Effects of Thickening Time on the Application of Cement Slurry for High Pressure /High Temperature Drilling.

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Abstract

High pressure/High temperature operations remain a high challenge for the industry as deeper reservoir operations are pursued around the globe. In addition to deeper depths, an increasing number of wells are still being drilled and completed in much more hostile down-hole environments. Though high pressure/high temperature wells have always presented drilling challenges, their operations continued to remain very high as the vast reserves of hydrocarbon promised to bridge the gap between demand and supply for energy. The world's energy demand is rising and favorable economics have allowed oil companies to continue to prospect and drill in these more challenging areas that are actually prone to high pressures / high temperatures than ever before.

This paper addresses some of the challenges relative to cement slurry designs that requires careful engineering practices and needs proper cementing operations and optimization. It presents a simulation study using retarder sensitivity to select thickening time, optimize cement properties and also predict the subsequent HPHT sensitivity on cement slurries. The results showed that the modified Magnesium Oxide(mixture of water-glass and magnesium oxide) was best for slurry design for high pressure/high temperature which gave tighter matrix of cement paste. The application of retarder reduced the thickening time but the Water-Glass Solution improved the Magnesium Oxide cement thickening time, indicating that thickening time was dependent on time of exposure and on temperature. The rheological properties of the slurry showed that at HPHT, there were decreases in plastic viscosity, gel strength and the yield point. The study therefore determined one of the best cement slurry design practices for different down-hole applications in HPHT wells.

KEY WORDS : Cement slurry, Thickening Time, Modified magnium Oxide,High temperature/High Pressure

Introduction

High pressure/High temperature(HPHT) wells are wells where the bottom-hole temperature is exceeding 300^{o}F (148 ^{o}C) with the maximum pore pressure in the formation in excess of 0.80psi/ft (180 bar /m) or requirements for pressure control equipment exceeding 10,000 psi (689.47 bar). In practice, the downhole equipment that is considered for HPHT wells are generally designed for pressure differentials between 10 and 15 psi. However the principles of well construction in HPHT area are not significantly different from those used in less demanding wells, but the challenges remain because of the conditions that limit the range of suitable materials and affect equipment performance. The margins for error are small and the potential consequences of failure are great. Despite the challenges, interests in these wells have remained high and number of HPHT wells has grown steadily. These challenges need to be addressed during design and planning

High pressure/High temperature wells present special cement system challenges. The physical and chemical behavior of cement slurries changes significantly at elevated pressures and temperatures and are associated with, Temperature regimes ,Pressure regimes, Narrow margin between fracture and pore pressures, Wellbore geometry, Control of flow after cementing and also the chemical behavior of mud and its additives. It is very important to evaluate and predict accurately the correct temperature, pressure and formation regimes in order to best simulate and test the cement slurries before executing the cement operation to be able to achieve best results. This is because both the cement and the cement additives are very sensitive to changes in temperature. Hence sensitivity and stability tests should always be performed before cementing in a high temperature well.

Background Information

Small changes in testing temperature can make substantial changes to the slurry properties and thickening time in particular. Increased temperature can escalate the hydration of the cement and therefore decreases the thickening time. Other factors such as rheology, fluid loss, stability and compressive strength also vary greatly with temperature. It is important therefore to obtain the most accurate temperature data from the well. Some of these data are normally in the form of maximum logged temperature at a maximum log depth, details of the circulation and static periods with the temperature data, so that analyses can be performed to estimate the Bottom Hole Static Temperature from which the Bottom Hole Circulating Temperature will be derived. Bottom hole static temperature is the natural temperature of the formation under static conditions. It is commonly estimated from wire-line logs. The temperature can also be logged at different time intervals after different circulation times and by extrapolation techniques calculated back to static bottom hole temperature. The bottom hole circulating temperature is a qualified guess of temperature or can be determined approximately by API tables based solely on well depth and temperature gradient. However, the evolution of bottom hole circulating temperature is also influenced by flow rate, formation properties, circulating time, inlet temperature, fluid rheology and well inclination.

Cement Slurry Sensitivity and Properties

Small difference in the amount of retarder can result in dramatic changes in thickening time. Cement slurry properties are thus very sensitive to small changes in retarder concentration at very high temperatures. The uncertainty in temperature prediction further influences the sensitivity of designs. Most importantly thickening time and compressive strength development can be significantly affected. Sensitivity analysis must therefore be carried out on the cement slurry to determine whether the proposed cement slurry is acceptable. The selection of correct retarder is very important to avoid over-retardation. A uniform cement slurry with the correct density is best obtained by using a batch mixed. However, utilizing batch mixing requires close monitoring of the mixing energy to be able to simulate the same conditions in the laboratory. Batch control and the properties of the cement itself are very dependent on quality of slurry achieved. The cement can vary over time in storage and transportation with humidity. it is important therefore, that in laboratory test, the same cement as being used in the field is tested because all cements respond differently with additives.

Effect of Gas Migration on Cement Slurry Design

An improved development in high pressure/high temperature wells was the control of flow after cementing because without proper slurry design, gas can migrate and flow through the cement matrix during the waiting on cement time. Failure to prevent gas migration can cause problems such as high annular pressure at surface, poor zonal isolation and loss of production. One of the primary objectives of cementing is to prevent fluid migration in the annulus and achieve proper zonal isolation therefore effort must then be taken to obtain a good cement job by utilizing gas tight cement slurry. During the setting phase of the cement, the cement builds up gel strength and the mechanism that allows gas to invade the cement matrix is the gel strength development of the slurry as it changes from liquid to solid. The hydrostatic head of the cement column may thus be reduced down to that of the mix water. This may be too low to control the formation pore pressure and fluid or gas may enter into the cement, creating channels or contaminate the cement. One of the methods to prevent gas migration is the Right angle set cement slurry .The Right angle set cement have short transient period from the gel strength build-up until the cement is set. Right angel set cement slurries (RAS) can be defined as well dispersed systems that show no progressive gel tendency yet sets very rapidly because of rapid hydration kinetics. Such systems maintain a full hydrostatic load on the gas zone up to the commencement of sets, and develop a very low permeability matrix with sufficient speed to prevent gas intrusion.

Materials and Method

A modern re-circulation mixer was available for the cement mixing and the mix water was initially premixed for better control because of slurry sensitivity to retarder response. The slurry was batch mixed for uniform monitoring of the density in the laboratory which is very important for well control issues in the field. The slurry density was measured with a pressurized balance and recorded at the time the sample was mixed. The cement slurries were prepared in the laboratory according to API operational procedures. A 2-speed (4000 and 12000 RPM),

propeller-type mixer, high precision weighing balance, HPHT expansion cell for the expansion tests and HPHT Consistometer for consistency behavior and Autoclaves for permeability .
Different commercial pure MgO at 105-120^{o}C, Portland class G cement, Lignosulphate retarder and defoamers were used. The Coarse-grained magnesium carbonates were calcinated to obtain different particle sizes and reactivity of MgO. The MgO was further grinded,to achieve smaller specific areas and grain sizes. Different water-cement factors (0.45-0.55) were tested to determine the influence of density on the cement slurry. The separate portions were dissolved after one minute and properly stirred with an electric paddle. The prepared slurry was vacuumed to expel air bubbles before the start of the experiment. A part of the slurry was poured into six small cylindrical metal cells having dimensions 30 x 22mm, for permeability tests and into rectangular (5 x 5 x 5mm) moulds for mechanical strengths determination. The samples in the cells and moulds were cured in moisture of water medium in an autoclave for 7 days at different pressures and temperatures. The set cement under atmospheric conditions were then pressured in a hydraulic press until failure to test for compressive and shear bond strengths. Samples permeability were determined . Free-water test was conducted for each run to assess separation tendency by visually observing any distinct settling. The swelling behavior of MgO, pressure, temperature and thickening time were measured continuously under simulated downhole conditions on a Multi- Channel strip of paper and the values recorded. Different quantities of MgO,8,10 12, 14, 16,18,20, 22 and 24% by weight of cement were used to determine the optimum amount of the expanded agent needed for slurry design..

Slurry Thickening Time Determination

The HPHT Consistometer was used to determine the thickening time of the cement slurries under simulated downhole conditions. Cement was mixed and poured into the slurry cup assembly. The slurry cup was placed into the test vessel and the pressure was increased via an air-driven hydraulic pump. A temperature controller governed the internal heater which maintained the necessary temperature profile, while a magnetic drive mechanism rotated the slurry cup assembly at 150 rpm. A potentiometer controlled the output voltage, which was directly proportional to the amount of torque the cement exerted upon an API-approved paddle. A dual channel strip chart recorder registered the cement consistency and temperature as a function of time. The temperature and the consistency were digitally displayed. The thickening time test ended when the slurry reached a consistency of 100 Bc (Beardon consistency).

Results and Discussion

Table 1: Water-Glass on MgO-Cement Expansion and Cement Paste Properties.

Parameter	Without water-glass	With water -glass
Class G cement, (kg)	120	120
MgO swelling agent, % BWOC	15	15
Water/cement ratio (WCR)	0.50	0.50
Temperature, °C	120	120
Presure,(MPa)	100	100
End of Expansion, (inches)	1460	1647
Beginning of Expansion(inches)	950	1250
Expansion values,(%)	3.45	4.80
Static temperature,(°C)	120	120
static pressure, (MPa)	24	24
Duration, (days)	7	7
Compressive strength, (MPa)	25.67	39.27
Shear strength, (MPa)	12.25	10.25

Table-2. The Effect of Water- Glass Mixture on thickening time : Conditions : Pressure =100 Mpa, Temperature =120^{0}C

Experiments.	H20.glass %	Bc	t30	t70	T/time(mins)
1	5	11	60	70	80
2	10	12	67	110	125
3	15	14	80	120	128
4	20	15	86	135	140
5	25	17	90	145	155
6	30	18	92	160	175
7	35	19	110	200	235
8	40	22	112	220	260
9	45	23	115	230	280
10	50	25	120	235	300
11	55	22	95	190	210
12	60	21	90	187	205
13	65	2	88	185	200
14	70	19	84	180	201
15	75	17	80	175	200

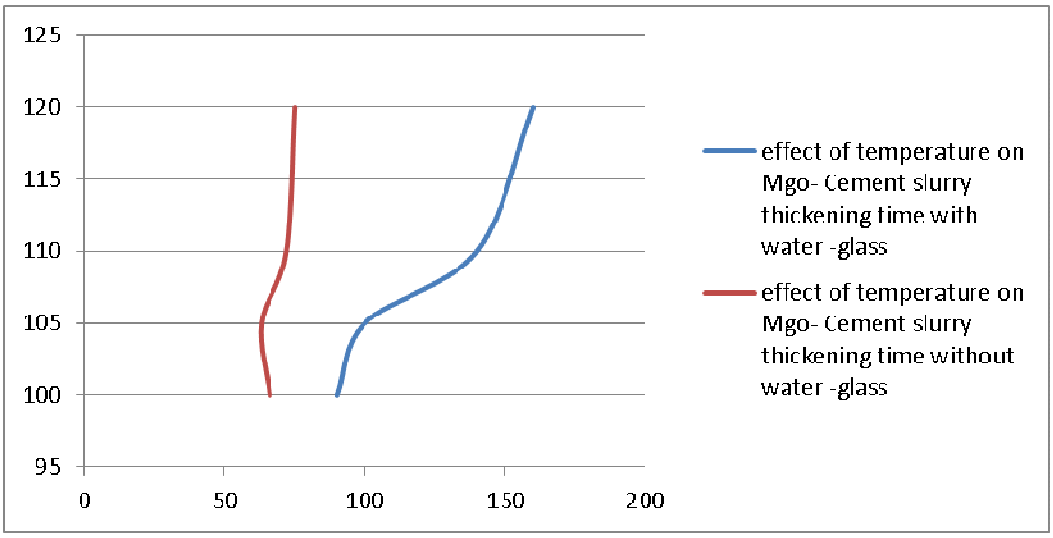

Figure 1: Effect of Temperature on Thickening time with water glass and without water glass.

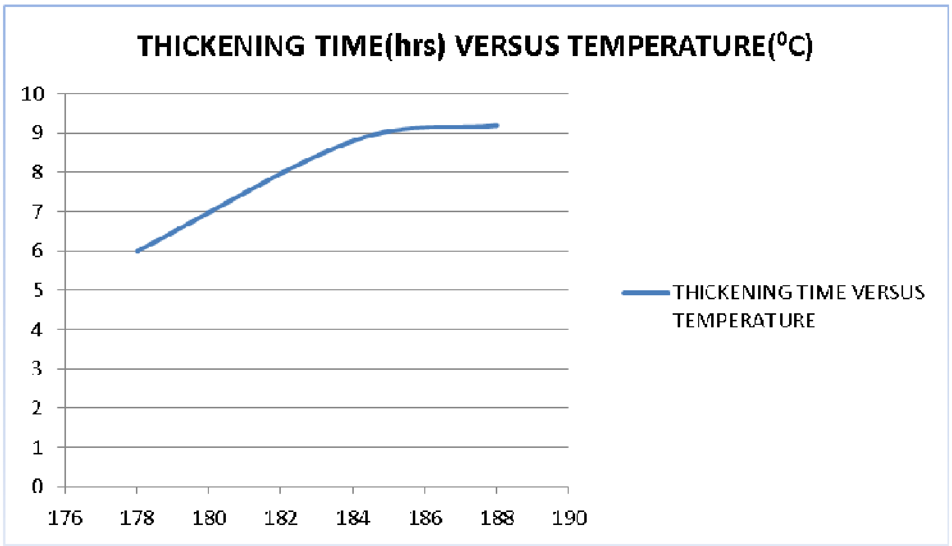

Figure-2.Thickening time for cement at different retarder temperature

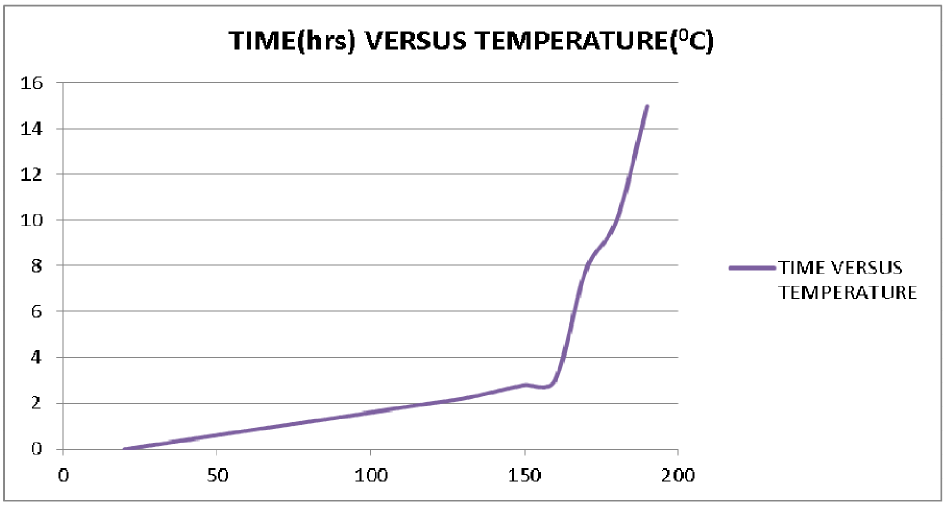

Figure-3 : Cement-Temperature Variation different Time of exposure.

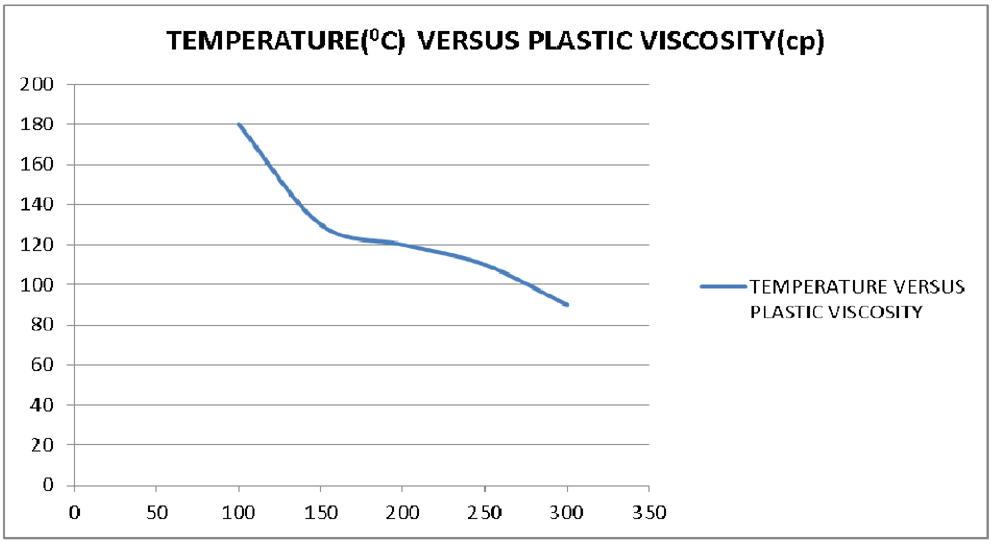

Figure-4. Effect of temperature on cement plastic viscosity

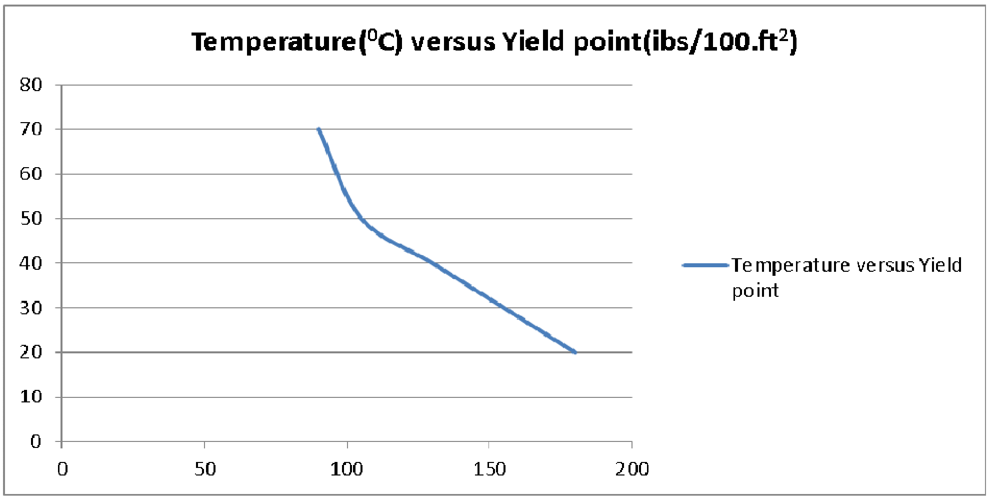

Figure-5. Effect of temperature on cement yield point

DISCUSSION

Figure-1, thickening time increase with increase in temperature independent water-glass. This consequently will affect the stability of the cement paste matrix and the solution of the expanding agent with its velocity. At laboratory conditions, the modified MgO-expansive cement was best suited for temperatures between 100 and 120°C. Slurry thickening for this ranges increased from 60 to 70 minutes without water-glass and corresponding from 90 to 170 minute, using water-glass solution.

The cement paste matrix stability depended on the properties of the cement, temperature and pressure. Effective matrix expansion was observed even under high hydrostatic pressure up to 120Mpa. MgO, during the design of cement, ended up in tighter matrix with permeability values less than 1μD (micro Darcy). Static aging the cement slurry resulted in excessive gelation and the effect was observed more in MgO slurry than with water-glass solution. Expansion lasted for about 10 hours though depended on the expanding product (MgO), which was based on the reactivity, gain sizes and size distributions. Shear strength value fell from 12.25 to 10.25 MPa; Permeability was as low as(0.59 to 0.37nm^2) though compressive strength increased,table-1 . Therefore, because expansion increases with increase in temperature leading to rapid increase in gel strength, high temperature stability products and additives are recommended in HPHT applications.

From table -2, 30-40 5% water-glass solution improved MgO-cement slurry thickening time by a factor of about 3, within the optimum initial consistency value range of 10 to 30 beardon consistency(Bc). Above a concentration of 50%, thickening time dropping below the 35% value and the time to achieve 30 Bc ,(t_{30}) was also reduced showing that 30 to 50% of water-glass concentration was beneficial for increasing thickening time. Figure-2, showed that application of retarder reduced the thickening time rate which was slightly constant at the range 184 to 190^{o}C of retarder temperature. Figure-3, showed that the setting temperature of cement depended on the time of exposure, Therefore a decrease in temperature leads to an increase in the plastic viscosity of cement and results in increase of the yield point ,figures 4 and 5.

Conclusion

Both micro silica and the modified MgO-expansive cement are capable of preventing gas mitigation at high pressure and high temperature provided the design parameters are met and proper operational procedures followed during cementation of a well. Wells in which cement sheaths are subjected to large changes in pressure and temperature are at very higher risks of experiencing zonal isolation failure leading to well control issues. Hence, successful isolation of reservoir fluids is critical to attain commercial production rates from HPHT wells. Predicting thickening times and pumping viscosities are always problems in HPHT wells. However, improvements in high temperature chemicals, cement testing and proper slurry design with an improved displacement modeling will actually have better results. Cement systems therefore should be simulated, pilot tested and developed in the laboratory at high pressure/high temperature and also adopted to meet the properties determined from the analysis.

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