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Modern Effective Cementing Practices: A Case Study of Well "A" in the Niger Delta

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Abstract

Cementing is one of the most important operations in the drilling phase of an oil and gas well and it should therefore be efficiently carried out. The main factors that contribute to an effective cementing operation are cement slurry design, displacement mechanism, pre-job operation and finally the calculations involved. These factors were carefully analyzed in this work. A field cementing procedure of the 13-3/8"and 9-5/8" casing cementation for well "A" was observed, all data from the cementing and casing program, volumes of cement slurry, number of sacks of cement used and cement bond evaluation result were also analyzed as postmortem criteria. From this, a conclusion was drawn that the cementing procedures of the well were of standard which prompted its adoption for other wells. Thus, we present effective cementing practices in this work.

Keywords: *Cementing; Displacement mechanism; Cementing procedure; Casing; Slurry, Spacer fluid*.

1. Introduction

Cementing is a procedure that involves the mixing and pumping of cement slurry through the annulus. When setting, the cement will establish a bond between the pipe and the formation. Cementing plays an important role in the life of an oil well; therefore, the most important stage of well drilling is the cementing stage. Cement is used as the main impenetrable seal in gas and oil well drilling. It is used extensively as a seal between the casing and the borehole, bonding the casing to the formation and providing a barricade to the flow of fluids from, or into the formations behind the casing and into the subsequent hole-section. Cement is used for corrective work on producing wells. It can be used to repair leaks in casings.

Fluid migration is usually prevented by the cement sheath between the hole and casing [1]. Cement serves as backing for the casing at the surface where the axial loads on the casing, due to the weight of the wellhead and Blow-Out Preventer (BOP) connected to the top of the casing string, are extremely high. Buckling of the casing is prevented by the presence of the cement sheath. However, in oil and gas industries, skills and technology with which jobs are carried out are dynamic. Over the years, new technologies have been developed and used in the cementation of oil and gas wells. Consequently, the present-day oil and gas cementing job is all about how cementing job is done and it involves technology, skills and developments which has been discovered over the years to enhance a very good cementing job.

A poor cementing job is a serious problem during the drilling phase of an oil and gas well. Consequences of failing to perform a good cement job includes: migration of fluid from one zone to another and this can lead to a blow-out, vibration of casing string while drilling the next hole-section, corrosion of casing, collapsing of formation, and sand production when flowing the well.

This work is aimed at investigating the process, procedure and to analyze the problems encountered during the cementation of a well in the Niger Delta. In order to achieve this, the following will be embarked upon: analysing the wellbore condition before the cement job is carried out, determining laboratory test and slurry composition, determining slurry volume to be pumped, using the necessary equipment to blend, mix & pump slurry into the annulus, monitoring the cement slurry displacement, and analysing the cement bond log report.

Though this work has been aimed at producing one of the best present day oil and gas cementing jobs procedure both literally and practically, access to other useful information was not granted and as such, it is limited to using only field "X" (well A) a case study.

2. Statement of theory and definitions

Portland cement was developed from hydraulic limes (cements). In the beginning of the 19th century it was manufactured in Britain and obtained its name due its resemblance to Portland stone. The patent for manufacturing cement was then established in 1824. Cements are manufactured from limestone and shale or. Some iron and aluminum oxides may be added if not present in sufficient quantity in the clay or shale. These materials are finely grounded and mixed, then heated to 2,600-2,800°F in a rotary kiln. The resulting clinker is then grounded with a controlled amount of gypsum to form Portland cement. The chemistry of cement is very complex and its performance in a well is usually defined by the simple oxide analysis and performance tests based on pump ability, strength, rheology etc.

For an effective cement slurry design, nine major valuable slurry performance properties must be ascertained: thickening time (pumpability), fluid loss, compressive strength, slurry density, free water, rheology, corrosion resistance, permeability, and mix water requirement. The thickening time is calculated in order to decide the duration of the slurry in its pumpable state considering bottom-hole pressure and temperature situations. The consistency of the cement slurry is usually measured in Bearden consistency units (Bc). It was stated by [2] that the testing temperature and pressure are controlled to feign the environment that the slurry would encounter down hole, and that the slurry is considered un-pumpable down-hole when it attains a consistency of 70 Bc. The lapsed time between 40Bc and 100Bc should be accounted for and their difference in values is noted as the transition time. The transition time indicates the rate at which the cement slurry changes from a pumpable state to an un-pumpable one.

The state of the wellbore usually has a major effect on the thickening time. There would be a reduction in the quickening time when there as a surge in pressure, temperature or fluid loss. These conditions are actually considered when the slurry is being formulated and tested in the laboratory before the operation is carried out [1].

Slurry densities are usually transformed due to a change in the quantity of mix-water or by the presence of additives in order to meet specific operational requirements. The rheological properties of the slurry with respect to temperature should be known in order to properly predict the frictional pressures that will occur while pumping the various fluids in the well [3]. During primary cementing several factors such as displacement velocity, cement density differences and casing centralization, usually affect the displacement of the slurry by the drilling fluid. The benefits of centralizing the casing have been known for many years. It is much harder to remove mud from an eccentric annulus compared to an annulus with centered casing. For a non-Newtonian fluid, the velocity on the narrow side of an eccentric annulus is slower than the velocity on the wide side of the annulus. Therefore, an eccentric annulus promotes channeling [2]. As a rule of thumb, it was stated by [2], that one centralizer should be placed for every 2 joints & 1 on each joint at the bottom & top of the interval cemented if the deviations of the hole do not exceed 25°C. Else, more centralizers should be incorporated. But if good cement jobs are being provided by the current centralizer program, then the program should not be changed. Nevertheless, if cement jobs are not satisfactory, then the centralizer program can be reviewed [4].

The condition of the hole is important from a cementing standpoint. Shell Petroleum Development Company [5] stated two all-important key points. First, the hole should be relatively clean to allow running the casing without much problem. Trouble running the casing would destroy some centralizers Secondly, with numerous washouts is difficult to be cemented. In the case of severe washouts, the annular velocity is reduced when compared to other sections of the annulus. This will usually result in the mud cuttings being in their gelled state making it difficult to be displaced by the cement.

Primary cementing is performed immediately after casing has been run in the hole. This basic principle varies with the many materials used to perform the many cementing operations. More and deeper wells are being drilled that have extreme temperatures, both hot and cold, in new and more hostile environments.

Crook [6] laid emphasis on the use of reverse circulation in cementing where loss circulation is encountered as this gives room for a broader range of cement slurry compositions. Calliper surveys should be carried out before running in the casing in order to determine the right quantity of cement slurry, thus reducing over-placement [6].

3. Description and application of equipment and processes

The volume of slurry that is needed will determine the quantity of cement, mix-water and additives required for a cement job. In addition to the calculated volumes, an excess of slurry is mixed and pumped to accommodate any mistakes in the volumes calculated. Errors usually occur as a result of inexactness in the bore-hole size. An extra 30% to 50% of the computed open-hole volumes is mixed in order to account for any inaccuracies. Equations (1) to (13) formed the basis of this cementing program and was followed in this sequence.

Volume of casing (bbls) = capacity(bbl/ft) x length(ft.) (1)

$V_{ta} = ((D_{oh}^2 - OD_{c2}^2)/ (1029.4)) \times L_{ta}$ (2)

$V_{la} = ((D_{oh}^2 - OD_{c2}^2)/(1029.4)) \times L_{la}$ (3)

$V_{l1,2} = ((ID_{c1}^2 - OD_{c2}^2)/ (1029.4)) \times L_{1,2}$ (4)

$V_{st} = ((ID_{c2}^2)/1029.4)) \times L_{st}$ (5)

$V_{r,h} = ((D_{oh}^2)/1029.4)) \times L_{rh}$ (6)

$V_{hl,c} = ((ID_{c2}^2)/1029.4) \times H_{l,c}$ (7)

No. of Sacks = (Total volume of slurry)/(yield of cement) (8)

Mixwater Vol. = Mixwater per sack x No. Sacks (9)

Number of sacks of additive = No. sxs Cement x % Additive (10)

Weight of additive = No. sxs of Additive x 94(lb/sk) (11)

Displacement Vol. = volumetric capacity of casing x depth of float (12)

Number of strokes = volume of displacement fluid/vol. of fluid per stroke (13)

3.1. Sequence of operation for cementing 13-3/8'' casing

The following procedures were followed during the cementing job.

1. After drilling ahead to TD @ 5060ft, a wiper trip was made to the previous casing shoe @ 331ft,13 3/8" 68# BTC casing was ran in hole (filled every 5 joint with mud during the process) to shoe at 5060 ft., pick up 10ft to shoe depth at 5050ft. Cementing head was made up to casing and 200% casing content was circulated to condition the mud in hole (reduce viscosity and yield point to allow for enhanced cement slurry flow).
2. Pre-job safety meeting was held with the drilling crew (highlighted all hazards associated with the job).
3. Cement lines was flushed and test same to 3,000 psi. Pressure was bled off.
4. Break circulation with Cement servicing companies pump.
5. Circulated conditioned mud in hole @ 10 bbls/min
6. Pumped 60 bbls of chemical wash @ 6 bbls/min.
7. Pimped 60 bbls of 11ppg MUDPUSH II spacer @ 6bbls/min.
8. Drop bottom plug.
9. Pumped 580bbls 12.5ppg lead slurry @ 6 bbls/min
10. Pumped 72 bbls of 15.8ppg Tail slurry @ 6 bbls/min
11. Drop top plug.
12. Pump 5 bbls MUDPUSH II spacer @ 5 bbls/min

13. Displace cement slurry in stages: 500bbls at 10bbls/min; 224bbls at 5bbls/min and 20bbls at 3bbls/min [sudden increase in pressure was noticed (plug bumped)].
14. Casing was pressure tested to 2000 psi – pressure held. Bled off pressure and checked for back flow.
15. Waited on Cement and monitor returns closely.
16. Two of the slurry samples were stored at generator room (higher temperature) to see when they harden.

Top of cement is designed to be at 4550ft. Top of Tail slurry is 6800ft (500ft above shallowest hydrocarbon zone). Design calls for having good zonal isolation of hydrocarbon zones.

3.2. Sequence of operation for cementing 9-5/8 casing

The following procedures were followed during the cementing job.

1. After drilling ahead to target depth at 9510ft a wiper trip was made to the previous casing shoe @ 5050ft,9-5/8″ 47ppf BTC casing was ran in hole to TD at 9510ft, pick up 10ft to shoe depth at 9500ft. cementing head was made up to casing and 200% casing content was circulated to condition the mud in hole (Reduce viscosity and yield point to allow for enhanced cement slurry flow).
2. Pre-job safety meeting was held (highlighted all hazards associated with the job).
3. Cement lines was flushed and test same to 3000 psi. Pressure wash-bled off.
4. Break circulation with Cement servicing companies pump.
5. Pumped conditioned mud in hole @ 10 bbls/min
6. Pumped 60 bbls of chemical wash @ 6bbls/min.
7. Pimped 60 bbls of 11ppg MUDPUSH II spacer @ 6bbls/min
8. Drop bottom plug.
9. Pumped 176bbls 12.5ppg lead slurry @ 6 bbls/min
10. Pumped 234bbls of 15.8ppg Tail slurry @ 6bbls/min
11. Drop top plug.
12. Pump 5 bbls MUDPUSH II spacer@ 5 bbls/min
13. Displace cement slurry in stages:
    i) 500bbls at 10bbls/min
    ii) 169 bbls at 5 bbls/min
    iii) 20bbls at 3bbls/min, sudden increase in pressure was noticed (plug bumped).
14. Casing was pressure tested to 2000 psi – pressure held. Bleed off pressure and check for back flow.
15. Waited on Cement and monitored returns closely.
16. Two of the slurry samples were stored at generator room (higher temperature) to see when they harden.

4. Presentation of data and results

The topmost hydrocarbon zone at 7,310ft. So, 9 - 5/8″ casing was cemented from the shoe at 9,510ft MD to a depth of 6,810ft MD (2,710ft annular height and 500ft above the topmost hydrocarbon zone) with 15.8ppg tail slurry, and from 7,100ft to 4,550ft with 12.5ppg lead slurry (2,250ft annular height). This was to ensure proper bonding of the casing with the cement.

From the analysis of the cement slurry volume and sacks of cements used in both the 13-3/8″ and 9-5/8″ casing cement jobs, the lead slurry had the following results as stated in Table 1 and table 5, by the application of the already stated equations.

From Table 1, the lead slurry had a higher volume (in bbls) in terms of the total lead slurry comared to that of the tail slurry for the 13-3/8″ casing. This is because for the lead slurry, more quantity is usually required to fill more of the upper section of the annulus which is usually at lower temperatures and pressures than the lower section. The lead slurry is also usually lower in density and strength compared to the tail slurry and this can be seen in the results for the total number of sacks of cement used for the lead slurry compared to that used for the tail slurry. For the tail slurry, there is an increase in the number of sacks used and a decrease in the total tail slurry volume (in bbls) for casing 13-3/8”. This is due to the high strength and density required by the tail slurry in order to ensure proper bonding of the casing to the wall of the wellbore. There is also a reduction in total tail slurry volume to 71.90bbls because the tail slurry is usually more expensive but of high quality, thus smaller volume is required.

Table 1. Analysis of cement slurry volume and sacks of cements used in 13-3/8” casing cementing

Lead Slurry	
Annular volume between 13-3/8” x 24” casing (bbl)	106.40
Annular volume of lead slurry between 13-3/8” casing and 16” open hole (bbl)	316.00
Total lead slurry (bbl)	580.40
Total number of sacks of cement for lead slurry	1,144.00
Tail Slurry	
Volume of track (bbl)	12.00
Volume of rathole at 50% estimated washout	3.70
Tail volume between 13-3/8” casing and 16” open hole (bbl)	37.45
Total tail slurry volume (bbl)	71.90
Total number of sack of cement	1,492.00
Displacement volume (bbls)	744.00

Table 2. Well “A” data summary for 13 -3/8” cementing

	MD (ft)	OD (in)	ID (in)	Joint (ft)	Wt (ppf)	Grade	Collapse (psi)	Burst (psi)	Thread
Previous casing	331	24	22.58	40	182	-	-	-	-
Casing	5,050	13.3/8	12.41	40	68	K-55	1,950	3,450	BTC
Landing collar	4,970	-	-	-	-	-	-	-	-
Float collar	5,050	-	-	-	-	-	-	-	-
Section TD	5,060	-	-	-	-	-	-	-	-
Bit size	-	16	-	-	-	-	-	-	-

Table 3. Formation data for Well “A” 13-3/8” casing cementing

MD (ft)	Fracture pressure (psi)	Fracture gradient (psi/ft)	Fracture density (ppg)	Pore pressure (psi)	Pore pressure gradient (psi/ft)	Pore density (ppg)	Formation
5,060	3,547.06	0.701	13.5	2,190.98	0.433	8.33	Shale
BHST, (°f)	BHCT, (°f)						
151	120						

Table 4. Casing centralization program for Well “A” 13-3/8’’

Depth(ft)	Joint	Centralizers/joint	Centralizers
0 – 4,970	124	1 cent/5 joints	24
4,970 – 5,050	2	1 cent/joint	2

From the results for the 9-5/8” casing (Table 5), the total number of sacks of cement also increased for the tail slurry just like that for the 13-3/8” as a result of the same reasons already stated. However, there is an increase in the total slurry volume (in bbls) for the tail slurry instead of a decrease (Table 1). This is because of the depth at which the 9-5/8” casing is placed which is at a higher measured depth than that of the 13-3/8” casing. The deeper the well, the more the integrity of the well cannot be compromised. Therefore, more quantity of the stronger tail slurry will be (or was, though it has been done already) utilised in order to always ensure the well integrity.

Table 5. Analysis of cement slurry volume and sacks of cements used in 9-5/8″ casing cementing

Lead Slurry	
Annular volume between 500ft of 13-3/8″ x 9-5/8″ casing (bbl)	30.00
Annular volume of lead slurry between 9-5/8″ casing and 12-1/4″ open hole (bbl)	97.60
Total lead slurry (bbl)	176.40
Total number of sacks of cement for lead slurry	461.00
Tail Slurry	
Volume of track (bbl)	5.80
Volume of rathole at 50% estimated washout	2.20
Tail volume between 9-5/8″ casing and 12-1/4″ open hole (50% estimated washout)	151.20
Total tail slurry volume (bbl)	234.00
Total number of sack of cement	1,123.00
Total sacks for the job	1,584.00
Displacement volume (bbls)	689.00

From the well data summary (Table 2 & Table 6) for both casings, there is an increase in the burst and collapse values for casing 9-5/8″ owing to the higher pressures, densities and temperatures at the measured depth where the 9-5/8″ casing is placed. This casing must be able to withstand any loading force such as fluid pressures and mechanical crushing loadings due to earth-shift forces that would be applied from outside the casing. The largest force from pressured fluids usually occurs at the bottom of the wellbore and since the 9-5/8″ casing is located lower than the 13-3/8″, the values for collapse should be high in order to withstand such pressures, thus ensuring the integrity of the well. Burst pressure for the 9-5/8″ casing is also higher than that of the 13-3/8″ which is necessary because the casing must be able to withstand the forces applied from inside the casing due to workover operations, hydrostatic mud load, and produced fluid pressures.

Table 6. Well "A" data summary for 9 -5/8″ casing cementing

	MD (ft)	OD (in)	ID (in)	Joint (ft)	Wt (ppf)	Grade	Collapse (psi)	Burst (psi)	Thread
Previous casing	5,050	13-3/8	12.41	40	68	k-55	1,950	3,450	BTC-
Casing	9,500	9-5/8	8.681	40	47	N-80	4,760	6,870	BTC
Landing collar	9,420	-	-	-	-	-	-	-	-
Float shoe	9,500	-	-	-	-	-	-	-	-
Section TD	9,510	-	-	-	-	-	-	-	-
Bit size	-	12-1/4	-	-	-	-	-	-	-

The formation data (Table 3) shows that casing 13-3/8″ was placed in a section dominated by a shale formation to a measured depth of 5,060ft. at a pore pressure gradient of 0.433psi/ft. At this depth of 5,060ft, the pore pressure amounts to 2,190.98 psi. This pore pressure and pore pressure gradient values are lower than that obtained for the 9-5/8″ (Table 7). For the 9-5/8″ casing, higher pore pressure and pore pressure gradient values were expected as this casing was placed at a higher measured depth of 9,510ft. Due to this increase in depth down the hole, there was a corresponding increase of the pore pressure to 4,1173psi. There was also an increase in the Bottom Hole Static Temperature (BHST) and Bottom Hole Circulating Temperature at the section covered by the 9-5/8″ casing. This is also due to the fact that as you go down the hole, because of the increase of over burden, there is an increase in pressure and since pressure is directly proportional to temperature, the temperature thus increases for the 9-5/8″ casing section compared to the 13-3/8″.

Casing centralizations for the 13-3/8″ and 9-5/8″ were also obtained and tabulated in table 4 and table 8 respectively. These centralizers are usually mechanical and fastened securely around the casings at various locations ensuring that the casing does not contact the wall of the well. More centralizers were actually required for casing 9-5/8″ because, at a higher measured depth, extreme caution is needed to ensure proper bonding and sealing of the cement to the well. These centralizers ensure that there is a continuous clearance in the annulus around the casing which allows cement to completely seal the casing to the walls of the wellbore.

Table 7. Formation data for Well "A" 9-5/8" casing cementing

MD(ft)	Fracture pressure (psi)	Fracture gradient (psi/ft)	Fracture density (ppg)	Pore pressure (psi)	Pore pressure gradient, (psi/ft)	Pore density (ppg)	Formation
9,510	7,408	0.779	15	4,117.3	0.433	8.34	Sandstone
BHST(°f)	BHCT(°f)						
190	136						

Table 8. Casing centralization for Well "A" 9-5/8" casing

Depth(ft)	Joint	Centralizers/joint	Centralizers
4500 – 7620	78	1 cent/3 joints	26
7620 – 9420	45	1 cent/joint	45
9420 - 9500	2	2cent/joint	4

5. Conclusions

The cement bond log result for well "A" shows clearly that a good cement job was done and no problem was encountered. From this work, the following conclusions are made.

1. In order to achieve a good cement bond, the cement slurry properties should be designed to suit the formation condition of the well bore.
2. The proper cement slurry displacement mechanism should be used. The mud in hole should be conditioned (low plastic viscosity and yield point) and cement slurry should be at least 0.5 ppg greater than mud in hole for effective mud displacement. The required pump rates should be followed as per program and the correct spacer fluid should be used to prevent slurry contamination.
3. Proactive planning in the well site should also be done before the cement job commences. Supervisors and well site engineers should confirm that all casing and cementing accessories are available and meet all required specification for the job. Also, service contractors should adhere to safety rules during the operation.
4. Calculations on cementing should be carried out carefully and the experience of the field being drilled should be taken into consideration in order to ensure that the right correct volumes are pumped into the hole. This will prevent cases of wet-shoe that occur due to over-displacement of cement. This also confirms that limits of pressure are not exceeded which would normally result in fractured formations or burst casings.

Recommendations

Since well "A" was cemented without any constraint, such methods should be adopted for similar wells in that field. Furthermore, other operators could copy this procedure. However, there should be little modification in the slurry design in case of slight changes in well bore condition.

Nomenclature

BTC	*Buttress thread casing*
BC	*Bigger casing*
C2	*Smaller casing*
MD	*Measured depth*
MUDPUSH II	*Advanced cement spacer, Schlumberger Trade Mark*
IDc1	*Internal diameter of the bigger casing in inches*
IDc2	*Internal diameter of the smaller casing in inches*
ODc2	*External diameter of the smaller casing in inches*
Doh	*Open hole diameter in inches*

Vta	*Volume of tail slurry between open hole and C2 in barrel*
Lta	*Height Vta in feet.*
Vla	*Volume of lead slurry between open hole and C2 in barrel*
Lla	*Height of Vla in feet.*
Vrh	*Volume of tail slurry in the rat hole in barrels*
Lrh	*Height of Vrh in feet.*
Vst	*Cement slurry volume in shoe track (barrels)*
Lst	*Length of shoe track in feet*
Vl1,2	*Volume of lead slurry in between C2 and C1 in barrels*
L1,2	*Height of L1,2 in feet*
Hl,c	*Measured depth of the well to top of landing collar in feet*
Vh,lc	*Volume of C2 to top of landing collar in barrel (displacement volume).*
TD	*Target depth*

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