Effect of Stratigraphic features on Deep-Water Cementing Operation – A Review

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Abstract-
Drilling operations in deep-water environment is faced with technical challenges despite its massive record of huge hydrocarbon reserves when compared with onshore oil and gas fields. The weak, unstable formations coupled with adverse deep-water conditions poses as a challenge to cementing operations. Narrow pressure window conditions are encountered when the wellbore pressure required to contain subsurface pressures lies close to the pressure at which losses may be sustained. This is evidence in the ratio of pore pressure to vertical stress moving close to lithostatic condition. This can either be caused by porous formation or by the way of inducted fractures in weak or sheared or unconsolidated zones in the subsurface. This study showed an overview of some possible challenges faced in deep-water cementing operations in relation with stratigraphic features of the deep-water environment. From the review it was gathered that the stratigraphic nature of deep-water environment has a huge effect on cementing operations for oil and gas wells. The study also highlighted some gaps in the literature which require urgent attention to reduce loss circulation. These gaps include but not limited to: spacers generating sufficient downhole force to overcome the yield stress of the mud and the need for a new type of treatment for lost returns. Managed pressure cementing operations may control wellbore pressures.

Key words: Deep-water cementing, Stratigraphic effect, Narrow pressure margin, Lost returns

1. Introduction
Drilling and well completions in deep-water has created challenges for operators. As operators continue to explore and develop their deep-water resources, they are faced with an exponential increase in drilling and completion challenges due to the very narrow pore pressures and fracture gradients typically seen in deep-water environment. When the pressure needed to sustain the formation pressure is close to pressure required to sustain it, the pressure window is said to be Narrow [1]. This is evidence in the ratio of pore pressure to vertical stress moving close to lithostatic (Fig. 1) condition (that is, very close to 1).
Cement is applied after casing each hole section, to prevent fluid migration and interaction between subsurface formations. Complete cementing of casing strings is critical in wells to protect the casing and provide mechanical integrity to the wellbore. Typically, wellbore stability is achieved by replacing the drilling fluid in the annulus with cement, thereby providing effective zonal isolation [3]. Achieving effective zonal isolation usually requires pumping a spacer system to replace the mud prior to the introduction of cement to the annulus [4]. It is imperative that the spacer generate sufficient downhole force to overcome the yield stress of the mud, enabling it to be successfully displaced.

Drilling operations in deep-water environment is faced with technical challenges despite its mostly recorded huge hydrocarbon reserves when compared with onshore operations. The weak, unstable formations coupled with adverse deep-water conditions poses as a challenge to cementing operations. For ideal situations, successful cementing is aimed at providing good zonal isolation, adequate casing and wellhead support. This is a difficult goal to achieve at water depths greater than 2,000 ft because, the cement slurry not only stay within the narrow pressure margin; but, it also must set or thicken at an optimum time frame [5]. Wellbore cementing is the process of replacing hydrostatically overbalanced drilling fluid system within the annulus, with overbalanced cement slurry. The key major activity is to maintain the overbalance in the
wellbore to maintain well control. Though, one of the major key factor that influence the hydration rate of a slurry made with cement in deep-water conditions is temperature [6]. Low temperature will prolong the time it takes for a cement slurry to thicken or set and also contribute to casing shoe failure due to the insufficient shear stress of the annular cement sheath to support the casing within the period [7].

This paper looked at challenges facing deep-water cementing operations and these challenges are organized as follows: a highlight on the cementing operation, issues of narrow margins between pore and fracture pressure; lost returns during the cementing operation and shallow water/ gas flow hazards associated with deep-water. This paper climaxes with some concluding remarks and suggestions for further research are made.

2. Deep-water Cementing Operation

Zhao et al., [8] in their experimental investigation on deep-water formations highlighted the technical challenges and borehole instabilities encountered in the upper 1000 m range below the mudline. Density log and its integrations has shown the situations where the overburden pressure in some oil and gas wells is replaced by the hydrostatic pressure of the seawater due to under-compaction. Gao et al., [9] in their risk analysis in deep-water drilling, estimates the daily cost of drilling in deep-water to be many times higher than the onshore drilling. They attribute some of these cost to wellbore instability challenges, these challenges hinder the implementation of drilling operation plans by the well engineering department.

Zhang et al., [10] explain the well drilling process and operations conducted in the oil and gas field. They defined cementing isolation system in drilling operations as the combination of the drilled formation, the cement slurry and casing. The main function of cementing isolation system in their study was to seal the borehole wall. The importance of cementation and its possible failure in the deep-water drilling operation cannot be over-emphasized due to the water environment. Liu et al., [11] identified the characteristics of the cement sheath as the main determinant in the success of a cementation operation in an oil well. The permeability of the sheath directly contributes to the success or failure of seal in the well; and the strength of the cement is also an important indicator in evaluating the sealing ability.

Although, researchers have different views on the effect of compressive strength, cement composition, stratigraphic structure and time of solidification of the cement slurry [12-15]. There is need to direct research attention in developing a significant correlation or mathematical model that will establish with facts which of these properties: compressive strength, stratigraphic structure and composition of the cement slurry; that will have a significant effect on cementing sealing ability for deep-water operations. The relationship between these three properties and sealing ability of cementing operation is uncertain.

Well cementing is a critical aspect of well construction in deep-water environment and downhole. The way to minimize risks, daily cost of well construction and non-productive time; requires essential good cementing practices, understand the constraints for deep-water cementing and plan for contingencies in locations where cement slurry must be placed. From the existing literatures on deep-water cementing operation [16-18], we can highlight narrow margins between pore and fracture pressures, lost circulation during drilling, lost returns during
cementing jobs and shallow water/gas flow hazards as challenges facing deep-water cementing operation. Wang et al., [19] in their deep-water well cementing identified low temperature as a formidable challenge when cementing the casings.

3. Lost Returns challenges in Deep-water Oil Well Cementing
Depleted reservoirs and unconsolidated formations contribute to lost circulation while drilling and loss return during cementing. Other causes of partial or total loss of circulation that occur during cementing are existing lost circulation zones induced losses due to the excessive hydrostatic head of the cement column exceeding the formation pressure [20], or the presence of washouts (hole enlargement) that require more cement than initially calculated (Fig. 2).

![Figure 2: Lost Returns that leads to Cement Dehydration](image)

Whether a well is for producing hydrocarbons or injection of fluids, proper cementing is necessary to provide a hydraulic seal between formation and casing pipe, to protect and support the casing pipe and to isolate production zones. Lost returns challenges in a formation may result in casing failures [21]. These induced stress from these failures when they occur leads to cement sheath failures. Common practice [22] to address these well integrity problems is the application of lost-circulation materials and/or low-density cementing systems designed with densities of 10.5 to 11.0 lb./gal. The rule of thumb is that cement slurry be designed for specific application for a particular formation, with good properties for placement in a normal time period [23]. Thus, the success of the curing will be dependent on the impact of the treatment on the reservoir bearing formation, treatment placement and temperature limitation. Another important factor is the compatibility of the drilling mud, cement slurry and the spacer; API [24]
compatibility procedure is highly recommended for operators. The flow rate, fluid properties and contact time are important parameters that governs the effectiveness of the process. Existing lost circulation zones induced losses due to the excessive hydrostatic head of the cement column exceeding the formation pressure [25], or the presence of washouts (hole enlargement) that require more cement than initially calculated. When considering a proper control of hydrostatic pressure, the cement slurry will have no significant free-water; it should provide an adequate control of return lost from the formations and should have the appropriate ratio of additives to ensure proper placement. Cement-bond log is an evaluation technique for cement sheath in an oil and gas well; it is achieved by wireline tools running in a cased borehole. The success level for lost return treatments varies from one case to the other and there is need for a new type of treatment.

4. Narrow Margins between Pore and Fracture Pressure
A wellbore has different dimensions along the process. As the length increases the outside diameter decreases with depth, this structure applied to oil and gas wells. Seabed and near-seabed formations tend to be loose and poorly consolidated. These weak zones are vulnerable to damage from drilling operations, as there is normally a narrow margin between the pore pressure and fracture gradient [26]. Because of this narrow margin, high flow rates or excessive rheology in low-temperature conditions can wash out the wellbore or fracture the formation. Thus, hole cleaning becomes complicated during drilling and while cementing the large casing into the wellbore [27]. Field investigation has shown that the fracture gradient and pore pressure margin for deep-water oil and gas wells can be as low as 0.2 [28-32]. The tight fracture pressure window impacts on all aspects of the operations, which includes drilling to running of casing at each casing shoe depth, cementing and even completion operations. The cementing service company must carefully balance the cement slurry design to achieve the ideal density, viscosity and slurry properties so as to stay within the narrow margin window.

5. Shallow Water or Gas flow
Density log and its integration has shown the existence of shallow geological formations under the deep-water (Fig. 3). These formations are under-compacted; thus, has poor formation strength due to weak cementation [33].

Figure 3: Density Log for Offshore Formation [2]
Shallow water flows occur in the permeable formation that exist below the mudline in deep-water drilling [34, 35]. The top-hole unit is a portion of the well often drilled without a marine riser and it serves as an exit point at the seafloor for mud and cement slurry coming from the wellbore annulus. The hydraulic and structural integrity of the top-hole can be compromised by the shallow water flow [36]. This challenge can hinder the success of a deep-water drilling operation if the overpressure shallow water flow is penetrated by drill bit prior to installation of the blowout preventer, casing and cementing of the initial casing string [37]. When the drill bit penetrates the impermeable layer, the pressure is released, causing sand mining [38]. This will initiate an uncontrollable flow of water and sand from the overpressure formation in the wellbore [39].

Flows from these shallow formations are usually an effect of abnormally high pore pressure in under compacted and usually unconsolidated sediments formed in a quick depositional location [16]. The apparent result of an unforeseen shallow fluid flow is a hysterical blowout condition with no drilling blowout preventer in place [40]. In some stated cases, after the flow was controlled prior to running casing, fluid flow occurred even after the surface pipe was cemented, emanating from poorly consolidated, geo-pressured sands. Although weighted mud can maintain the hydrostatic balance in the shallow flow; but, the cement may lose hydrostatic pressure while setting. Hence, the cement slurry that will be placed across a shallow water/gas flow zone must be designed to compensate for the hydrostatic pressure loss [41].

There is need to design a proper practical procedure that will prevent shallow water flow during drilling and cementing operations in deep-water oil and gas fields. A new technique for preventing this challenge is a priority to the exploration and development industry.

6. Learnings from the review

The available information from existing literature are indicative of the impact and relevance of stratigraphic features on deep-water cementing. Wellbore cementing is the process of replacing hydrostatic overbalance drilling mud system within the annulus of the borehole with overbalanced cement slurry. But, deep-water operators encounter challenges during drilling and completion operations due to narrow pore pressure and fracture gradients. The replacement of drilling mud with the cement slurry uniformly around the casing is a progressive challenge in the deep-water environment due to the narrow safe margins for pore pressure and fracture gradients.

Shallow water/gas flows can be a challenge when drilling with the seawater with return to the mud line before installation of safety equipment. The success of cementing operation in deep-water environment will be determined by the temperature profile, pore pressure, fracture gradient, well architecture, stratigraphic features and cement slurry volume determination.

7. Conclusions

The tight fracture pressure window impacts all aspects of the drilling and completion operations. The cementing service company must carefully balance the cement design to achieve the ideal density, viscosity and slurry properties. Designing sustainable slurries will mitigate these challenges and the application of high strength cement slurries will be a proper treatment for low margin situations.

In view of the findings made in this review, the following are proposed as research directions for the future on this subject:
i. Data is important and real time data is even better, further research should focus on linking real time drilling data with cementation program for proper identification of depleted reservoir and unconsolidated formations; since these two are mostly responsible for poor cement bond log and top of cement failure.

ii. The challenges of lost return during cementing can be cured by the use of formation non-damaging fibers. These fibers can be viewed as the new curing approach that will be suitable for treating lost return for any environment; because of their ability to increase compressive and tensile strength of the formation.

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