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A Practical Solution to Control Gas Migration

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Abstract

Drilling through gas formations poses unique risks such as annular gas flow after cementing. Annular flow related to cementing surface casing has been identified as one of the most frequent causes of loss-of-well control incidents in the Gulf of Mexico (GOM).[1] Poor cement bond has been credited with the most significant cause of annular casing pressure in outer casing strings. Statistics from the GOM indicate that thousands of wells have casing pressure and potential to lose hydrocarbon reserves, pollute the potable water column, or leak at the sea floor.[2, 3]

When zonal isolation of gas wells is not achieved, gas can migrate behind the casing, thus charging shallow formations. These shallow gas formations become a costly problem when they are drilled into unexpectedly. They can also become a formidable challenge when the fracture gradient and pore pressure become nearly equal. In these situations, gas can broach the casing and cause a blowout. Clearly, well plug-and-abandonment is complicated when casing annulus squeeze cementing becomes necessary to eliminate gas migration.

Several techniques to control gas migration have been individually utilized with varying degrees of success. These methods involve drilling processes, cementing systems, and mechanical barriers. Three wells in Eugene Island Block 273 have been drilled and completed by using these methods jointly. No gas migration has been detected.

In combination, these practices have the potential to improve the oil and gas industry by making it safer and environmentally friendlier and could ultimately reduce exploitation costs.

Introduction

Eugene Island Block 273 is a mature natural gas field located 75 miles offshore in the GOM. In early 2001, while drilling a developmental well in Eugene Island Block 273, the drilling rig Ensco 51 was evacuated and subsequently sustained severe damage. After cementing a third casing string at a depth of 1,650 ft, an uncontrolled annular flow occurred, causing rig personnel to be evacuated and a fire to ensue.

Known shallow gas accumulations pose a unique challenge as they are drilled. When proper precautions are taken, risks are mitigated. When these accumulations are formed by migrating gas from offset wells that lack zonal isolation, they become an unknown. They then become a greater formidable challenge when the fracture gradient and pore pressure become nearly equal. In these cases, gas can broach the casing and cause a blowout.

The oil and gas industry has long been plagued by issues caused by gas migration into the cement sheath, resulting in a lack of zonal isolation. This situation is exacerbated while drilling in gas zones because of well control concerns. A three-component technique has been developed to address this concern. These components are as follows: drilling a gauge hole; mixing and pumping correct cement systems; and, utilizing a mechanical barrier to prevent gas migration.

This paper will discuss how each component of this technique contributed to elimination of gas migration in a three-well project in the Eugene Island Block 273 gas field.

Objective

The operator's objective was to eliminate gas migration into the cement column. This enabled successful annular tests and circulation of cement to surface and will later simplify the removal of these wells when they are plugged and abandoned.

Scope of Study

Gas migration can be classified into two categories, namely primary and secondary.[4] Primary gas migration occurs during cement displacement. Secondary gas migration, on the other hand, occurs some time after cement placement has been completed. It is often caused by the integrity of the cement and not by placement techniques. Specifically, this paper will address the prevention of primary gas migration through use of proper drilling, cementing, and completing techniques.

Procedures

Inhibiting gas migration begins with the drilling process. Simply stated, by utilizing correct mud systems when drilling a gauge hole, drilling and circulation rates need to be maintained at appropriate levels in order to remove cuttings without creating washouts. Once a gauge hole is drilled, the drilling mud must be removed prior to placing the cement. It has been stated that this is the first step in preventing annular gas migration.[5] Bypassed mud can lead to channeling of gas behind the pipe. Cooke, *et al,* suggests[6] that the volume of mud bypassed during a cement job can approximate that of the hole in excess of the bit size. Centralizers and cement spacers are also useful in facilitating mud removal.

Next, understanding cement chemistry is necessary to eliminate gas migration. As cement hydrates, gas will enter the annulus when its pressure is lower than that of gas bearing formations. This phenomenon is caused by gel strength development and a reduction in cement volume.[6]

As cement hydrates, it develops gel strength and becomes self-supportive. This leads to a reduction in hydrostatic pressure exerted on the formation. As pressure in the annulus drops below the pressure in the formation, gas enters the cement column.

There are several factors that contribute to the reduction in cement volume which results in a loss of hydrostatic pressure. These factors include: the loss of free water; the slurry hydration process itself; and, uncontrolled fluid loss. This reduction in volume enables gas to occupy a space and gives it the opportunity to enter the wellbore as the pressure becomes insufficient to hold the gas influx.

The slurry hydration process, that is, when liquid cement is transformed into a solid state, is known as the transition period. As cement hydrates, calcium-silicate-hydrate ($C_3S_2H_3$), also called C-S-H gel, precipitates and water is consumed. This hydration process causes the cement to occupy less volume than the components from which it is created. Porosity is formed in this manner. Cement bulk volume reduction has been estimated to be approximately 1%, while internal shrinkage can be in the 4 – 6% range.[7] This reduction in volume and increase in porosity can lead to gas migration.

Numerous advances in cement slurry have been achieved to prevent gas the opportunity to enter the casing annulus. Gas blockage cements were developed to combat gas migration by utilizing several mechanisms. These mechanisms include the following: reducing cement slurry porosity and permeability; improving fluid loss control; and, building gel strength rapidly.

The first building block to chemically eliminate gas migration into the cement column is to reduce cement slurry porosity and permeability. Permeability in the cement during the liquid to the solid transition period allows gas to enter the cement column. During this critical time, reducing permeability in the cement by viscosifying interstitial water or reducing space in the cement matrix can eliminate gas migration.

Reducing transition time in cement slurries is also a means to mitigate gas migration. Cement systems that rapidly build gel strength are known as right angle set cements. Graphically, these cements resemble a right angle as gel strength increases rapidly with time until the slurry is set. They have low gel strength and low permeability and exert full hydrostatic pressure on the formation. Then these systems build gel strength, leading to a rapid set. In this manner, gas is not given ample time to invade the cement.

Proper placement of the cement system is just as important as the system itself. Placement design includes the cement system, density control and mud removal.[7]

Density control can be defined as the designing of fluid hydrostatics necessary to hold back formation fluids, while not exceeding fracturing pressures in the wellbore. Any deviation below pore pressure will cause reservoir fluids to flow into the cement sheath. Any deviation above the fracturing pressure will cause a zone to fracture. This breakdown will cause a lack of returns, thus reducing hydrostatic pressure available in the annulus. It should be noted that before the cement sets, any change in the hydrostatic pressure can cause well control issues, even those induced by poorly managed rig operations, the human factor.

Without proper mud removal, channels filled with mud will be left in the cement sheath, thereby creating a pathway for gas to migrate. Mud can also contaminate cement, thereby changing the properties of the pumped cement.

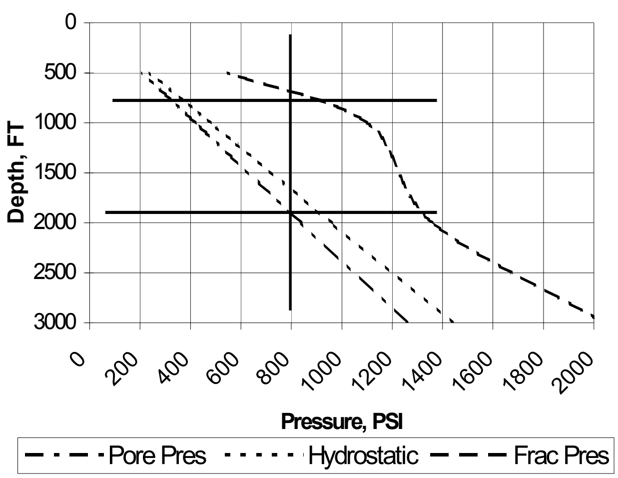
The final process that must be understood is how to utilize mechanical barriers to create obstructions to gas migration. Casing annulus packers provide annular isolation, while port collars can provide the ability to stage cement without needing to drill out cement. Port collars are not just limited to stage cementing, but can also include cementing contingencies, casing retrieval contingencies, and the ability to dispose of cuttings and mud.[8]

Specifically, in order to stop gas from entering the annulus during cementing operations, a casing annulus packer can be used to form a seal in the annulus directly above a gas bearing formation. This inflatable packer can be filled with either mud or cement to form an impermeable barrier, thereby not allowing gas to invade the cement sheath above the gas zone. Utilizing a port collar placed above the casing annulus packer and pumping a second stage cement job will ensure that the cement above the casing annulus packer will not be gas-cut.

Vrooman, et al., indicate that gas migration can be eliminated from reaching the surface by utilizing mechanical barriers.[9] Two concerns must be addressed while using barriers such as casing annulus packers. These concerns are the ability to effectively achieve a seal between the open hole and the inflatable element in soft, unconsolidated formations as well as the accumulation of gas below a casing annulus packer that is of a higher pressure than the minimum stress required to fracture the surrounding formation.

If indeed the well conditions do make the environment non-conducive to creating a mechanical barrier to gas migration, the casing annulus packer must be set in the previous casing string. As distance between the gas formation and the casing annulus packer increases, fracturing pressure must be reviewed. As Figure 1 illustrates, an accumulation of gas from a deeper zone that migrates upward can reach fracturing pressures for shallow formations and cause the gas to broach the casing and well control will be lost.

Figure 1
Shoe Integrity Plot



Results and Observations

Three wells were drilled and completed using a three-component process to eliminate gas migration. These three components included modifying drilling techniques, using chemical gas blocking cementing systems, and utilizing mechanical barrier systems.

First, drilling was modified by boring a gauge hole that facilitated improved efficiency in mud removal.

Second, a cementing system that had the following properties was utilized:

1. Fluid loss less than 50 ml / 30 minutes
2. No free water
3. Cementing setting times kept to a minimum
4. Right angle cement system with gas migration additives utilized
5. Correct additives for low temperature
6. Use of weighted spacers to maintain the proper hydrostatic between pore pressure and fracturing pressure.

The third component of the strategy was the use of mechanical barriers to ensure good zonal isolation. This was accomplished by utilizing a casing annulus packer, a port or stage collar, and a two-stage cement job. The design called for pumping the tail cement, followed by a casing plug. Once the casing plug landed, pressure was increased and the casing annulus packer was mud inflated. Next, the port collar was opened utilizing a shifting-cementing tool (combo tool). This tool, which was run on drill pipe, was then pumped through until circulation was achieved in the casing annulus. Cement followed and was circulated to the surface.

The operator chose to run a casing annulus packer and a port collar on the conductor, surface, and intermediate casing strings in two of the wells. He used a casing annulus packer and port collar on the surface and intermediate casing string in the other well. He then pumped two stage cement jobs in each well. Figure 2, Well D-2, illustrates the typical configuration used in the three-casing annulus packer configuration.

Typical Well Architecture

Field experience gained from EI 284, D1 was used to design wellbore architecture for the three wells.

Casing Annulus Packer Depths

The casing annulus packers were set in the previous casing strings because the compressive strength of the formations was low, the open hole interval geometry was unknown, and the pore pressure of the sand at 1,700 ft would not be sufficient to broach the shoe at 680 ft.

Drive Pipe

In Well D2, the 26-in. drive pipe was set at a depth of 667 ft, MD. This depth was chosen to isolate a lost circulation zone experienced in the previous D1 well. In case the drive pipe setting depth was not sufficient to cover the lost circulation zone while drilling the conductor hole to + or – 20 ft above a known shallow gas formation, mud squeezes, LCM pills, and drilling ahead without returns were planned as contingencies.

Conductor Pipe

Next, an 8 ½-in. pilot hole was drilled to the conductor casing point of 680 ft. The hole was circulated with the appropriate mud weight to minimize gas influx. The hole was progressively opened and 18 5/8-in. casing was set with no rigid centralizers. The casing annulus packer was set at 485 ft and the port collar at 473 ft.

The first stage cement was pumped utilizing tail slurry only. After the top plug was bumped, pressure was increased in stages, inflating the casing annulus packer with wellbore fluid. The combo tool was run in the hole and manipulated to open the port collar. The pump was engaged, and circulation was established through the 18 5/8-in. annulus and out of the plus ten valve.

The second stage of the conductor pipe cement job was then pumped, utilizing tail slurry only. In order to clear the combo tool, the cement was over-displaced by one barrel. The port collar was closed and tested.

Surface Pipe

The surface hole was drilled with a 9 7/8-in. bit through two suspected gas formations, at approximately 707 ft and at 1,700 ft. The same drilling procedure described in the previous casing section was followed. The hole was opened using a 9 5/8-in. x 17 ½-in. hole opener. Then, at 1,695 ft, the 13 3/8-in. surface casing was set.

The surface casing was deployed with 15 rigid centralizers. The same cementing procedure employed during conductor pipe cementing was followed when cementing the surface casing. Both a lead and a tail slurry were pumped for the first stage cementing, and only tail slurry was pumped for the second stage cementing. Cement was circulated to the surface.

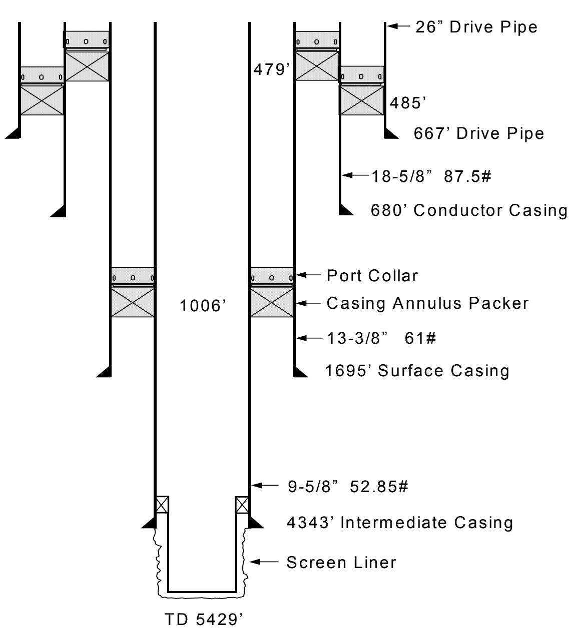
Intermediate Pipe

The intermediate hole was drilled with a 9 7/8-in. pilot hole and back reamed to a 12 ¼-in. hole. The 9 5/8-in. casing was deployed and set at 4,343 ft MD, utilizing 70 rigid centralizers. Tail slurry was pumped for the first cement stage. During the first stage of cementing, the plug failed to bump. At this point, one additional barrel was pumped. To prevent over-displacing the cement and possibly creating a wet shoe, the combo tool's flexibility was used to inflate the casing annulus packer. After the casing annulus packer was inflated, the combo tool opened the port collar and established circulation. The second stage was then cemented with only tail cement which was subsequently circulated to the surface.

Finally, the production hole was drilled below the 9 5/8-in. casing and both screen and liner were installed.

Two additional wells were drilled and subsequently completed similarly with no gas migration problems.

Figure 2
Well D-2 Wellbore Architecture



Conclusions

1. Understanding the mechanisms which cause gas migration and addressing them in the drilling program can eliminate it.
2. Gas migration can be mitigated by utilizing proper drilling techniques, gas block cement systems, and casing annulus packers.
3. Wellbore mechanics need to be understood before casing annulus packers are deployed.
4. Wellbore abandonment is simplified with the elimination of gas migration.
5. Before infield drilling is done, gas migration is a concern that needs to be addressed before problems arise.
6. Through better completion practices, the industry will be safer and more environmentally responsible.

Acknowledgments

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