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Research paper

Laboratory research on the influence of swelling clay on the quality of borehole cementing and evaluation of clay-cutting wellbore tool prototype

Mateusz Kmieć*, Bartłomiej Karpiński, Michał Antoszkiewicz, Marek Szkodo

Gdańsk University of Technology, Mechanical Faculty, Department of Materials Science and Engineering, 80-233 Gdańsk, Poland

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ABSTRACT

Swelling clay phenomenon is frequently observed during oil and gas drilling operations and has a significant impact on the quality of cementing procedure. Certain types of clayey minerals increase their volume in contact with water-based drilling fluids. After drilling is completed, borehole remains unsupported and filled with water-based drilling fluids for several hours, before a casing string is inserted and secured with cement. In the period of time between completing the drilling and inserting the casing string the clay can expand hindering proper cementing or blocking the casing string in a wellbore. Filling the annular space between a casing pipe and wellbore walls with cement is crucial for further exploitation of a well. An improper performance of displacement work (primary cementing) may cause both financial losses and environmental damage. The aim of this study is to describe the impact of distorted annular space geometry on cement sheath quality and to examine the possibility of improving the distorted geometry with a prototype wellbore tool. The tool was designed to be mounted as a first pipe section on the casing string (cementing shoe/reamer shoe). Two test stands were designed and constructed. The first one simulates the well cementing process, while the second one simulates the downward movement of the casing pipe in the well (run in hole process) drilled in expansive clay. Six distorted annular space sections were cemented using the first test stand. The sections were scanned with µXCT (computed micro-tomography) to locate discontinuities in the cement sheath. This research has confirmed an adverse influence of annular space obstructions on the cement sheath quality, thus the necessity of removing them before cementing. The obstructions can be removed by means of newly designed clay cutting wellbore tool. Therefore, the prototype of such a tool was tested on the second test stand. The experiment allowed to evaluate an influence of a swollen clay obstruction on the force needed to push the prototype tool through the obstruction. The same experiment was conducted with a standard cementing shoe in order to obtain comparative data. Hole geometry improvement, ability to fragment and remove clay cuttings have been observed. The research has confirmed that the prototype tool efficiently improves the borehole geometry and, consequently, improves the cement sheath quality.

1. Introduction

1.1. Fundamentals of cementing

Cementing is a process of placing a cement sheath around casing strings in a well. It is a critical part of well construction and the process is extensively designed and fully engineered. Cementing fills in the space between the well casing and drilled wellbore, isolating different subsurface zones and providing structural support for the well. Cementing has crucial meaning for the well integrity throughout its life and protects the casing from potential corrosion (Fig. 1).

Proper design and realization of lowering and cementing each column of casing within the borehole, especially tubing, have significant impact on the efficiency of exploration work and the efficient usage of drilling consumables for both operating and newly discovered fields. Failure to achieve proper zonal isolation can have a significant economic effect in terms of lost well productivity (Nelson 1990), [pp. 1–1]. Lack of hydraulic seal can also cause environmental contamination followed by expensive rescue and recovery actions and payment of possible compensation.

Zonal isolation relies on effective mud removal: the displacement of drilling fluids and accompanying debris from the casing – borehole wall annulus (Docherty et al., n.d.). Good operational practices have essential meaning for proper cementing. Two most important factors ensuring good cementing are: centring the casing by densely mounted centralizers and forcing reciprocal or rotational movement of the casing

* Corresponding author.
E-mail addresses: matkmiec@gmail.com (M. Kmieć), mszkodo@pg.gda.pl (M. Szkodo).

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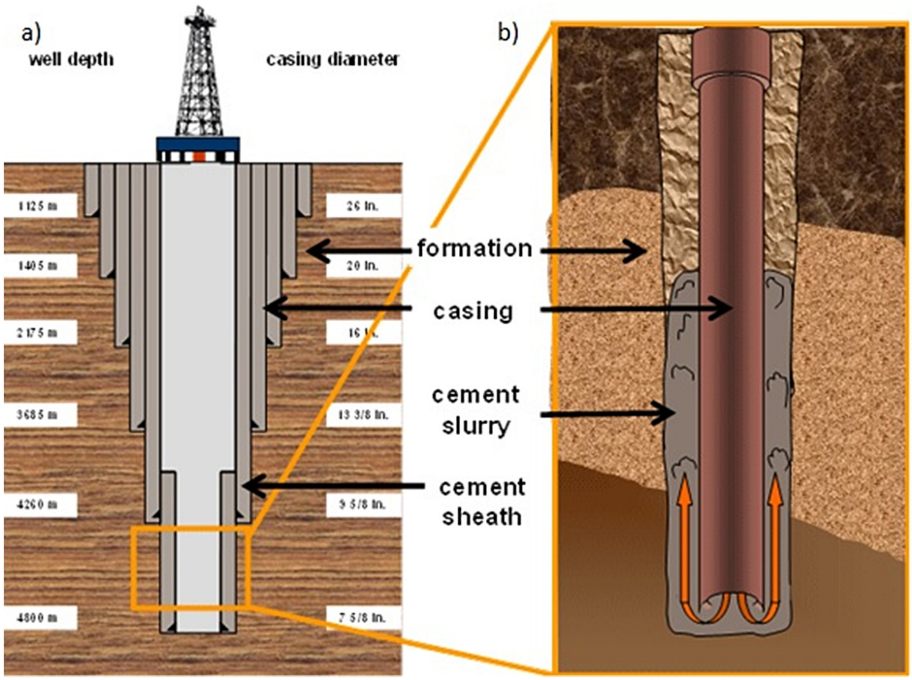

Fig. 1. Schematic of a cased and cemented oil well (a); principle of placing the cement slurry between the casing and the rock formation (b) (Mangadlao et al., 2015).

during the cementing operation. It is important to insert the casing at a speed that will not fracture the rock formation. Another important factors are: using proper displacement techniques, such as a pre-flush and applying spacers and cement plugs (Nygaard, 2010).

To qualify as properly cemented, a well needs to feature a continuous and impermeable hydraulic seal, isolating each zone along the wellbore, within the annulus.. To obtain such a seal, cementing operations must prevent the cement from bypassing, mixing with or being contaminated by fluids in the annulus.

1.2. Cement failures

Cement is a well-known material whose properties are well documented. However, some of these properties prevent this material from handling the well integrity challenges related to loss of pressure and leakage of fluids(Fig. 2) . These challenges include: cement shrinking, gas migration during setting, fracturing after setting and long term degradation by exposure to temperature and chemical substances in a well (Etetim, 2013)

According to the classification (Teodoriu et al., 2013) criteria listed below there are several reasons for wellbore integrity issues. The ones having the highest impact on cementing job quality and hydraulic seal have been listed and described below. Explanations are based on references (Bourgoyne et al., 1991), pp. 137–144], (Lyons and Plisga, 2011; Teodoriu et al., 2010; Karpiński and Szkodo, 2015; Bittleston and Guillot, 1991; Nelson, 2012).

1.2.1. Inadequate drilling mud removal

During cementing operations, a cement slurry is pumped into a well in which the annulus is filled with drilling fluid. Displacing mud with cement through a narrow annulus several thousand meters deep is not easy. Drilling muds are non-Newtonian fluids which typically show thixotropy which means that they build a gel-like structure under low shear rates (low flow or no flow). This behaviour is meant to prevent an accumulation of cuttings at the bottom of the well in periods without circulation. After this period, the gel structure has to be broken up and the flow has to be ensured further in the well. Otherwise, mud pockets will compromise the integrity of entire well. The flow regime of the fluids is also an important factor (Fig. 3).

In laminar flow, viscous friction forces dominate hence, the maximum velocity is at the centre of the borehole, and its value gradually drops to zero at the wellbore wall. In turbulent flow, the particles move in an erratic circular motion and, in this case, the velocity of the fluids along the walls is nearly the same as at the centre of the borehole. In most cases, turbulent flow is preferred for drilling fluid removal, because turbulent flow's uniform-like velocity profile and swirling motion is considered to enhance mud removal. To maximize displacement, the flow must be turbulent all around the annulus. However, this requires higher pump rates in eccentric annuli, which may not always be attainable.

1.2.2. Contamination of cement by mud or formation fluid

Another factor significantly impeding cementing is the fact that cement slurries and drilling fluids are usually chemically incompatible. Their mixing may result in forming a thickened or gelled mass at the interface which is difficult to remove from the wellbore and possibly prevents placement of a uniform cement sheath throughout the annulus. However, complete replacement of mud with cement is crucial to the viability of a well and its future stability (Bittleston and Guillot, 1991). Therefore, engineers employ chemical and physical means to maintain fluid separation. Chemical washes and spacer fluids may be pumped after the drilling fluid and before the cement slurry. These fluids contribute to better cleaning of the casing and rock formation surfaces which helps to obtain good cement bonding (Nelson, 2012).

1.2.3. Casing centralization (incomplete cementing)

In case of insufficient centralization of the casing, the cement might not fully displace the mud from the annulus during cementing operation. It has been found that uneven velocity distribution around eccentric casing causes possible coexistence of different flow regimes in a given annular cross section (Fig. 4). Cement flows in the wide opening of the well rather than in its narrow opening. This results in cement eccentricity and non-uniform cement thickness.

1.2.4. Swelling clay minerals

Water-based drilling fluids are increasingly being used for oil and