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Research Article

Investigating Rheological Properties of High Performance Cement System for Oil Wells

Khalil Rehman Memon, Muhannad Talib Shuker,
Saleem Qadir Tunio, Arshad Ahmed Lashari and Ghulam Abbass
Universiti Teknologi PETRONAS, Malaysia

Abstract: The main purpose of designing cement slurry for extreme and deep environment (HPHT wells) is to develop high performance cement system in well bore to achieve zonal isolation. The primary objective of cement slurry is to improve rheological properties and displacement efficiency of cement system. Oil well slurries depend on its homogeneity of additive concentrations, quality and quantity to contribute the placement and success of a well drilling cementing operation. This research study is focused on the laboratory study of the High Performance Cement System (HPCS). This investigation of cement slurry was prepared with Silica Fume (SF) and excess amount of water to decrease the slurry density in order to observe the rheological properties above 120C at different concentration of SF. Results indicates that the designed cement rheological properties are directly influenced by the shear rate and shear stress on the pump-ability of the cement with the increase of the SF concentration for the rheological improvement.

Keywords: Cement additives, high performance cement system, rheology, silicafume

INTRODUCTION

During a well cementing operation purpose should be achieve zonal isolation (Nediljka *et al*., 1994). That belongs to the slurry design, to ensure the best quality of cementing especially at high temperature environment such a HPCS Silica Fume (SF) use as a cement slurry additive to reduce the density of cement (Siddique and Khan, 2011).

SF 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 (Nediljka *et al*., 1994). The function of SF is allows a well to reach full production potential besides producing a blocking effect in the oil well. It is also responsible to prevent gas migration and highly effective for proper placement and decrease permeability for better control of weak zones (Siddique and Khan, 2011).

SF helps to improve the integrity of primary cementing in oil and gas wells and prevents loss circulation resulting from the failure of weak zones (Shadizadeh *et al*., 2010). SF use as extender to reduce the quantity of cement and produce effective output during cementing operation; ultimately result of a greater economy (Mueller *et al*., 1991). Different types of extenders are used as the additives, such as bentonite, pozzolan; microspheres and foam are use in Light weight cement slurry (Shadizadeh *et al*., 2010). Silica can be used as an extender allows additional 0.532gallonsof water will be added to the slurry per pound of SF (4.4 cc water/g) (Mueller*et al*.,1991). SF is frequently referred to by other names such as, condensed silica, micro silica and volatilized silica. Commonly SF available and cost-effective, due to presence of amorphous silica composed of 58 to 95% Sio_2 the particles are very fine (95% SiO_2 of less than 1 μm) and thus act as micro filler set in cement. Micro-structure and pozzolanicre action with the free lime in Solid response to natural temperature so thus substance imparts significant improvements in the physical and mechanical properties with Portland cements (Siddique and Khan, 2011). It begin concretereact chemically to form additional interaction to binder that called calcium hydrate silicate that gives more stiffness (Mueller *et al*.,1991).

Comparison result analysis to silica fume and fly as hrecommends that silica fume is highly control effect towards gas migration as fly ash, if the static gel strength of cement slurry rapidly increases from 100 to 500 lb/l00 ft^2 that often cement transition taken place rapidly, so it is seen as desirable and favorable to control gas migration. In tight gas, cement, it is recommended that a transition period is less than 30 min. A key element in the design with high-purity amorphous silica cement, which produces and controls the tight gas (Grinrodand Vassoy, 1988).

Corresponding Author: Khalil Rehman Memon, Universiti Teknologi PETRONAS, Malaysia

Compared the performance of silica fume as early compressive strength between silica fume and fly ash additives. Compressive strength of concrete containing SF was proved higher strength; as increase the concentration of silica fume it improves stress resistance in the early development and reduces the free water (Mehta and Gjorve, 1982).

The mixing of silica fume into cement several optimum conditions are noticed (Shadizadeh *et al*., 2010):

- It is nature to consume more water to prove as s function of extender and substitute for lightweight cements.
- High water adsorption to increased pozzolanic reactivity promotes enhanced compressive strengths.
- The purity and solubility of the material makes it suitable for combating strength retrogression in cements at temperatures above 230°F (110 °C).

The hardened cement-micro silica provide better bonds strength and reduced permeability, improved durability and reduced its strength retrogression. Silica (Mehta and Gjorve, 1982).

SF particles in the filter cake decrease the loss of fluid in high permeable formation. Particle size of silica fume is very small (less than 0.5 microns) and thus can result filler cake between the cement particles and mitigate the entry of a narrow path of fluids, which finally decrease permeability of the cement slurry and enhanced Water Cement Ratio (WCR).This improves the permeability which increasing the performance of cement slurry (Shahriar and Nehdi,2012).

This study is related with various concentration of silica fume for preparing 600 mL cement slurry for high performance cementing operation.

LITERATURE REVIEW

Rheological properties of cement slurry play important role to determine the workability of slurry, fineness (Shahriar and Nehdi, 2012). The mixing process is very important parameters for rheological behavior of cement slurry, the criteria of designing slurry depends on formulation, density, plastic viscosity, shears tress, yield point and gel strength for enhance durability and toughness for cement slurry (Shahriar and Nehdi, 2011) Cement grout is used for sealing geothermal wells for is olatezones during drilling cementing operation. Rheological behavior of cement slurry is important for the drilling process; it will be optimum to predict correctly about slurry placement (Bannister, 1980). Cement slurry is concentrated suspensions of small and heavy particles so rheological measurements are suffering to the disruption of cement operation (Miranda *et al*., 2010).

Rheology of Oil Well Cement (OWC) should be considered when it applied on the originally and primarily casing cementing. Therefore, fundamental knowledge of OWC slurry rheology is necessary to evaluate the ability to mix and pump grout, remove mud and slurry placement optimization and to predict the effect of temperature on the slurry pit (Shahriar and Nehd, 2011). Incomplete mud removal can result in poor cement bonding, zone communication and ineffective stimulation treatment (Bannister, 1980).

A rheology is study related to the flow of fluids and deformation of solids under stress and strain. In shear flows, fictitious parallel layers of liquid past each other in response to a shear stress to produce a velocity gradient, in term of to shear rate, which is equivalent to the rate of increase of shear strain (Guillot, 2006).

Rheology of cement slurry is complex which has the appearance and interactions between the additives (Banfill and Kitching, 1991). The chemical composition of cement, particle distribution, test in g methods, size shape, W/C ratio, mixing time and temperature (Frittella *et al*., 2009). Cement slurry is viscous plastic materials that exhibit yield stress and tension below the yield stress ultimately slurry behaves as a rigid and solid (Mirza *et al*., 2002).

Bingham plastic and power-law model is widely used to describe the rheological properties of cement slurry measurements. Frittella *et al*. (2009) that can be determined the properties of cement flow i.e., plastic is cosity, yield point, friction characteristics and gel strength (Harris and Service,1991).

Concentration and form of so lid particles has a significant impact on the rheological properties of the OWC slurry to yield stress and plastic viscosity of cement paste usually increase as the cement becomes finer and increases the stability of slurry (Boukhelifa *et al*., 2004).

Equivalent Circulating Density (ECD) is important factor to understand the flow behavior, flow rate, annular velocity and differential pressure; for that purpose number of computer simulation software is available to predict the ECD. The displacement efficiency achieving the maximum mud displacement. A standoff value of the percentage of casing centralization in the wellbore, job operation time for proper thickening and Reynolds numbers base on laboratory methods to measuring rheological properties to understand flow behaviors (Labibzadeh *et al*., 2010).

These parameters will be evaluating the cement pump-ability and cement grout with strength correspond to behind the casing to increase efficiency and displacement. High flow rate may cause fracture the formation there should be investigated the current effective equivalent cement density (Hodne, 2007).

Maximum drilling cement or colloids or emulsions as a non-Newtonian liquids in plastic or behave in such circumstances is that the gel analysis function of the intermolecular forces. The initial 10-sec and 10-min gel strength measurements gelation indications of the gel that will occur after the flow was stopped and the cement remain static (Teodoriu *et al*., 2008) When circulating drilling mud and fluids during cementing operations abnormal results in bottom hole, which may cause challenge to the integrity and safety. Soliman *et al*. (2008) To maintain hydrostatic pressure of the fluid column below the fracture gradient but above the pore pressure and designing cement slurry to improve efficiency and displacement without causing any form of collapse to the formation for this condition to focusing on ECD and rheological properties (Stephen and Samuel, 2008).

DESIGN OF CEMENNT SLURRY

Oil well cement compositions are typically used for sealing subterranean zone at High Temperature and High Pressure (HTHP) such as the annular space in oil well between the surrounding formation and casing (Shahriar and Nehdi, 2011).

Slurry blend consist of cement class G with additives and water. The productivity of an oil well is significantly affected by the quality of cementing between the well casing and the surrounding strata (Teodoriu *et al*., 2008). Cement slurry flow ability and stability are major requirements for successful oil well cementing (Kulakofsky and Vargo, 2005) because the cement is the most active component of the slurry and usually has the greatest unit cost. Its selection and proper use are important in obtaining an effective, for long term integrity of the well (Williams *et al*., 1999).

Portland cements can be used for cementing around the casing of oil and gas wells having deeper depth wells usually require special oil well cements (Teodoriu *et al*., 2008). There are currently eight classes of API Portland cement designated A through H that are arranged according to the depths to which they are placed at pressure and temperature to which they are exposed (Harris and Service, 1991). In oil well drilling industry class G and H type well cement are well known for deep wells; because enoaddition other than calcium sulfate and water both shall be inter-ground or blended to the clinker during manufacturing of these oil well cement. Therefore with addition of ample quantity of additives such as retarders and dispersants can change their setting time to the cover wide range of well depths, pressure and temperature (Kulakofsky and Vargo, 2005).

In this study silica fume used as extender, as it is function to reducing slurry density also light slurry is used to control hydrostatic pressure during cementing operation. This slurry has greater strength to use in weak and unconsolidated formation.

Mixing energy: The cement slurry is a mixture of cement, water and additives (Stephen and Samuel, 2008). The mixing process is exothermic and the energy required to this called is mixing energy.

The mixing energy equation is given as Williams *et al*. (1999):

$$E/M = k\omega^2 t/V$$

where,

E = Mixing energy (KJ)
M = Mass of slurry (kg)
K = $6.1*10^{-8} m^5/s$ (constant found experimentally)
ω = Rotational speed (radians/s)
t = Mixing time (sec)
V = Slurry volume (m^3)

The prepared cement slurry was dispatch to Viscometer for measuring rheological properties.

SOURCE OF MATERIALS

Silica fume is obtained from WR Grace Malaysia which a global specialty in chemicals and cement materials.

Standard of well cement test: American Petroleum Institute (API) has presented "Recommended practice for testing well cements (American Petroleum Institute, 2005). The standard has been followed which is used worldwide. These tests were advise and very helpful to drilling personnel for determine a given cement composition will be feasible for well conditions according to API-10B (American Petroleum Institute, 2005)

Experimental procedure: Cement slurry was prepared according to API-10B (American Petroleum Institute, 2005). The mixing method strongly influences on slurry and set cement properties. Cement additives can be wet blended in cement slurry. When additives are mixed in water prior into cement, it is called wet blending.

Electronic balance: This is used for weighting dry cement, distilled water and additives, to use for preparation of cement slurry.

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 of slurry were 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 35 sec at that condition set mixer at 12000 RPM followed at 70 sec.

Rheology measurement: 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 behavior at different condition. In this study the temperature was set at above 120°C the viscometer heat bath help to simulate down whole condition. After heat conditioning the viscometer start to take the dial reading at different RPMs to measuring rheological parameter at down whole condition.

RESULTS AND DISCUSSION

The rheological property of cement slurry formulation Table 1A, Fig. 1 shows that change in shear rate from one condition to another condition, shear stress decrease with plastic viscosity decrease. It is highly effected on the performance of slurry and water cement ratio also considerable for using the density of 13 PPG cement slurry with 15% SF to a great extent improve its strength and durability to compacted slurry reduce permeability and binding to the slurry but not useful for achieving appropriate results of rheological properties due to slurry formulation and temperature.

As concentration increase with plastic viscosity and yield point increase with using 17% silica fume for improve little bit rheological property's shows in cement slurry formulation Table 1B, Fig. 2 as a fact to increase its concentration with improves early compressive strength and reduce the free water; increase thev is cosity of cement slurry and their packing untimely will decrease permeability. So in this condition one thing is noticed that a certain level slurry is going to improve as decrease shear stress as in term of transition condition that slurry became highly compacted due to temperature and water cement ratio both factors can be considerable for preparation to optimum cement slurry.

In third condition cement slurry formulation Table 1C, Fig. 3 as increase the concentration of additive to improve rheological properties at temperature above 120°C. All slurries were prepared in sample A,B, where is the class G cement and silica fume by mixing water an approximately equal mass basis. Generally to enhance performance of slurry because increase the rate of hydration i.e., C_3S continue

Table 1: Slurry formulation

(A)	
Cement	421.3 g
Silica fume 15%	63.2 g
Water	390 g
Slurry density	13 ppg
Rheology temperature °C	123
Plastic viscosity PV Pa	1.8
Yield point Yp Pa	1
GS for 10 sec	2
GS for 10 min	2.5
(B)	
Cement	415.55 g
Silica fume 17%	70.64 g
Water	420 g
Slurry density	13 ppg
Rheology temperature °C	123
Plastic viscosity PV Pa	2.20
Yield point Yp Pa	1.50
GS for 10 sec	2
GS for 10 min	2.90
(C)	
Cement	404 g
Silica fume 21%	84.9 g
Water	370 g
Slurry density	13 ppg
Rheology temperature °C	123
Plastic viscosity PV Pa	4.1
Yield point Yp Pa	3.2
GS for 10 sec	3.2
GS for 10 min	6

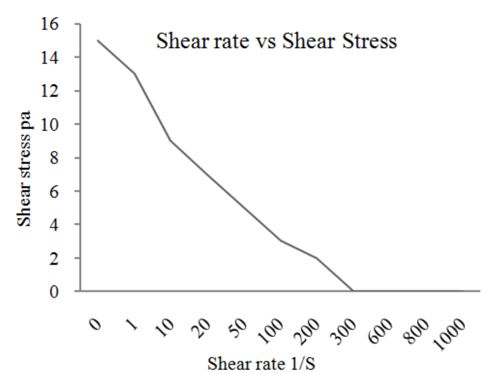

Fig. 1: Shear rate vs shear stress of Table 1A

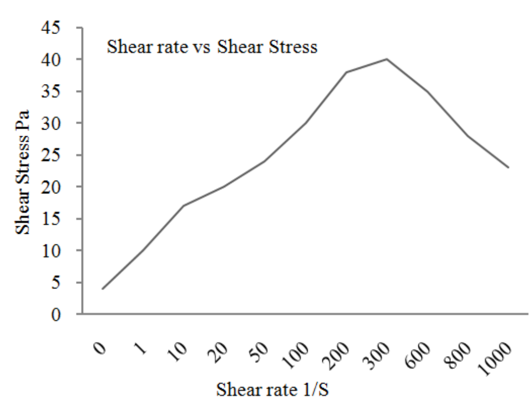

Fig. 2: Shear rate vs shear stress of Table 1B

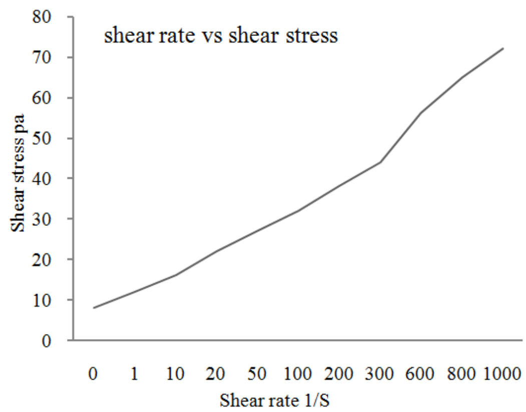

Fig. 3: Shear rate vs shear stress of Table 1C

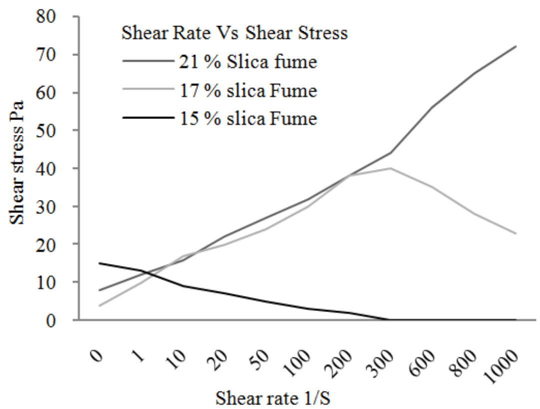

Fig. 4: Combination charts, shear rate vs shear stress with different concentration of silica fume

to hydrate to grow into fibrils which eventually began to connect with other cement grain so C-S-H that is highly responsible for the high strength of slurry. Using concentration of silica fume at different ratios the rheological properties gradually improve with increase concentration but one thing should be noted that rheological properties does not always truly represent the material property and sometime could be misleading because of high error involved in the fitting model i.e., Bingham model (Fig. 4).

CONCLUSION

- Plastic viscosityincrease with increase concentration of silica fume
- Sample condition C is beneficial forrheological properties
- Improving strength and durability of to adding more silica fume
- Temperature is highly influnced to the performance of slurry
- SF use as extenders to require more waterfor mixing cement slurry

RECOMMENDATIONS

- Using silica fume to measuring rheological properties at high temperature an ges above 120°C for analysis proper adjustment of transional condition of cement slurry in deep environment.
- When using silica fume for early strength development along with dispersants and retarders must be used for high temperature environment for improving rheological properties.

ABBREVIATIONS

API	:	American Petroleum Industry
µa	:	Apparent viscosity cp
CP	:	Centipoises’
CSD	:	Cement slurry density
°C	:	Degree centigrade
C_3S	:	Tricalcium silicate
C-S-H	:	Calcium silicate hydrate
ECD	:	Equivalent circulating density
°F	:	Degree Fahrenheit
HPHT	:	High pressure high temperature
HPSC	:	High performance cementsystem
ISO	:	International organization for standardization
KJ	:	Kilo joule
Kg	:	Kilo gram
lb	:	Pound
ml	:	Milliliter
CP	:	Centipoises
PV	:	Plastic viscosity
Ppg	:	Pound per square
SF	:	Silica fume
Sio_2	:	Silicon dioxide

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