cement bulk shrinking, or incomplete mud removal at the rock-cement interface, leading to the formation of micro-annulus. The fluids could enter and pressurize the annulus resulting greater debonding (Ravi et al. 2002).

Mode 2: Cement-Casing Debonding. The cement sheath could also debond at the cement-casing interface due to stiffness contrast, where drilling mud could also exist due to incomplete mud displacement. With change of temperature and pressure in the casing, casing diameter is reduced or expanded, thus micro-annulus is formed, which could lead to vertical migration of fluids.

Mode 3: Cement failure. Oil well cement shrinks when they hydrate, and the effective reduction in volume is typically about 4% (Ravi et al. 2002). The entire cement sheath could crack due to the shrinkage of the cement, and tensile failure was the most dominant failure mode (Bosma et al. 1999). Also, expands of the casing due to an increase in pressure and temperature can lead to crack of part of the cement sheath, especially for cements that possesses a high Young's modulus (Goodwin et al. 1990). For ductile materials, crack is often accompanied by plastic deformation. Crack and plastic deformation of the cement may allow zonal or vertical migration of fluids.

Mode 4: Mixed mode. Combination of Modes 1, 2 & 3. Combined failure is resulted from cement failure or debonding at the outside/inside interface of the cement material.

Table 1 Basic Modes of Cement Failure during Service Life of Oil Well

Modes of Cement Failure	**Mode 1 Rock-Cement Debonding**	**Mode 2 Cement-Casing Debonding**	**Mode 3 Cement Failure**
Reason	Stiffness contrast, pressure and temperature change, cement bulk shrinkage	Stiffness contrast, pressure and temperature change	Cement shrinkage, pressure and temperature change, cyclic loads
Phenomenon	Formation of outer micro-annulus	Formation of inner micro-annulus	Crack, plastic deformation
Possible Failure	Vertical migration of gas, oil or water	Vertical migration of gas, oil or water, leakage at the well, even blowout	Zonal or vertical migration of fluids
Sketch			

4. Acknowledgments

This study was supported by THC-IT with funding from the industries and CIGMAT.

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