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Addressing Cementing Challenges in Ultra HP/HT wells

Vidit Mohan, Anirudh Toshniwal and Ashwin P Ramesh

Rajiv Gandhi Institute of Petroleum Technology, Rae Bareli, India

Vidit Mohan, E-mail: epe120039@rgipt.ac.in

Abstract

Ultra HP/HT wells pose a great challenge for cementing. The necessity of zonal isolation under hostile environment that includes high temperature and pressure, narrow ECD windows, strength retrogression of set cement and efficient fluid placement, and narrow window between pore pressure and fracture gradient has led to development of novel cement slurry systems and placement techniques. The challenges could be in placing the cement slurry to cement sheath integrity during the life of the well. Hence, placement of cement slurry under highest possible displacement rates is necessary to ensure good mud removal. Expandable liner hangers are used to ensure proper sealing of hanger after cementation. Cement additives are selected to evade any sensitivity issues under high temperature bottom-hole condition. Solutions pertaining to SGS, Temperature sensitivity, Settling, Shrinkage of set cement, UCA are presented and discussed for robust slurry systems under extreme conditions. Further, the issues encountered during slurry testing, planning and execution phase which led to successful cement job are addressed.

Introduction

Persistent escalation in hydrocarbon demand is impelling the petroleum industry to explore oil reserves in hostile subsurface conditions, which incorporates high temperature and high pressure. A well is considered to be high pressure and high temperature (HPHT) if the pressure exceeds 15000psi (1020 bar) and the temperature exceeds 300 F (149 C).(Figure 1) HPHT conditions generate lot of intricate challenges and mechanical concerns. One of the major challenges is caused due to the effect of HPHT conditions on cement's rheological properties. Cementing imparts structural stability to the well; it forges a continuous impervious hydraulic seal prohibiting unrestrained surge of formation fluids into the annulus. This influx of fluids into the borehole can instigate a blow out; which can lead to severe destruction of property, environment hazards and can even cause loss of life. So cementing being a vital operation in the process of construction of a well exclusive care is taken during cementing; especially in High pressure High Temperature (HPHT) wells. In HPHT conditions challenges are confronted not only through the well cementing operations but subsequently during the setting of cement casing all along the lifespan of a well.

Strength Retrogression

The CSH phase of Portland cement formed by addition of water, tricalcium and dicalcium silicate is an outstanding binding material at borehole temperatures below 230°F. In HPHT environment significant contraction in compressive strength of this phase takes place in conjunction with the augmentation in the permeability of the set cement. This phenomenon is known as Strength Retrogression. The increment in permeability poses a serious threat as within a few months the water permeabilities of the cement increases 10-100 times higher than the advocated limit. This can be prevented by using Silica flour or silica sand which modifies the hydration chemistry. The increment of 30 to 40% silica is generally sufficient to fabricate set cement with low permeability (< 0.1 millidarcy) which overcomes the strength retrogression. Silica reacts with cement and water at elevated temperatures to yield xonotlite in place of tobermorite. Xonotlite being exceedingly stronger, results in a considerably minor increment in permeability.

Antigas Migration Slurry Design for HPHT Wells

A Number of the cement jobs is unsuccessful due to gas migration. In HPHT formations, the wells encounter high temperature variations alters both the formation and the casings. The expansion and contraction of casing and in conjunction with plastic formation like salt results in development of cracks in the already set cement. The cracks formed provides a pathway for the migration of fluids into the annular space after cementing impeding attainment of zonal isolation and jeopardizing the integrity of the cement thus curtailing the lifespan of the well.

When the Hydrostatic pressure of cement column and the mud on top of it is exceeding pore pressure of gas-bearing formation, it averts the fluid from infiltrating the cement. However the hydrostatic pressure should not transcend the fracturing pressure of the formation to circumvent losses. The net hydrostatic pressure of the annular column is affected by the competence of the cement slurry to transmit hydrostatic pressure, which is a function of the cement slurry gel strength (1). Higher gel strength contributes to lower transmissibility of the annular hydrostatic pressure. The length of time from the point at which the fluid goes static until the SGS (Static Gel Strength) reaches 100 lb/100 ft2 is referred to as the “zero gel” time. Attainment of SGS value of 100 lb/100ft^2 commences the decrement cement slurry’s ability to transfer hydrostatic pressure. Further increment of the SGS value to 500 lb/100 ft^2 ceases the transition of hydrostatic pressure from the fluid (or the fluid above it).

The time required for the fluid’s SGS value to increase from 100 lb/100 ft2 to 500 lb/100 ft2 is termed as the “transition” time. Gas migration can be restricted by reducing the “transition” time as small as possible (preferably, less than 30 minutes) and for this the “zero gel” time can be extended.

Mud Removal

In HPHT condition for achieving strong cement bond and proper cement placement mud removal becomes an imperative process. Mud should have the following qualities to be effectively displaced (2):

(1) Have a low plastic viscosity to yield viscosity ratio, (P.V/Y.P.)
(2) Have a minimal gel strength development.
(3) The design of drilling fluid and displacement is important in cementing, because there must not be incompatibility issues which could cause sludge formation and downhole problems.

Mud removal incorporates the conditioning of drilling fluid, preflush, spacer, and application of mud removal tools such as scratchers. Circulation of drilling fluid conditioning in advance to cementing eliminates gas and cuttings. It also reduces the mud gel strength, and the mud viscosity. 10% density difference is recommended between spacer & mud and cement & spacer. Slurry contamination can be averted by maintaining separation from displacement. At least 650 ft of spacer ahead and 170 ft behind cement slurry is required (3). A good mud removal can be accomplished by enhancement in the pipe stand-off, increment in the µp / Ʈy ratio, decrement in the mud gel strength, and by escalating the flow rate. In case of Bingham Plastic fluids, higher dimensionless shear rate results in better circulation efficiency (Table 1). Top and bottom plugs should pumped ahead and behind the slurry to separate it from the mud.

Improvement in Cement Bond employing Expansion Additive

HPHT environment generates multifold complications to casing integrity and Cement Bonding as a result of the larger differential pressure between the formation and the casing as compared to that in case of normal wells. So proper cement placement in the annulus and strong cement-casing support become more significant. A strong cement bond between casing cement and formation can be achieved by addition of expanding additive. Expansion additive like Burnt Magnesium Oxide (MgO) enhances the shear bond strength but reduces compressive strength though still above the recommended minimal value. The expanding additives escalates the number of matrix in cement and, with hydration process, induces better expending in cement. Burning Magnesium Oxide impedes the hydration process when in contact with water. Cement containing Manganese Oxide (MgO) provides excellent expansive performance at curing temperatures as high as 550°F.

The Effect of Temperature, thickening time and use of retarders

The slurry being sensitive to elevated temperature, HPHT conditions lowers the thickening time of the slurry resulting in the cement setting faster in as compared to normal wells. Huge variation in thickening time can be induced due to small alteration (as small as 5 °C) in temperature, so accurate prognosis of Bottom hole Circulating Temperature (BHCT) and Bottom hole Static Temperature (BCST) becomes vital in cementing.

Bottom hole Circulating Temperature: The temperature at the bottom of a well while fluid is being circulated, abbreviated BHCT. This is the temperature used for most tests of cement slurry in a liquid state (such as thickening time and fluid loss). In most cases, the BHCT is lower than the bottom hole static temperature (BHST), but in some cases, such as in deep water or in the arctic, the BHCT may be higher than the BHST.(4)

Bottom hole Static Temperature: The undisturbed temperature at the bottom of a well, abbreviated as BHST. After circulation when the well is shut in, the temperature approaches the BHST after about 24 to 36 hours, depending on the well conditions. The BHST is the temperature used in most tests in which the cement slurry is required to set or is set. (5)

These environments also affect the rheological properties of the cement slurry. Increment in temperatures also leads to reduction in Plastic viscosity (PV) and yield viscosity

Effect of pressure

The well, drilling fluid and cement slurry are influenced by pressure. Inadequate estimation of pressure can result in collapse of the casing, it not being able to tolerate the formation pressure and a kick will be encountered. Weighting agents are used to uphold the formation pressure or minimum excess pressure and at the same time reducing the pumpability of the cement and hence impelling the development of premature compressive strength. The Class G cement mechanical properties were measured under the pressure of 2,610 psi, the temperature of 212 °F (6). The result depicts that the increment in curing temperature increases compressive strength of the cement. Figure 2 represents that for different wellbore angles, the maximum casing von Mises stress occurs between the cement channel angle of 80 and 120° (7). As the well deepens, there is an increment in ECD due to compression because of heightened hydrostatic head. Elevation in temperature results in a decrement in ECD due to thermal expansion.

Conclusions

According to a survey in HPHT Summit, (figure 4)cement design and formation has 12% HPHT technology gap which requires immense consideration. In these hostile conditions minute variations in temperature and pressure can have a large repercussion on entire well production system. Cementing being a very crucial element should be carried extreme awareness and proper diagnosis and simulation should be carried out before executing the cementing operation. The alteration in cements rheological properties due to HPHT environment should also be taken into consideration. Strength retrogression o cement can be controlled using by using Silica flour or silica sand. Thickening time can be controlled by blending adequate amount of retarders into the cement system. Excess of retarders leads to long wait on cement which in high pressure wells might lead to the influx of gas into the cement, it must be prevented. Mud removal is an imperative process for strong cement bond and proper cement placement; it is to be outlined properly ahead of implementation. High Pressure conditions leads to development of immense stress on the cement and casing which should be balanced by providing sufficient hydrostatic pressure.

Capital being an imperative feature for implementation of any system so the economic aspect of this system should be evaluated. For a production system to triumph the cost in every sector of well establishment is very important. So before any operation in HPHT environment proper cost assessment is vital. In case on cementing the various additives and technologies should be properly analyzed before implementation so as to avoid any redundant losses for cost diminution of the production entire system.

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Table 1: Minimum flow rates required to achieve complete flow around the annulus. Calculated for Bingham Plastic fluid

Stand Off (%)	Minimum Flow Rate (bbl/min)	
	Laminar Flow Around the Annulus	Mixed-flow Regime (Laminar & Turbulent) Around the Annulus
80	2	2
60	11	11
40	38	19
20	> 100	33

Figure 1: Classification of HPHT

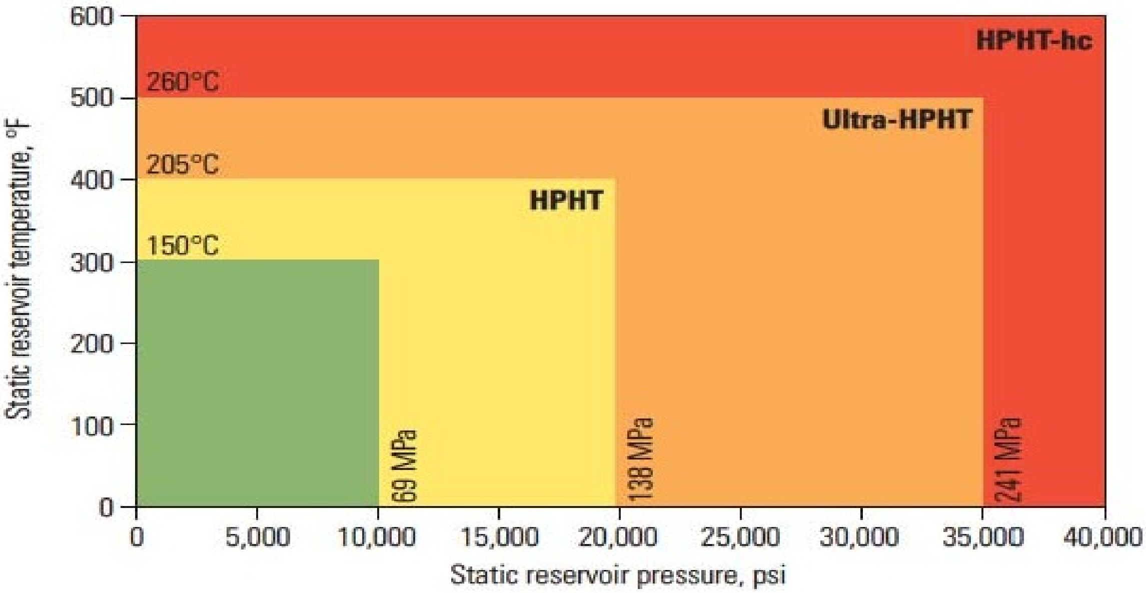

Figure 2: the Effects of Cement Channel Angle and Wellbore Angle on Casing von Mises Stress

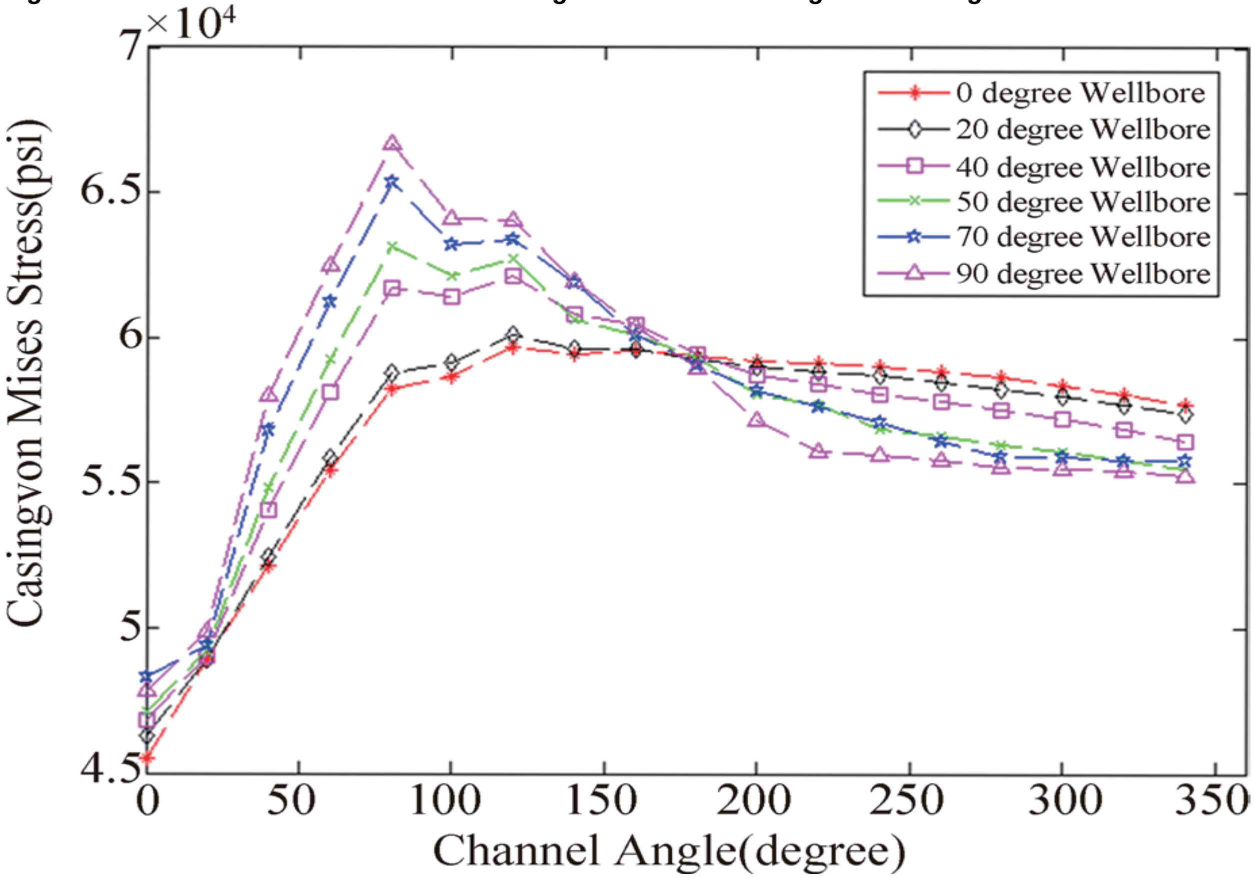

Figure 3: Cracks in cement sheath due to HPHT conditions

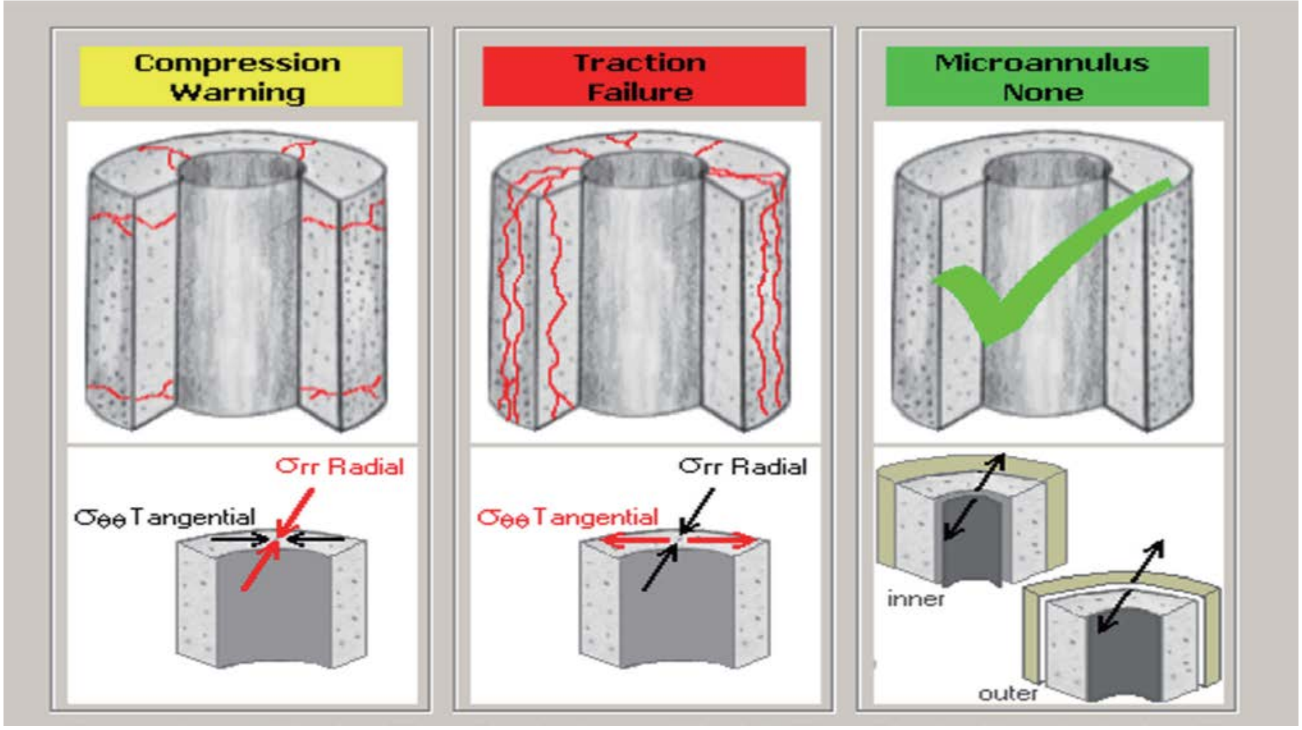

Figure 4: HPHT technology gap