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Cementing at High Pressure Zones in KSA "Discovering Mystery behind Pipe"

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Abstract

Cementing is one of the most important and crucial issues in the oil field, especially for high pressure and gas bearing formations. It is difficult to achieve a good zonal isolation in such formation types, where pressure is abnormal and formation fluid contains corrosive fluids and gases. A common problem associated with highly over-pressurized zones is cross-flow after cementing. Fluid flow from an over-pressured zone to a low-pressure, high-permeability zone can lead to deterioration of the existing production hardware. Work over operations that attempt to repair cement voids — including: perforation, squeezing and use of casing patches or scab liners — are not recommended, as they do not provide long-lasting results. In one onshore field in Saudi Arabia, there was a problem related to cementing at high pressure zones. Recently, communication between A (abnormally over-pressurized zone) and B (low-pressure zone) formations occurred due to long term sea water injection, and has resulted in production interruption in a few wells. This paper addresses the problem through investigating field practices, including: drilling, cementing, and completion. This study also reviews the field reports and cased hole logs. A three-month study was conducted to evaluate the effects of formation-A water on cement, where the cement was exposed to formation-A water under downhole conditions. The tests for permeability, mechanical properties TGA and EDXRF are presented, in addition to discussions of some of the preliminary findings.

Introduction

Cement channeling has been known as one of the major completion issues in the petroleum industry. Several attempts were conducted by cementing companies and individual researchers to tackle this problem. So far there is no reputable improvement. Fluid migration in cement happens in the course of or after spotting cement. The main cause of gas channeling is believed to be the inability of cement to maintain enough pressure on the formation before it sets. Fluid migration through wall cake is accredited to the cement's failure to make a good bond to the formation. There are several factors that directly affect this phenomenon, including; type of cement, chemical additives, mud and cement density, temperature, pressure, mud cake film, centralization, movement of casing string and reciprocation while pumping the cement slurry, and cement filtrate.

Most of the theories developed were based on problems associated with cement channeling to severe loss in hydrostatic pressure of the cement column during gelation (i.e., when cement passes from liquid to solid state). Most of the suggested solutions in the past focused on one property of the cement by neglecting the change in other properties, assuming that changes occur only for some of the physical or chemical properties, which may be directly responsible for the gas migration. Casing centralization, use of a scratcher to clean mud cakes, and use of fluid spacers are some of the solutions implemented to help improve zonal isolation.

The cement is capable of transmitting pressure as long as it is in the liquid state, until it attains gel strength enough to form an effective seal. Upon cement placement, cement suffers a gradual drop in hydrostatic pressure gradient till it reaches that of water. Hydrostatic Pressure will further drop and becomes less than that of water during gelation time, due to dehydration within the cement matrix and fluid loss. Excessive dehydration rate and fluid loss will cause high shrinkage that might form a passage for formation fluids, to transfer from a high pressure zone into a low pressure zone and into the well through filter cake or a casing leak. Cooke[2] studied the pressure behavior during the first six hours after pumping cement and observed that cement loses pressure at 39 psi/ft. Also; he found that application of annular pressure can make up for the drop in pressure — to maintain the pressure required to over balance the formation — until the cement develops enough compressive strength for effective zonal isolation.

Gas or fluid migration will not take place if cement is able to develop a gel strength between 500 $\frac{lbf}{ft^2}$ in 15 min after the start of transition time. It would be impossible for gas to migrate at 500 $\frac{lbf}{ft^2}$, especially if the cement has low permeability, zero free water, high gel strength, low viscosity and a short transition time. In such a situation, gas will enter into cement matrix and create channels within the cement. Sometimes the gas overcomes the tensile strength of the cement structure, breaks the cement matrix and travels through the micro fractures. Assuming that the hydrostatic pressure of the cement column will decrease when gas bubbles are already inside, the gas will try to expand — until the pressure difference is large enough to overcome the cement tensile strength — and in turn break the cement.

Since water is not compressible, it does not migrate in the same manner as gas,. There is no way a liquid like water or oil can travel up or down the cement column unless there are channels big enough within the cement that possibly form after gas migration — when the channels get wider and wider in HPHT environment. During cementing at an over-pressurized zone, the formation might be underbalanced before cement becomes strong in the sense it resists fluid movement. If this situation occurs, formation fluid will displace or squeeze cement into high permeable formations resulting in non-cemented pipe eventually.

Improper drilling practices can also contribute to poor cementing. For example, drilling with mud that has non controllable fluid loss leaves excessive filter cake that is difficult to remove. It has become evident that filter cake gives up at 2 psi. Also, high mud weight along with high circulation rate while drilling through high permeable zones or low pressure-high porous formations, encourage fractures and wash outs to develop that are difficult to cement. Hole conditioning practices are vital to a successful primary cementing job. The hole should be clear of fill, filter cake, and of full size before cementing. Therefore a clean out trip with a hole opener is made to removing any remaining filter cake and gelled mud. Other means, e.g., use of low viscous mud and high circulation rate, will help to effectively remove wall cake and mud pockets. Mud buckets, which emerge when mud remains static for a long time in the hole with formation cuttings inside, provide a route for fluid after it dehydrates.

It is very challenging to have well cemented pipe in highly deviated and horizontal holes. A couple of factors play an important role in cementing, such as centralizing, mud displacement efficiency and hole cleaning. It is well known from past research that fluid tends to flow more in the wide side of least resistance than in the low side that restricts flow. To get through this problem, the amount of centralization needs to be selected in a way that improves stand off; without increasing drag that might present additional dispensable problems. Also, the design or shape of centralizers should be optimized in a way that helps provide uniform flow regime around the pipe and improve the displacement efficiency ratio. Spacer volume that provides a four-minute contact time with the hole, and use of low viscosity mud at 3 BPM circulation rate, will improve filter cake removal efficiency as per field and lab results. The spacer should be compatible with, and lighter than, the cement, and heavier than the mud in hole. These qualities allow the spacer to improve displacement efficiency and avoid mud channeling and cement contamination as well.

During the life of the well, the cement sheath is vulnerable to failure when different events take place: e.g., stimulation, well testing, communication test, casing pressure and cement squeeze jobs. These events generate thermal and cyclic stresses as a result of the change in hydrostatic pressure and temperature. Mechanical stresses — generated by tubular run in holes — also contribute to cement fracture in the long-term. Cement contracts and expands frequently, in response to temperature changes. If the expansion/contraction exceeds the cement's tensile strength, the cement will fracture. Radial expansion of cement-casing interface, due to high pressure induced stresses, will compress cement radically and induce tensile tangential stress in cement that causes a crack. As a result, tensile strength of the cracked section will drop to zero and the distribution of stress in cement will be changed. This characteristic will help cracks creep radically outward and reach casing-formation interface. If it occurs across a long axial distance, a channel will form through which liquid can flow.

Cement deterioration can be accelerated in the presence of corrosive CO_2 gas. The effect of CO_2 is much worse in HPHT formations. In such an environment, cement degradation due to carbonation will occur in a short time. When cement comes in contact with CO_2,, three different chemical reactions occur:

Formation of carbonic acid (H_2CO_3): it lowers pH and its effect depends on temperature, partial CO_2 pressure and other ions dissolved in the water.

Carbonation of cement or cement hydrates: it causes an increase in density, which leads to increased hardness and decreased permeability of the cement sheath. As a result, CO_2 diffusion will decrease and the volume will increase by up to 6%. In such a case, cracks will develop.

Dissolution of $CaCO_3$: This phenomenon happens in the presence of water containing CO_2 for a long period of time. Effects of this reaction include an increase in permeability, porosity and loss of mechanical integrity. This dissolution process will lead to poor formation isolation.

It is still disputable whether or not carbonation is detrimental to cement integrity. Some researchers showed that mechanical properties of cement will suffer degradation due to CO_2 exposure leading to fluid migration. On the other hand, some studies conducted on 20 to 30-year old cement samples of CO_2 wells showed that they maintained their integrity despite carbonation. Cement mainly consists of tricalcuim silicate C3S and dicalcuim silicate C2S. When cement reacts with water, calcium silicate hyderate C-S-H and calcium hydroxide $CaCO_3$ evolves. During exposure to CO_2 dissolved in water, $CaCO_3$ will form. This product is harmful to the cement sheath — at high concentrations $CaCO_3$ cracks cement. To minimize the carbonation effect and prolong the life of cement, there are two solutions:

- Reducing cement permeability so that it withstands well operations with low dehydration volume shrinkage.
- Optimize the cement design so that dehydration products will have a lower amount of materials that are reactive with CO_2.

Cement mechanical properties, including: compressive strength, yield stress, permeability, Young's modulus and Poisson's ratio, should be taken into account when designing a cement system to guarantee that cement will survive longer, while being exposed to cyclic loads. Physical properties, e.g., thickening time, fluid loss and viscosity, must be designed carefully to help reduce transition time and give the required compressive strength as quickly as possible. Cement that is mechanically, thermally and chemically stable will be able to survive HPHT and a corrosive environment.

Communication Problem between A and B Formations:

The A/B communication problem emerged in several newly drilled and sidetracked wells. Three wells had a reoccurrence of a Formation-A casing leak. This problem required a quick intervention before it escalated and became a major issue. The reason why it occurred was not identified. There are three possible explanations of how it developed. First, Formation-A made its own way behind the cement, through the mud cake and then entered the well, since Formation-A pressure is higher than the pressure of the productive zone across Formation-B. Second, Formation-A gas was transferred through cement channels and reacted with the casing. As result, the casing wast corroded and holes developed, paving the road for Formation-A water to enter the well bore and eventually killed the well. Third, water influx attacked cement and created severe contamination in the cement. Its hydrostatic was not enough to overbalance Formation-A high pressure, allowing communication to take place during WOC.

Most of the wells with casing leak problems across Formation-A were in early 2006. Basically, these wells were completed as either vertical or horizontal open hole in Formation-B, with 7” liner across A and B formations. All wells were completed with 7” downhole packer and 4-1/2” tubing. Soon after first completion, these wells started producing Formation-A water and this was an indication of communication between the A and B formations.

It is important to note that the Formation-A had higher pressure than Formation-B, which resulted from the poor cement behind the pipe and the erosion of Anhydrite between the two formations. Formation-B injectors are feeding Formation-A, undesirably, besides Formation-B. In addition, high injection volumes and velocities eroded the Formation-B Anhydrite cap rock and established a communication between the reservoirs. Formation-A pressure is higher only in the central area. Formation-B pressure at the flanks is higher than Formation-A pressure due to peripheral injection. Formation-B pressure declines at the center by production; however Formation-A does not have any production, therefore Formation-A pressure builds up continuously in the center.

Field practices:

The field practices implemented where communication problem arose including drilling, hole conditioning and cementing, were reviewed. In addition, CBL was reviewed. Two wells were chosen for this study; well-A and well-B. Well-A is horizontal while well-B is vertical.

Drilling:

Well-A: This well was drilled and completed as a Formation-B horizontal open hole producer in mid 2007. In this well, an 8-1/2" curve section (0-81 degrees) was drilled from two formations above Formation-A all the way down to 2' TVD inside Formation-B with full circulation. Mud weight was 64 PCF at start till Formation-A was hit, when the well started flowing at 40 BPH. The well was then shut in until pressure stabilized. The stabilized shut in pressure was 450 psi. The mud weight was increased to 84 pcf to kill Formation-A. After that, the rest of hole was drilled till 2' TVD below the top of Formation-B. The hole was swept with Hi/Low Vis pill to effectively clean the well by improving cutting lifting efficiency. In addition, a wiper trip was performed from the bottom up to the 9-5/8" casing shoe, to boost the hole cleaning efficiency before running the 7" liner.

Well-B: This well was drilled and completed as a Formation-B vertical open hole producer early in 2006. In this well, an 8-1/2" open hole was drilled from two formations above Formation-A, all the way down to 2' TVD inside Formation-B with full circulation. The mud weight was 64 PCF at the start until Formation-A was hit when well started flowing at 25 BPH with H_2S traces. The mud weight was raised to 87 pcf to kill Formation-A. After that, the rest of hole was drilled to Formation-B. The hole was swept with Hi/Low Vis pill to effectively clean the well by improving cutting lifting efficiency. In addition, a wiper trip was performed from the bottom up to 9-5/8" casing shoe to boost hole cleaning efficiency before running the 7" liner.

The wells were placed on production mid 2006 and early 2007 respectively. They were both producing oil with zero water cut for 6 months before they were found dead due to communication that was confirmed by water sampling and PLT log as well.

Hole preparation and Cementing:

In both wells, 7" liner was run consisting of Float Shoe, Float Collar, Landing Collar, 7" casing Joints and mechanical hanger, along with Top Packer and tie back Receptacle. Upon reaching the bottom, the casing was rotated and reciprocated, besides circulating the well at the highest possible rate to remove mud cake. Then the mechanical liner hanger was set. After that, water spacer was pumped ahead of cement to remove any residual impurities and prevent any potential cement contamination if it gets in contact with mud.

In well-A, 7" liner was centralized as follows,

- Every joint from bottom till an inclination of 44 degrees and every second joint above to till Kick off point were centralized with spiral centralizer
- Every other joint was centralized with collapsible centralizer to 9-5/8" casing Shoe and after that every third joint was centralized inside casing to 7" liner hanger using bow rigid centralizer.

In well-B, 7" liner was centralized as follows;

- The first five joints and then every second joint to a 9-5/8" casing shoe, were centralized with collapsible Centralizers
- Every third joint was centralized inside the casing to a 7" liner hanger, using a bow rigid centralizer.

Then the wells were cemented using two-stage cement as follows;

Class G + 0.6% (Dispersant) + 0.3% (Fluid loss) + 0.05gps (Retarder)+ 0.005 gps (Defoamer)	
Slurry weight	101 PCF
Thickening Time	5 – 5.5 hours

Table#1: shows lead cement recipe.

Class G + 1.2% (Dispersant) + 0.4% (Fluid loss) + 0.22 % (Retarder)+ 0.01 gps (Defoamer)	
Slurry weight	118 PCF
Thickening Time	4– 5 hours

Table#2: shows tail cement recipe.

During cementing no lost circulation was encountered in both wells. At the end, the excess cement was reversed out and the liner top packer was tested with water upto 2000 psi with no leak detected.

CBL log was run across the entire 7" liner and showed poor cement across A and B formations and confirmed that Formation-A water was dumping into Formation-B.

Effect of Formation-A Water on Cement:

Originally, the cement was placed in a harsh environment where the pressure reaches 4000 psi and CO_2 and H_2S gases exist. It is still a debateable point whether Formation-A sour conditions have contributed to poor cement behind the liner that led to communication problems or not. The effect of Formation-A water should not be overlooked when rooting out the problem. In this study, it is assumed that there is no effect of Formation-A water on cement.

Experimental work and equipment:

A three month long study was conducted to find out the degree by which Formation-A water contributed to communication problems. In this study, cement was exposed to Formation-A water for three months under molded downhole conditions. Formation-A water contains 4.5% CO_2 gas and 1.28 PPM H_2S gas. The same cement used in those wells was used to prepare cement samples. Initially, cement samples were cured in raw water at 215 ^{0}F before being exposed to Formation-A water at 215 ^{0}F and 4000 psi. In parallel to that, some of the cement samples were cured in raw water at the same conditions. Upon completion of the curing process, cement samples were tested for physical properties: permeability, compressive strength, Poisson's ratio and Young's modulus. Besides, TGA and EDXRF tests were conducted.

A well was drilled to collect Formation-A water samples needed in this project. After hitting Formation-A, the well was flowed with a test packer isolating the zone until clean water reached the surface. A total of 40 gallons of water was collected.

Eighteen samples in total were prepared using the same cement recipe used in the field. Cement samples were then poured in different cubical and cylindrical moulds. These moulds were placed for 2 days in the curing chambers at 215 ^{0}F. After the curing period, cement samples were removed and the weight was recorded. Each test specimen was assigned a number. Four samples were tested for mechanical properties, permeability, TGA and EDXRF, after initial set. The remaining samples were divided into two groups. The first set was cured under sour conditions in Hastelloy metal autoclaves for 3 months, while the second set was cured in raw water in autoclaves for the same period of time. At the end, cement samples were taken out of autoclaves and tested for mechanical properties, permeability, TGA and EDXRF.

Permeability test:

The permeability test was conducted using permeability equipment. It consists of a core holder in which a cement sample is placed, a fluid cylinder for fluid injection, a beaker to collect fluid if any, pump for injection purpose and a computer to collect data. In this test, the sample is placed in the core holder after being cleaned and trimmed. Then, brine is injected into the cement sample at 700 psi differential pressure and an injection rate of 2 cc/min. At the end, the amount of water collected is measured.

Young's modulus and Poisson's ratio test:

The test is conducted to calculate Poisson's ratio, Young's modulus and peak strength. Axial stress is applied to the test specimen until cement starts to break or fracture. The cement samples were cut into 3" length X 1.5" OD size using the trimming machine. Then the sample surfaces are finished or ground using a surface grinding machine. The degree of parallelism of surface of sample is then measured. To ensure the load applied is evenly over the surface, the accepted tolerance should be equal to or less than 2/1000 inch. The sample is then placed inside Tri-Axial equipment. Basically, it consists of core holder, piston, vessel, control panel, camera and computer for data acquisition. At first, a plastic jacket is used to protect the plug while applying the confining pressure to avoid fluid entry into the plug. After that, the core is placed into the core holder before three VLDT wires are connected to the core holder. Two wires are used to measure the axial distance change while the third one for change measurement is in radial distance. Next, confining pressure is applied at 700 psi and axial load ranging from 5 to 15 MPA is applied to the piston at a temperature of 150 ^{0}C. Then Young's modulus, Poisson's ratio and peak strength are calculated.

EDXRF Test

In this test, the cement is tested to determine the elemental compositions that make up the cement system. The cement sample is crushed and milled until it becomes a powder. Then the powder is mixed with 0.5 gram chemical binder. Cement powder is poured in a pellet mould before being pressed at 15 psi by X-Press machine. The pellet is then placed inside spectrometer that consists of 400 watt x-ray tube, computer controlled high voltage generator for the x-ray tube, liquid N_2, cooled Si(Li) detector, multichannel analyzer & computer for data acquisition. The EDXRF analyzes the sample for element composition after entering weights of sample and binder.

TGA Test:

This test is conducted to measure the thermal stability and composition of cement as a function of time. The effect is quantified by the weight loss that elements suffer due to heat. First, cement sample is crushed and milled until it becomes powder. Then a pellet is filled with 50 mg of cement in a sample in the machine. Then the temperature is raised from room temperature at a rate of 2 ^{0}C/min until 1000 ^{0}C is reached. Data, including the amount of weight loss and the remaining mass percentage, are calculated.

Results and Discussion:

All samples were examined physically upon removal from the CO_2 autoclave. All samples were inspected and were found to be intact. All samples were found to have turned to a black color due to the reaction with H_2S gas. Mechanical properties including permeability, Young's modulus and Poisson's ratio were all calculated before and after Formation-A water exposure. According to the permeability test, the cement stayed solid for 15 minutes during brine injection at a pressure of 700 psi, indicating that it is impermeable. Also, results showed there is a slight change in the rest of the mechanical properties. For example, static Y increased from 2.322E+06 to 2.400E+06 psi while Dynamic Y increased 2.930E+06 to 3.001E+06 psi. Tests showed that Static E increased after exposure from 0.125 to 0.29 and Dynamic Y increased from 0.282 to 0.290. All results pertaining to mechanical property tests for all samples are in **tables 3 & 4**.

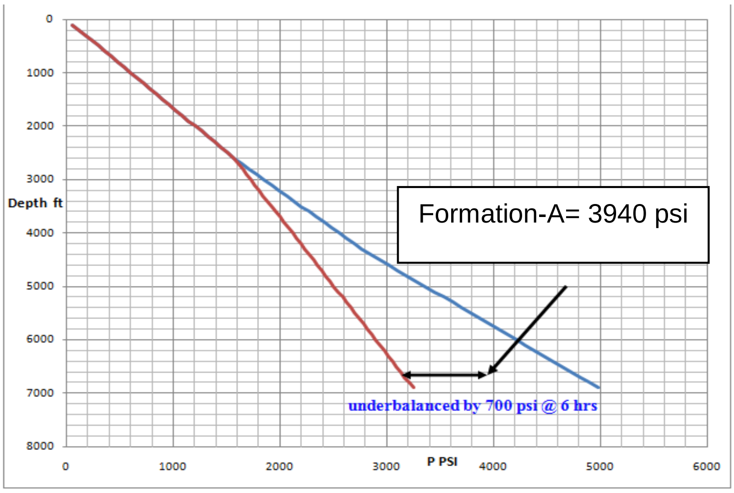
TGA analysis showed that cement lost approximatley 13% of mass due to moisture evaporation between 20 to150 ^{0}C. The cement sample suffered further weight loss of 13 % as temperature rose to 1000 ^{0}C due to decay of some elements. The sample mass decreased by 26% in total during the test. EDXRF results showed that cement samples after initial curing mainly consist of 60% of CaO and SiO_2 19% by weight. After curing in Formation-A conditions, less than 1% changes in mass occurred.

These findings showed that Formation-A water did not significantly harm cement integrity, even in the presence of high pressure for the 3-month test period. This finding was most likley due to the small amount of CO_2 gas present in the curing water. The picture will be clearer after the end of the 6-month test period.

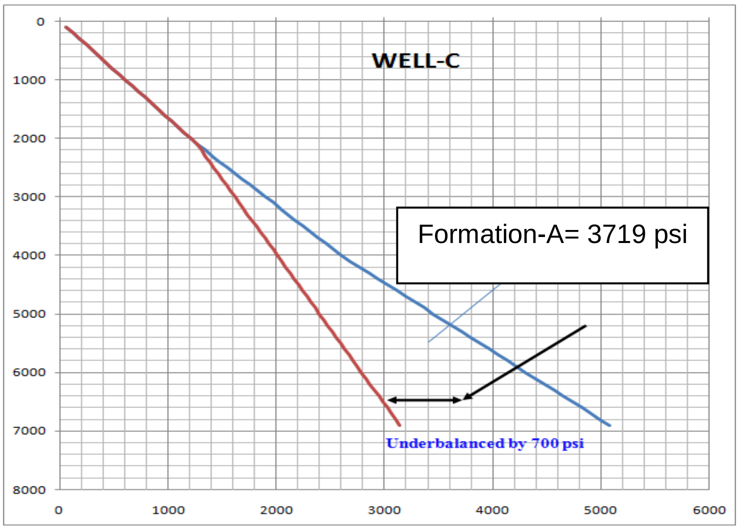
After an extensive review on the field practices, it is clear that the dominant factor contributing to communication between A and B formations is loss of hydrostatic pressure of the cement column, in addition to high Formation-A pressure. There were no deficiencies in field cementing practices, including: mixing and pumping cement, conditioning the hole prior to the cement job, mud cake removal, mud displacement and casing centralization.

A batch mixer was used in all cement jobs, as it gives an accurate density of cement slurry. The number of centralizers used in horizontal wells was selected to obtain 70% percent standoff across critical open hole sections. According to field findings, this degree of concentricity is fair enough for good zonal isolation. This result supports that centralization was not poor since that the problem also occurred in vertical wells where the stand-off is as high as 95%. Liner rotation and reciprocation within 60’ stroke in addition to circulation at rate of 4 BPM helped clean filter cake and provide uniform cement distribution around the casing. Conditioning mud to reduce its viscosity improves mud displacement efficiency through enhancing fluid mobility. In addition, liner rotation and reciprocation increases mud ability to erode and remove bypassed mud by reducing the casing to mud and wellbore to mud drag forces. The presence of spiral centralizer improved the flow regime of cement across horizontal sections. A compatible viscous spacer was used to separate cement and drilling fluid. The spacer helps avoid premature setting, channeling and contamination of, cement. The volume of spacer was calculated to give a contact time of 10 minutes, which is considered one of the widely used cementing practices. The spacer density was higher than mud and lighter than cement. This best cementing practices helps effectively displace mud and avoid mud bypassing cement.

Formation-A in this area has high reservoir pressure. Hence, it was easy for the cement column to be underbalanced against Formation-A before it was able to develop static gel strength of 500lb/100 sq.ft. When the under balance occurred, an inflow of water from Formation-A had contaminated the cement column in the annulus. Actual reduction in hydrostatic pressure experienced by a cement column is dependent on the development of its gel strength and a reduction in the slurry volume. To illustrate the occurrence of water flow from Formation-A during the primary cementing job in Wells A and C, the pressure loss profile calculated from Cooke [2] data was used. As shown below (Figure 1 and Figure 2), the loss in the hydrostatic pressure had likely caused the cement column to be underbalanced against Formation-A.



Figure#1: behavior of cement column pressure after 6 hrs from cement placement (well-A)



Figure#2: behavior of cement column pressure after 6 hrs from cement placement (well-C)

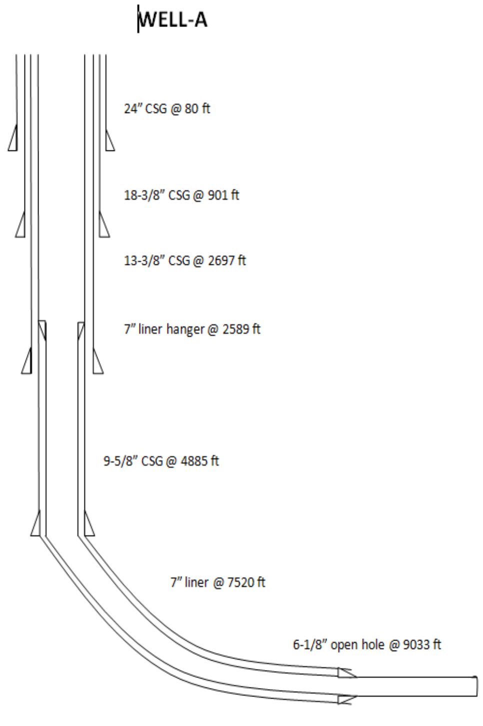
Figures 1 and 2, demonstrate that after the first six hours following the cement placement, the hydrostatic pressure of the cement column dropped by 700 psi, creating an under-balance situation and allowing for communication between formations. The main factor that caused poor primary cementing across Formation-A, behind the 7” liner was the loss of hydrostatic pressure in the cement column, after it was spotted in place in the annulus. In addition, setting the 7” liner top packer isolated the hydrostatic pressure from acting down onto the annulus and formations below. This isolation encouraged the flow of influx from Formation-A into the annulus. Use of 3000' long liner lap had also contributed to the loss of hydrostatic pressure, since the amount of loss in pressure is higher compared with a short cement column.

Conclusion:

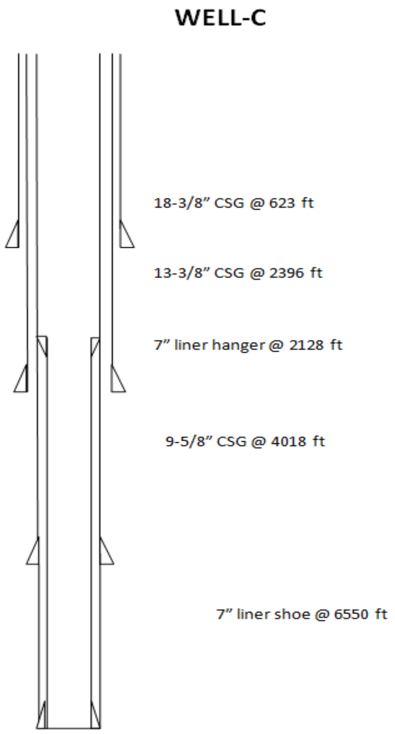
- The root cause of the communication problem was found to be the loss of hydrostatic pressure before the cement attained enough compressive strength.
- Cementing practices, including setting liner top packer and use of long liner lap, also encouraged water influx to attack and contaminate the cement.
- CBL logs showed poor cement, and water channeling confirmed the occurrence of communication.
- Three months of test results revealed that Formation-A water is not detrimental to cement during this period of time.
- Long-term test results will confirm if Formation-A is damaging to cement or not.
- Solutions, including: use of a short cement column, elimination of liner to packer, applying annular pressure and the use of zonal isolation packer between A and B formations, will help avoid cement contamination due to water influx during WOC.
- CBL should be run immediately after a cement job, such that corrective measures can be taken in a timely manner.
- Field practices showed no deficiencies except those previously highlighted.

Nomenclature:

CBL	: Cement bond log
WOC	: Wait on cement
EDXRF	: Energy dispersive X-ray fluorescence
TGA	: Thermo gravimetric analysis
N_2	: *Nitrogen*
pcf	: Pound per cubic foot
TVD	: True vertical depth
Y	: *Poisson’s* ratio
BPM	: *Barrel* per minute
E	: Young’s modulus
PLT	: Production logging tool
VLDT	: Voltage linear differential transducer



Figure#3: shows the well sketch for well-A



Figure#4: shows the well sketch for well-C

	Initial Curing		3 months Water Curing		3 months Formation-A water Curing	
	Sample- 11	Sample-12	Sample-17	Sample-18	Sample-113	Sample-114
Compressive Strength psi	8,609.1	10,024.8	11,587.7	12,030.6	11,279.9	12,270.0
Dynamic E psi	2.949E+06	2.930E+06	2.994E+06	2.933E+06	3.025E+06	3.001E+06
Static E	7.153E+05	2.322E+06	2.177E+06	2.120E+06	1.958E+06	2.400E+06
Dynamic Y psi	0.282	0.281	0.275	0.276	0.174	0.219
Static Y psi	0.125	0.125	0.298	0.275	0.290	0.258

Table#3: Shows mechanical properties

	Initial Curing		3 months Raw Water Curing		3 months Formation-A water Curing	
	Sample- 13	Sample-14	Sample-19	Sample-110	Sample-115	Sample-116
Permeability CC/min	0	0	0	0	0	0

Table#4: Shows permeability test results

Elements	Approximate Weight Percentages	
	8948 1-5 (Initial Curing)	8948 1-6 (Initial Curing)
CaO	60.12	60.30
SiO_2	19.85	19.76
Fe_2O_3	4.52	4.54
Al_2O_3	2.68	2.74
SO_3	1.89	1.88
MgO	1.87	1.93
K_2O	0.43	0.46
TiO_2	0.20	0.20
Mn_2O_3	0.04	0.05
SrO	0.04	0.04

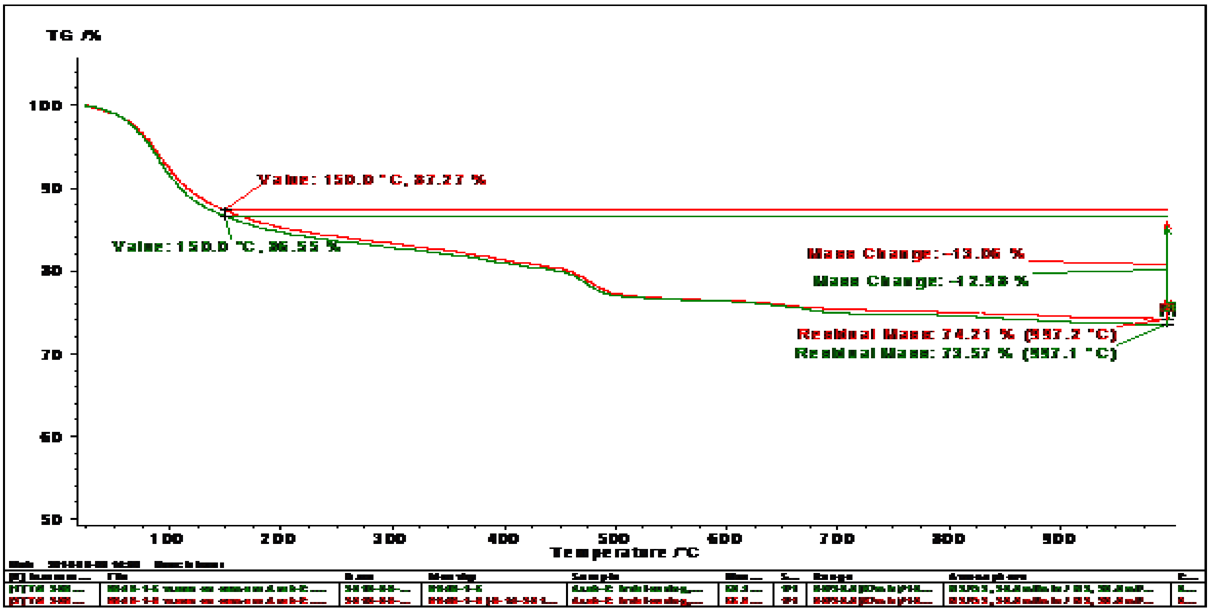
Table#5: Shows the chemical composition for cement after initial setting.

Compounds	Approximate Weight Percentages			
	Short term Formation-A water		Short term water curing	
CaO	58.89	59.32	60.92	60.88
SiO_2	18.08	18.32	19.15	19.10
Fe_2O_3	4.37	4.38	4.59	4.57
Al_2O_3	2.50	2.54	2.52	2.51
SO_3	2.53	2.49	1.94	1.94
MgO	1.90	1.86	1.76	1.79
K_2O	0.19	0.17	0.06	0.05
TiO_2	0.19	0.20	0.21	0.21
Mn_2O_3	0.04	0.04	0.04	0.04
SrO	0.06	0.06	0.04	0.04

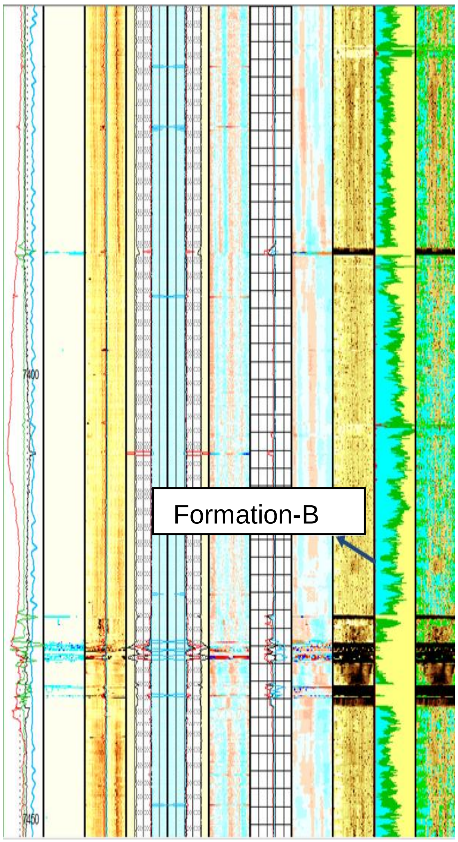
Table#6: Shows the chemical composion for cement after Formation-A water curing and raw water curing.

	Initial Curing		Short term Water Curing		Short term CO_2 Curing	
Sample#	116	115	111	112	117	118
Mass loss %	13.06	12.98	12.66	13.15	16.42	16.09
Residual Mass % (150-1000 ºC)	74.21	73.57	76.57	74.12	77.59	77.57
LOL % (20-150 ºC)	25.8	26.4	23.43	25.88	22.41	22.43

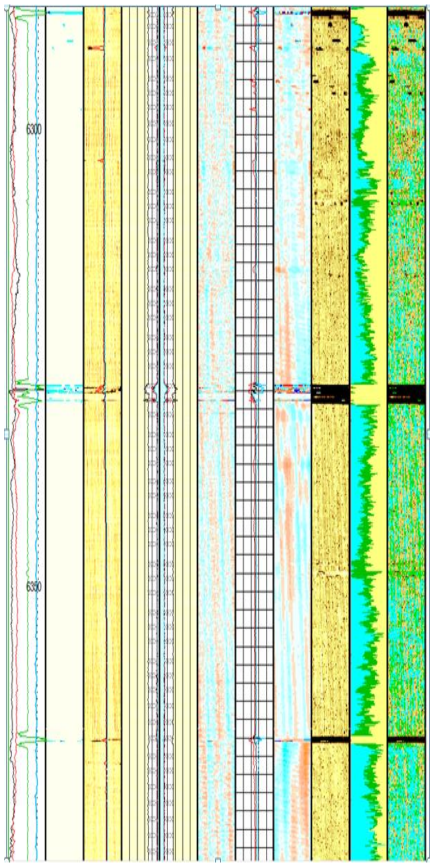
Table#7: Shows TGA results after initial setting, water curing and Formation-A water curing.



Figure#5: shows TGA chart for after initial curing



Figure#6: shows CBL for Well-A



Figure#7: shows CBL for Well-A

Figure#8: shows some cement samples before being exposed to Formation-A water.

Figure#9: shows some cement samples after being exposed to Formation-A water.

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