How Bottom-hole Conditions Affect Design of Squeeze Cement Jobs

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INTRODUCTION

Squeeze cementing operations normally are remedial cementing jobs performed for some purpose other than to set the pipe in the borehole during initial completion operations. The name probably is derived from the fact that the slurry is forced by applied pressure, or "squeezed", into place. In the past, this was done with neat cement slurries, and cement was pumped until high squeeze pressures were attained. The success ratio of these jobs was low because they did not take into account the down-hole conditions or the behavior of the slurry under these conditions. In recent years, tools have been developed which supply important down-hole information. This information, along with years of experience and study, have uncovered some of the necessary factors to be considered in the design of a successful cement squeeze job. Additives have also been developed which control the slurry properties and allow different placement techniques.

PURPOSE OF SQUEEZE CEMENTING

Squeeze cementing is done for one or more of the following reasons:

(1) Repair the primary cement job.
(2) Shut off unwanted water and gas.
(3) Shut off channels above or below producing zone.
(4) Repair casing leaks caused by rupture or corrosion.
(5) Abandon depleted or non-productive zones.
(6) Alter injection profiles.

It is apparent from these widely varied uses that a great amount of information is needed in order to design or plan a successful squeeze job. Actually, two types of information are needed: These are well information and cement slurry information. The well information is necessary so that we may resolve the problem and arrive at the most practical solution. Also, down-hole conditions affect the cement slurry and we must know these conditions in order to formulate the best slurry to suit the conditions. Then, a knowledge of the slurry properties and slurry behavior under the down-hole conditions is needed to permit safe and effective placement of the slurry.

WELL INFORMATION

Some of the basic well information needed to plan a successful squeeze cementing operation are:

1. ROCK CHARACTERISTICS. Permeability, porosity, fracture gradient, fracture orientation, bottom-hole temperature and pressure, type of rock, and type of permeability.

2. STIMULATION HISTORY. Type of treatment, type of fluid, injection rate and pressure, instantaneous shut-in pressure, and 15-minute shut-in pressure.

3. DIFFERENTIAL TEMPERATURE OR RADIOACTIVE SURVEYS. Logs indicating points of fluid movement through perforations, behind the casing, in open-hole are in or out of different zones.

Type of Rock. Sandstone and carbonate (limestone or dolomite) are the two basic types of producing formations. Sandstone is usually characterized by a porous matrix with production from the pores. Sandstone may contain fractures, either man-made or natural; but the major part of the oil is usually contained in the pore spaces. Limestone and dolomite can usually be characterized as very impermeable with production from connecting fractures or vugs. Core analysis along with experience in the field gives an excellent idea of the type of formation and of its physical properties such as permeability, fracturing gradient and fracture orientation.

Permeability. The permeability of a formation directly controls the dehydration of a cement slurry or the growth rate of a filter cake. In order to understand the dehydration of a cement slurry, it is necessary to consider the physical characteristics of the cement slurry. A cement slurry consists of small particles in a suspension. These particles are small, but not small enough to be forced into the pore spaces of formations. Because of their size, the only way a cement slurry can be forced into the formation is to create a fracture or open up an existing fracture and pump the cement slurry into the fracture. When a cement slurry is forced against the face of a sandstone formation with a permeable matrix, the cement particles will be filtered out on the face of the formation and the filtrate will be forced into the formation. During a squeeze job, it is necessary to control the rate at which these particles are filtered out. As these particles are filtered out, they form a hard, immovable filter cake. If the filter cake forms too fast, we experience what is known as premature dehydration. This amounts to no more than losing all of the fluid from the slurry to the formation by filtering the solids out on the formation. The dehydration rate can be controlled by low-water-loss additives in the cement or by a formation that is so impermeable as not to accept filtrate except at a very slow rate. Limestone or dolomite formations in this area of West Texas and Southwestern New Mexico usually have impermeable matrices with fluid flowing through connecting fractures and vugs. These fractures are further characterized by hairline fractures extending from the main fractures. These hairline fractures do not open up under the fracture pressure of the formation, but will accept fluids under these pressures. By accepting fluids, the filter cakes are formed at the intersection of the hairline fracture with the main fracture in the same way that the cement slurry dehydrates upon contact with a sandstone formation.

Fracture Gradient. The fracture gradient has a marked influence upon the slurry designs as well as the placement techniques. The carbonate formations in this area are characterized as having high or low bottom-hole fracturing pressures. In formations with low bottom-hole fracturing pressures, fluid can be pumped into the formations with low bottom-hole injection pressures. In some cases, the formation will not even support a full column of water. A column of cement will usually fracture these formations and enter the formation on a vacuum. The objective for squeezing this type of formation is to stop the movement of cement into the fracture. This can best be accomplished by using an accelerated cement with lost circulation materials followed by neat cement. By the use of a high-water-loss cement, a filter cake will build up as fast as the formation can take the filtrate and hopefully build up a low squeeze pressure. A high squeeze pressure is very difficult to obtain and is not necessary for a successful squeeze. In carbonate formations with high fracturing pressures, a different type of slurry is required. A high-water-loss slurry would rapidly dehydrate and lock up with the usual result of an unsuccessful squeeze job. With a low-water-loss cement, the desired volume of slurry can be pumped into the fracture in sufficient quantities to shut off the migration of unwanted fluids. When the fracture is filled with slurry, pumping can be stopped and the slurry allowed to dehydrate and fill the fracture with hard, immovable filter cake. If the initial slurry does not give a successful fluid shut-off, more slurry can be pumped and allowed to dehydrate by the hesitation method of pumping.

The formation fracturing pressure is the pressure of the fluid in the hole on the formation when fracturing occurs. The surface pressure is an indication of the fracture pressure, but the bottom-hole pressure is the sum of the weight of the fluid in the hole plus the surface pressure. Where it is desired to squeeze a perforation or channel, it is necessary to stay below the bottom-hole fracture pressure until the channel or perforation is completely filled with filter cake. Squeeze pressures higher than formation fracture pressures, although not necessary, can be attained by building a filter cake inside of the casing so as to completely isolate the formation from the pressure exerted on the slurry.

Well Surveys. Squeeze jobs are often performed to shut off water from outside the perforated production interval. Fractured formations and communication through channels past the cement in the borehole are the usual sources of this water migration. If a zone tests waterfree on a D.S.T., then produces water upon completion, a faulty primary cement job or a manmade fracture is expected. A study of the stimulation treatment reports could indicate the possibility of a fracture or show that there is no reason to expect a fracture. When there is uncertainty about the source or path of incoming water, it might be advisable to conduct a differential temperature or a radioactive survey. Instead of a flow channel behind the pipe or a fracture, these surveys have shown the source of water to be a hole in the pipe. To efficiently design squeeze jobs to shut off the water, it is necessary to have this information. In order to squeeze a flow channel due to a faulty cement job, it is necessary to use a low-water-loss cement having a low viscosity and place the cement without exceeding the bottom-hole fracture pressure. If squeeze pressure is not attained after allowing the initial channel volume to dehydrate, the hesitation pumping method can be used to fill the channel with filter cake. Bottom-hole pressures higher than fracture pressure cannot be attained until the filter cake has grown into the casing and completely isolated the formation from the pressure exerted on the slurry column. Holes in the casing string are the most difficult type of water shut-off to be performed with cement slurries. A recently-developed cementing system having the unique property of developing high gel strengths has greatly improved the success ratio. The great advantage of immobilizing the cement until it can set, along with the short setting time of this cement, makes it especially suited for this application. In order to prevent the migration of fluids through a fracture, it is necessary to fill the fracture with hard, immovable filter cake. The most efficient method for doing this is to fill the fracture with a thin low-water-loss cement slurry, then stop pumping and allow the slurry to dehydrate. If this does not give a satisfactory squeeze, slurry can be pumped into the fracture by the use of hesitation pumping techniques until a standing squeeze pressure can be attained.

Laboratory Testing. Use of modern cement-testing equipment, along with quality control checks periodically conducted on the cements and additives, increases the reliability of a prediction of how long it will take a cement slurry to set, gain strength and dehydrate. In a modern cement squeeze job, it is not uncommon to perform the actual squeeze at temperatures far above ambient. The slurry is first modified to have the water-loss characteristics at the bottom-hole conditions by tests designed to determine the fluid loss under these conditions of high temperature and pressure. These tests are very critical when it is considered that too little low-water-loss additive could result in premature dehydration and too much could result in insufficient filter cake build-up before the thickening time of the slurry is reached. After the proper concentration of low-water-loss additive is determined, the retarder will be added to give a sufficient thickening time. This slurry is then tested under the conditions of high temperature and high pressure to determine the length of time it requires for the slurry to become stiff and unpumpable.

The recent development of a liquid fluid-loss additive for cement has improved fluid-loss control and eliminated some mixing problems. This material is mixed in the mix water instead of being dry-blended in the cement as all others are. This material does not alter the viscosity of the cement slurry and has little effect on the thickening time. It performs well at high temperatures. An ideal fluid-loss agent should give good fluid-loss control, but have no undesirable side effects. This liquid fluid-loss agent approaches such an ideal material.

An expanding cement has become available in this area in the last few months. This cement is milled in this area and is available in bulk at a cost per sack comparable to Class C type cements. We have used this cement in a number of wells for both primary cementing and squeeze work. Bond logs show good bonding with this cement. We believe it has an important application in squeeze cementing due to its expansion and gelling properties. This cement will obtain high gel strength when movement is stopped or slowed down.

This cement is being mixed at 14.8 pounds per gallon. Thickening times are shorter than Class C at a given temperature and pressure. A special retarder is available for high temperature conditions. The cement is compatible with most fluid-loss additives, accelerators, and dispersants. The per cent linear expansion and shear bond strength is much greater than with any other expanding-type cement. The expansion-producing ingredients are mixed in this cement at the mill.

CONCLUSIONS

While progress has been made in materials, tools and techniques used in squeeze cementing, improvements are still needed. The success ratio of squeeze cementing still must be increased. The number of stages needed to obtain desired results must be reduced. As better cementing materials become available and better tools are developed to furnish more and more knowledge, the success of squeeze cementing operations will continue to improve.