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Durability and Rheological Evaluation of Cement Slurries from Atmospheric to High Thermal Condition

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Abstract: The Knowledge of the behaviour of cement slurries under elevated temperatures is necessary to understand properly cement rheology in moderate to deep-well cementing operations. The design of optimum cement slurry for oil well is highly challengeable for high temperature wells because slurry stability is a major requirement for successful oil well cementing the main objectives of cementing include, control abnormal pressure, zonal isolation, prevent from caving and wash out holes, support casing. For this purpose to understand rheological behaviour of cement slurry is essential for proper displacement and optimum placement at different temperature condition. Silica fume commonly available and cost-effective having sufficient quantity of amorphous substance to improvements in the physical and mechanical properties of cement slurry also a play very important role in strength development and increase rate of hydration. This paper describes to development of a cement slurry composition under laboratory condition to investigation the phenomena of optimum pump- ability through different concentration of silica fume from atmospheric condition to high thermal condition. Laboratory experiments showed that cement slurry is probably the more influenced by temperature; as temperature increased the changes occur in placing of cement slurry and the effect of high temperature decreasing plastic viscosity and yield point with the increasing temperature. The formulated cement slurry had advantages of low density, high strength, excellent rheology and high temperature tolerance, controlling the rheological behaviour of cement slurry can help to improve the relevant movement between particles, the stability and substitutability; according to the API standard.

Key words: Rheology, silica fume, low density, temperature

INTRODUCTION

OILWELL cementing process involves proper placing and pump-ability of cement slurry of class G cement, adding additives and water into a wellbore, for developing high stability and durability for long term integration of cement slurry (Saunders and Walker, 1954).

Cement slurry is pumped into the annular space between the borehole and a steel pipe, called a casing intended to produce a conduit from the reservoir to the surface.

Stable cement sets in place to support the casing in the hole, to isolate various formations from one another and to control fluid movement within the well (Backe *et al*., 1999). Typical cement slurry density ranges from 14 to 17 lb/gal. Certain conditions can be encountered during the well construction process for that necessitates to suitable slurry density for particular application of cements with much lower density. Lower density is required to limit hydrostatic pressure exerted on formations through which the wellbore passes in order to prevent from abnormal condition to the formation fracturing and absorb the well fluid. This phenomenon, named lost circulation, increases time to drill and complete the well and increases construction cost due to expensive remedial treatments. Most common sections of a well in which lost circulation occurs are the upper sections; surface casings and intermediate casings. Since formations covered by these casings are relatively close to the earth's surface, application temperatures for these low-density cements are relatively low (Saunders and Walker, 1954; Garcia-Gutierrez *et al*., 2005).

The Equivalent Circulating Density (ECD) is an effect that occurs when pumping of cement slurry or in-situ condition of the well. This critical well monitoring measurement is derived from a formula according to a series of variables, including mud weight, rheological properties of fluids or cement pumped down the well and the frictional pressure drop in the annulus, among other factors (Ugwu, 2009). Properly managing ECD is a critical challenge in the case of wells with a narrow window between the fracture gradient and the

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pore-pressuregradient; such pressure may cause to break the rock at a given depth, which may cause fluid losses to the formation. Pore-pressure gradient refers to the hydrostatic pressure required to maintain primary well control and prevent influxes from the formation. When encountering a narrowing window between these two gradients, persevering management of the ECD is required to prevent both fluid losses into the formation (Farris, 1941).

The rheological properties of cement slurry are very complex and critical to the field performance of setting cement in terms of flow and workability (Saunders and Walker, 1954). The Rheology of cement slurry is strongly influenced by mixing process and material selection, including water-to-cement ratio and temperature (Garcia-Gutierrez *et al*., 2005). Physical measurement of rheological properties of cement slurries with additives evolutions are important tools in cementing jobs to understand properly placing cement slurry without accidents (Calvert and Griffin, 1998). Because during the well life, the chances of cement sheath is collapse when uncertainty take place during different well treatment operations e.g. well stimulation and pressure testing; communication test and cement squeeze jobs. These events generate thermal and cyclic stresses and cause to change in well profile (Nygaard, 2010).

The rheological theory of cement slurries is closeness between the cement and water molecules. Physical properties of hardened cement and concrete depend on large extent to the chemical reactions and mixing of water change its physical condition (Allan and Kukacka, 1994). Rheological study is very useful for petroleum industry to predict the cement slurry stability for zonal isolation, where cements slurry pumped down many feet to the earth for seal vertical limit of casing and formation, for that purpose cement must sustain in pump-able for several hours without any effects during placing at high temperature and pressure. Therefore, chemical additives are used to stable all mechanical properties for proper design cement slurry (Nygaard, 2010; Allan and Kukacka, 1994).

A description of flow rate (shear rate) and pressure (shear stress) is related to flow properties of fluid movement (Kwelle and Mofunlewi, 2008). Most of studies have resulted in the development of several mathematical models which describe the relationship between shear stress and shear rate. Mostly three models are used for above relationship , the Newtonian, Bingham Plastic and Power Law models. All most fluids and cement slurries for drilling cementing are non-newtonian fluids and have been treated using a bingham plastic or power law type model (Bannister, 1980).

Temperature effect on non-newtonian behaviour fluids: The durability and firmness of cement slurry will reduce with increase in temperature for the level above a critical temperature. The complex condition will be appeared at approximately temperature above 2200-2400 F (Fawzi, 2012).

The potential and toughness of oil well cement can be considered to achieve confine seal in prevailing reservoir condition. Currently a fact that the strength and durability of the cement slurry reduce with increasing temperature and optimum value was brought to the great attention of the industry (Kwelle and Mofunlewi, 2008). When the design of high strength cements slurry to oil wells the planner requires the temperature profile of the well (Fawzi, 2012; Al-Yami *et al*., 2007). The Bottom Hole Static Temperature (BHST) is used for measuring the results on the rate of cement strength development. The Bttom Hle Circulating Tmperature (BHCT) is used to determine the cementing properties. The following parameters should be evaluated for designing cement slurry (Bannister, 1980; Ravi and Sutton, 1990):

- Ement circulating time and rate
- Well formation temperature
- Geothermal temperature
- Hole dimensions and deviation
- Depth and flow current

The influence of the temperature to cement slurry that changes during drilling cementing. As the temperature increases, the hydration of slurry and transition condition of the cement takes place quickly. In deep wells for cementing require more additives, because of high temperature conditions, to keep the cement slurry pump-able for long time and placement of the slurry in the annulus. If the temperature is not properly calculated, then task will not achieve for zone isolation (Ugwu, 2008; Ravi and Sutton, 1990).

Thermal stress may cause changing cement appearance as shrinkage, packing of cement slurry compact and expands usually, variation of temperature. If the reduction in cement may cause gas migration and increase or decrease the length of slurry increase the cement's tensile strength will break up the slurry sheath. A uniformly pressure applied to the cement slurry it will compress radically this stress cause to crack the cement. A final value tensile strength of broken section reach at critical point where the appropriate flow of stress in cement may cause a channel through liquid can flow (Holloway and Rudd, 2013). Impact of temperature to cement deformations can occur at down hole as a result of thermal stresses, during cement hydration, wellbore treatments, steam injection, stimulation and perforation (Bannister, 1980). Loss of strength in cement sheath integrity, due to stresses brought on by temperature and pressure cycling that occur throughout the completion and production process. These problems could be annular pressure build up or losing hydrocarbons through a micro-annulus or small cracks in the cement sheath (Al-Yami *et al*., 2007). For an oil well cementing should to maintained at optimum rate with economically, to achieve complete zonal isolation; with combination of additives to combat at wide ranges of temperature to with stand cement slurry at any environment (Al-Dossary *et al*., 2011). Class G oil well cement is used as a basic well cement and, mixed with additives, to covers a wide range of well depths and temperatures (Vidick and Schlumberger, 1990).

Silica fumes use as a cement slurry additive to reduce the density of cement and increase slurry performance and control hydrostatic pressure during drilling cementing. This mixture used as primary source for a hydraulic seal in the well bore as secondary application is used for remedial operations including depleted zone closing, splits and leaks repair (Siddique and Khan, 2011). The functions of silica fume as additive to provide effective seal to a formation of oil well. It is also responsible for prevent gas migration and highly effective to enhanced flow for easier, proper placement and decrease permeability for better control of weak zones (Shadizadeh *et al*., 2010).

It helps to improve the integrity of primary cementing in oil and gas wells. It prevents loss circulation resulting from the failure of weak zones more positive step should be taken to reduce the chances of primary cementing failure (Vidick and Schlumberger, 1990).

Silica Fume (SF) use as extender to reduce the quantity of cement and required amount to produce effective output during cementing operation; ultimately result of a huge economy (Siddique and Khan, 2011).

Several types of extenders are used as the additives, such as pozzolan bentonite, foam, microspheres and beads are used as Lightweight cement slurry (Al-Suwaidi *et al*., 2008). Silica can be used as an extender to require ample quantity of water i.e. 0.532 gallons water to be added in the slurry (Mueller and Dillenbeck, 1991). Silica fume is frequently referred to by other names such as, condensed silica, micro silica and volatilized silica. Commonly silica fume is available and cost-effective, due to presence of amorphous silica is composed of 58- 95% Sio2 the particles are very small (95% SiO_2 of less than 1 μm) and thus perform as micro filler set in cement structure and pozzolanic reaction with the free lime in solid response to natural temperature so thus combination play significant improvements in the physical and mechanical properties with Portland cements (Siddique and Khan, 2011).

SF mixes into concrete start react chemically to form additional interaction to the binder that called calcium hydrate silicate that gives more stiffness (Al-Dossary *et al*., 2011).

The hardened cement-micro silica provide better bond strength and reduced permeability, improved durability and reduced its strength retrogression (Shahriar, 2011; Hodne *et al*., 2007). Particle size of silica fume is very small and thus can result filler cake between the cement particles and mitigate the entry of fluid in a narrow path in finally decrease permeability of the cement slurry and enhanced Water Cement Ratio (WCR) which allow to increase the performance of cement slurry (Frittella *et al*., 2009).

Source of materials: Silica fume is obtained from WR Grace Malaysia is a global specialty chemicals and cement materials company.

Standard of well cement test: American Petroleum Institute (API) has presented “Recommended practice for testing well cements”, API recommended practice 10B (API, 2005). The API standard has been followed during cement test.

Experimental Procedure: Cement slurry was prepared according to API RP-10B (API, 2005). The mixing method strongly influences on slurry and set cement properties. Cement additives can be dry blended or wet blended in cement slurry can be used.

Electronic balance: To dry the cement weight, distilled water and additives in order to prepare of cement slurry which meets API standards.API RP-10-B (API, 2005).

Electronic standard 7000 Constant speed mixer: Measure cement and additive prepared in lab using the standard 7000 Constant Speed Mixers provide all the necessary functions to mix cement slurries according to API and ISO specifications and recommended practices. Normally, 600 mL slurry was prepared. Slurry was mixes for 70 sec. The mixer is operated at 4000 RPM during first 15 sec which the dry cement is added to water this is followed by 55 sec at that condition set mixer at 12000 RPM followed at 70 sec.

Rheology Measurement at room temperature: The prepared 350 mL cement slurry is placed into stainless steel cup in the Fann viscometer model 35 it is use to measuring gel strength and changing rotors and torsion springs. it operate at six speeds ranging from 3 rpm to 600 rpm ;at every dial reading note the value for measuring cement properties.

Rheology measurement at high temperature: The prepared cement slurry is placed into sample cup i.e.Bob1 having capacity of cement is 42 mL slurry different Bob having different capacity for cement slurry's high performance advance pressurized viscometer model 1100 with ORCADA software is used for measuring rheological properties of cement slurry's. According to API recommended practice 10B viscometer is used for oil well cement testing materials having wide range of temperatures. Where the viscosity is determined, the dial readings at various rotational speeds were giving the slurry behaviour at different condition. In this study the temperature was set at 60°C, 90°C and 123°C the viscometer heat bath help to simulate down hole condition; after heat conditioning the viscometer start to take the dial reading at different RPMs to measuring rheological parameter at down hole condition.

RESULT AND DISCUSSION

Rheological properties are highly influenced on temperature the rate and amount of heat evolution may be attributed to the performance of its chemical and physical effects on slurry formulation, from data Table 1. A measuring physical properties at ambient temperature the plastic viscosity and yield point increasing with increasing concentration of silica fume. To using Fann Viscometer to measuring rheological properties at 21% SF given optimum reading but with concentration values is going to improve at atmospheric temperature condition; so 21% reading is more imperative to other percentage of using silica fume at that level slurry have sufficient strength and durability to sustain down hole thermal condition and placing is smoothly without delaying time.

The temperature reading at 600C by using HPHT Viscometer in this condition the rheological properties change by increasing temperature with concentration of silica fume, this quick change of stress and strain. The rheological values directly measured after slurry mixing (Table 2) plastic viscosity and yield points are measured by HPHT viscometer at 60°C. The temperature increase the PV and YP going to decrease.

All measured rheological properties showed lower values of plastic and yield point are beneficial to maintained low Equalizing Circulating Density (ECD).

Table 1: Experimental result

Cement	SF (%)	PV (cP)	YP (lb/100ft^2)	Temperature (°C)
100	15	11	6	23
100	17	14	7	23
100	21	17	8.8	23

Table 2: Experimental result

Cement	SF (%)	PV (cP)	YP (lb/100ft^2)	Temperature (°C)
100	15	9	4	60
100	17	11	5.5	60
100	21	15	6	60

Table 3: Experimental results

Cement	SF (%)	PV (cP)	YP (lb/100ft^2)	Temperature (°C)
100	15	7	3	90
100	17	9	3.5	90
100	21	12	4.2	90

Table 4: Experimental results

Cement	SF (%)	PV (cP)	YP (lb/100ft^2)	Temperature (°C)
100	15	1.8	1	123
100	17	2.2	1.5	123
100	21	4.1	3.2	123

Cement is probably the one influenced most by changes in temperature, as temperature increased the changes in cement setting take place at greater rate due to effects of temperature, as changes in result of rheological performance of slurry designed to difference in measured reading may effect to the efficiency of mud removal as well as the friction pressure while placing the cement slurry.

The temperature change from 60-90°C the rapidly change is found in PV and YP readings as mentioned in Table 3. At high temperature condition the larger change in measured data, in this condition the cement slurry is quickly become harden and large change came in rheological measured values, so at higher temperature additives are required to keep cement slurry pump able for sufficient time to allow placement of slurry in the annulus at high temperature condition without additives cement slurry is not suitable for pump-ability.

Temperature is highly influenced to the formulation of cement slurry in above 120°C condition shown (Table 4) temperature and concentration may change the values with Effect of high temperature for plastic viscosity and yield point were found to decrease with the increase temperature; both parameters are not dependent on slurry composition but by increasing concentration of SF at 21% improving rheogical properties to maintained low ECD.

CONCLUSIONS

- Rheological behaviour of cement slurry is essential for proper displacement at high temperature condition
- Silica fume use as a low density and cost effective additive for deep environment

- Temperature is effect on performance of cement slurry as it is increase plastic viscosity and yield point decrease
- Silica fume concentration is increase with improving rheological properties at high temperature

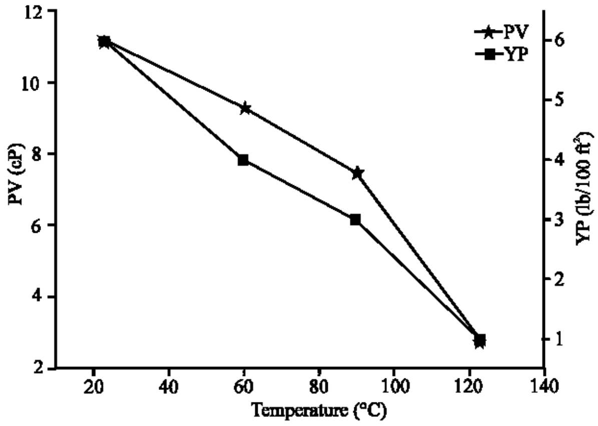

Fig. 1: 15% SF at different temperature ranges

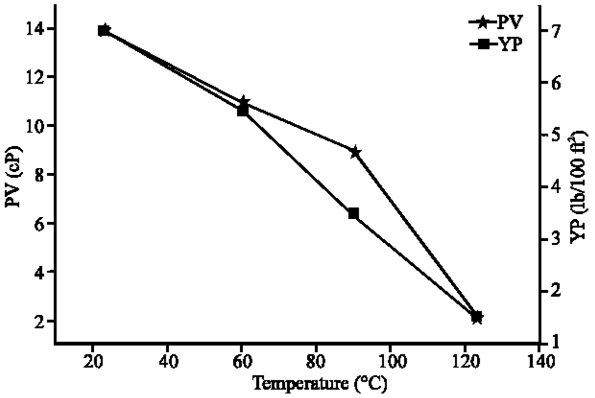

Fig. 2: 17% SF at different temperature ranges

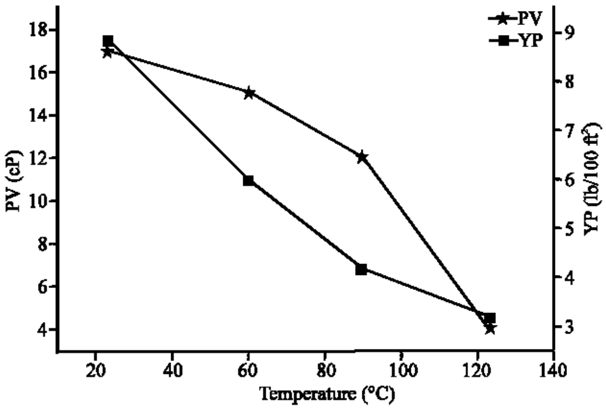

Fig. 3: 21% SF at different temperature ranges

APPENDIX.A

API = American petroleum industry
BHCT = Bottom hole circulating temperature
BHST = Bottom hole static temperature
°C = Degree centigrade
cP = Centipoises
ECD = Equivalent circulating density
°F = Degree Fahrenheit
lb = Pound
mL = Milliliter
µm = Micro meter
PV = Plastic viscosity
rpm = Revolution per minute
SF = Silica fume
Sio_2 = Silicon dioxide
WCR = Water cement ratio
YP = Yield point (in lb/100ft^2)

APPENDIX.B

The following Fig. (1-3) are perpared at SF-15, 17 and 21% on atmospheric condition to above 120°C temperature condition to easily differentiate the effect of temperature on rheological properties.

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