Squeeze Cementing In Carbonate Reservoirs

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INTRODUCTION

Production in the West Texas area is primarily from carbonate (dolomite and limestone) reservoirs. This environment presents a special set of conditions in the realm of squeeze cementing. Techniques have been modified in recognition of these features. As a result, a formerly poor squeeze record in the area has seen noticeable improvement.

A major problem in this carbonate background is the existence of fracture network systems. These fractures occur naturally, are created inadvertently during drilling and completion, or result from well stimulation efforts. To compound the difficulties in remedial squeeze efforts, they are of probable vertical extension. This is supported by modern theories on hydraulic fracturing, and temperature and radioactive tracer work.[1]

Other common problems include abnormally low temperature gradients, low standing well fluid levels, and long intervals of perforations.

In contrast to squeeze cement applications in permeable sandstones where prime interest is basically on slurry behavior within the perforations (or at least of nominal penetration), a major consideration in squeezing in a carbonate environment is the cement fill of fractures and/or channels. There is less emphasis on filter cake buildup. This approach results in the use of larger volumes of slurries than normally used in squeezing of permeable sandstone reservoirs.

RESERVOIR CONDITIONS

Obviously, the application of squeeze cements has a limited range in the reservoir. It is basically a tool to help correct problems near the wellbore.

Induced fractures in the vicinity of the wellbore result from ordinary drilling, completion, and production practices. Some of the fractures are easily visualized as being too small to readily accept a squeeze slurry containing solids. On the other hand, vertical communication is created; undesirable gas and/or water enters the production zone, and/or injected fluids are not confined to oil-bearing formation.

These fracture networks are not easily plugged. Pump pressure in conjunction with the hydrostatic head of the cement column may tend to extend the fracture network. Cement slurries used for squeeze applications result in a minimum pressure gradient of .75 psi/ft which is greater than the fracture gradient for most carbonate reservoirs, as shown in Table 1.

The squeeze cement slurry must therefore be designed to properly fill the fracture network in order that the area of interest be isolated. This fracture network includes the hairline fractures as well as the primary network.

TECHNIQUES OF SQUEEZE CEMENTING

The most successful techniques of squeeze cementing carbonate reservoirs are (1) highly accelerated cement slurries pumped ahead of moderate fluid loss cement slurries, (2) moderate fluid loss cement slurries pumped ahead of slurries containing bridging materials, or (3) combinations of the two.

Accelerated cement slurries designed to set up shortly after reaching the formation are pumped into areas of least resistance and allowed to take initial set. Once this has occurred, moderate fluid-loss cement slurries can be forced into less accessible fractures. These accelerated slurries vary with BHT and depth. The prime objective is to design a slurry compatible with bottom-hole conditions that will take initial set 10 to 15 minutes after placement. Pumping times for some of the slurries used under different conditions are recorded in Table 2. Accelerated cement volumes range from 35 sacks up to 100 sacks.

Due to the low permeability of most carbonate formation, low percentages of fluid loss additives give desired control. Fluid loss control is adequate when placement of sufficient volumes of slurry can be obtained without premature dehydration. On filter paper the amount of control is only moderate, thus the term moderate

Comparison of Flood Front Advancement

Parallel to Grid Axes.

Formation	Field	County	Average Depth	BHTP Gradient
Santa Rosa	Pegasus	Midland	1304	0.900
McKnight	Sand Hills	Crane	3469	0.744
San Andres	Penwell	Ector	3528	0.888
San Andres	Dunes	Crane	3626	0.765
San Andres	Foster	Ector	4235	0.558
San Andres	Addis	Ector	4285	0.595
Grayburg	No. Cowden	Ector	4296	0.485
San Andres	Andrews	Andrews	4309	0.526
San Andres	Goldsmith	Ector	4328	0.595
San Andres	No. Frankel City	Andrews	4510	0.750
San Andres	Triple N	Andrews	4605	0.495
Glorietta	Penwell	Ector	4612	0.559
San Andres	So. Cowden	Ector	4713	0.534
Tubbs	Sand Hills	Crane	4814	0.817
5600 Clearfork	Goldsmith	Ector	5674	0.596
Wolfcamp	Sand Hills	Crane	6360	0.657
Tubbs	TXL	Ector	6499	0.579
Clearfork	Furman-Mascho	Andrews	7000	0.636
Upper Spraberry	Driver	Midland	7184	0.489
Upper Spraberry	Stanton	Martin	7223	0.503
Upper Spraberry	Tex-Harvey	Midland	7293	0.470
Upper Spraberry	Midkiff	Upton	7418	0.459
Wolfcamp	TXL	Ector	7745	0.578
Devonian	TXL	Ector	7930	0.638
Lower Spraberry	Stanton	Martin	8045	0.498
Lower Spraberry	Midkiff	Upton	8454	0.533
Montoya	TXL	Ector	8602	0.680
Devonian	Dune	Crane	9140	0.666
Waddell	TXL	Ector	9470	0.735
Devonian	Emma Cowden	Andrews	10545	0.630
Devonian	South Andrews	Andrews	10962	0.580
Devonian	Headlee	Ector	12077	1.686
Fusselman	Pegasus	Midland	12287	0.740
Fusselman	Pegasus	Midland	12296	0.633
Devonian	Pegasus	Upton	12388	0.705
Ellenberger	Pegasus	Upton	13120	0.764

fluid-loss control slurries. Fluid loss tests on cores are shown in Fig. 1.

A combination of two basic slurry types is utilized in a second technique for squeezing carbonates. A moderate fluid-loss cement is utilized as a lead slurry to fill the primary existing fracture and channel extremities. This is followed by a high-strength slurry incorporating lost circulation materials. The bridging agents immobilize the slurry in the fractures to create resistance against free flow or loss of the slurry through the fractures due to the hydrostatic weight of the fluid in the tubing. The bridging agents help to plug the fractures so that a pressure differential may be developed to force slurry into the entire fracture network.

The end result is the same in either technique; fracture and channel openings in the

TABLE 2

ACCELERATED CEMENT SLURRY

Cement Mixture	Weight	Temp.	Pumping Time	Strength
1:1 Calseal Type C	14.1 lb./gal.	80°F	30 min.	2 hr. 400 psi 4 hr. 600 psi 8 hr. 850 psi
1:1 Calseal Type H	15.3 lb./gal.	80°F	23 min.	2 hr. 680 psi 8 hr. 730 psi
Type C with 2% $CaCl_2$	14.1 lb./gal.	80°F	3 hr. 30 min.	8 hr. 940 psi
		100°F	3 hr. 10 min.	8 hr. 1280 psi
		120°F	2 hr. 30 min.	8 hr. 1400 psi
Type H with 2% $CaCl_2$	15.6 lb./gal.	100°F	2 hr. 30 min.	8 hr. 850 psi
		120°F	2 hr. 06 min.	8 hr. 1260 psi

vicinity of the wellbore are filled with cement slurry.

A variety of bridging materials is used with the squeeze slurries, such as sand, gilsonite, walnut hulls, and flocele. Sand is the most common in concentrations of 5 to 10 lb per sack of cement. The cement slurries containing lost circulation agents are normally mixed at heavier than normal densities; this improves the suspension of the solids in the slurry.

The second slurry in either technique outlined above is frequently densified. This serves two purposes. First, it promotes a more rapid dehydration since the slurry is prepared with minimum mixing water. Secondly, the densification promotes higher strength, inhibits breakdown of the squeeze during drillout, testing, and subsequent recompletion.

Table 3 depicts compressive strength values for various normal and densified slurries.

A proper design of squeeze cement should be based on individual well study. Emphasis is placed on a single-stage squeeze application. Sufficient slurry volume is of prime importance. An average carbonate squeeze consists of 200 to 400 sacks of cement, as reported by Goolsby.[2]

It should be noted that the volume of 200 to 400 sacks is considerably larger than amounts normally associated with squeezing sandstone formations.

The advantage of a one-stage squeeze is mainly economics. The added cost of extra cement to provide the 200 to 400 sack requirement is justified in contrast to the cost of several small squeeze stages.

EXAMPLE JOBS

A temperature log showed that water was being injected above the San Andres formation. Open hole was plugged back with sand and the thief zone was squeezed below a drillable retainer. Fifty sacks of 1 to 1 Calseal—Class C cement mixed at 14.3 lb/gal were followed by 250 sacks Class C with 0.2 per cent fluid loss additive

TABLE 3

COMPRESSIVE STRENGTH OF DENSIFIED CEMENTS

Type Cement	Slurry Weight Lb./Gal.	Strength in 12 hr.	
		80°F	100°F
Type C	14.1	300 psi	490 psi
	16.0	3000 psi	5719 psi
Type H	15.6	410 psi	900 psi
	17.5	1412 psi	2692 psi
Type C, 0.2% Halad 9, 10 lb. Sand	15.5	1068 psi	2136 psi
Type H, 0.2% Halad 9, 10 lb. Sand	16.5	379 psi	1500 psi

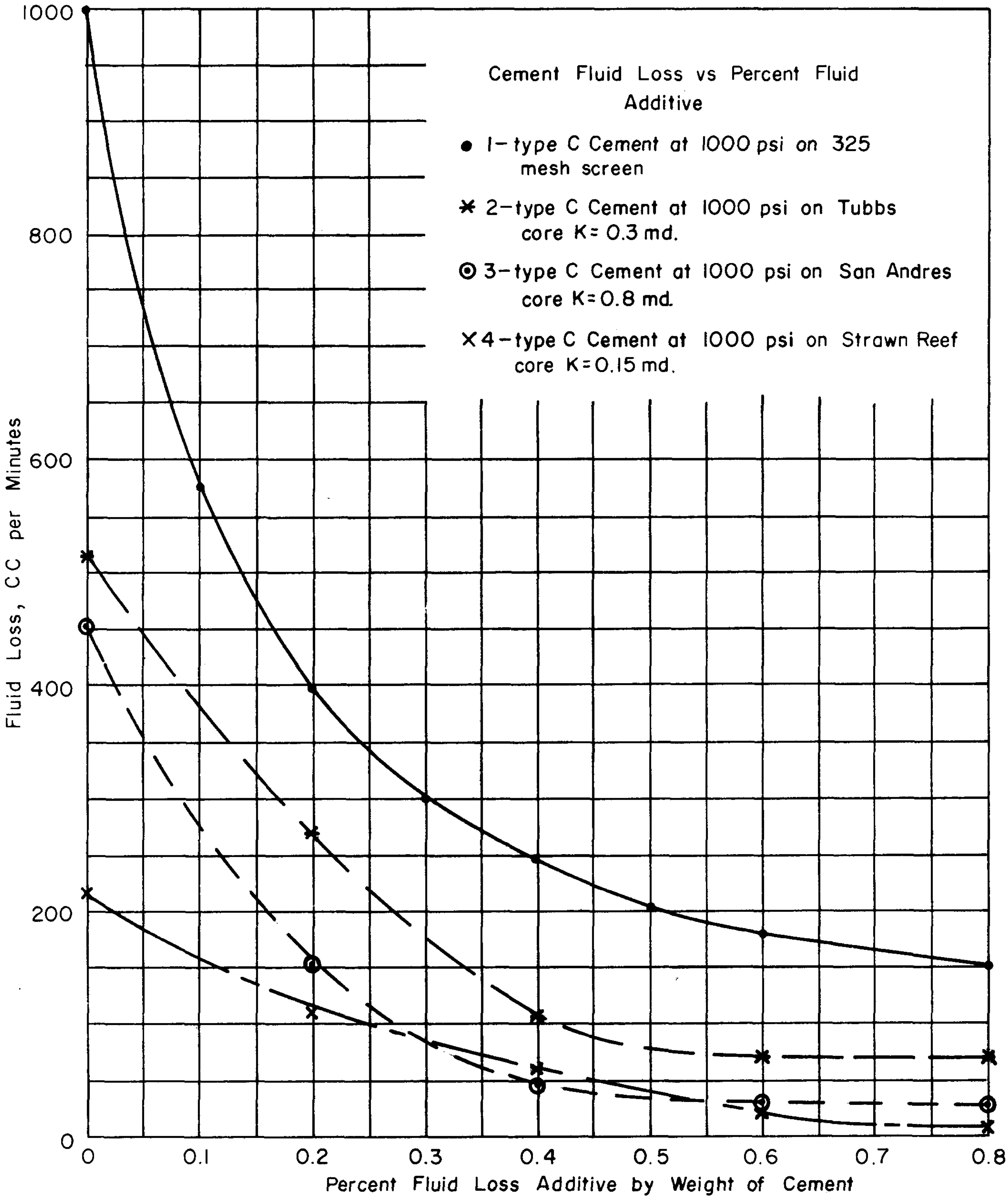

FIGURE 1

Fluid Loss Per Minute Versus Percent Fluid Loss Additive, By Weight Of Cement.

and 10 lb 16-50 mesh sand mixed at 14.8 lb/gal. The rate was reduced when accelerated cement was in the formation to allow cement to set. The cement was staged and a final squeeze pressure of 1500 psi was obtained. The well was again logged after drillout and reinjection. Fluid is now being injected into the desired interval.

Following is a design of moderate fluid-loss cement ahead of cement containing bridging materials that has proven very successful for water shutoff in the Grayburg. Two-hundred sacks Class C with 0.3 per cent fluid-loss additive mixed at 15.5 lb/gal are followed by 200 sacks Class C with 3 lb salt per sack and 6 lb 16-50 mesh sand per sack mixed at 17 lb/gal. Initial pump-in pressure was 500 psi and the final squeeze pressure 2200 psi. This one-stage squeeze resulted in 100 per cent water shutoff after recompletion. Many jobs of this type have held, even in wells that were fractured during recompletion.

SQUEEZE PRESSURES

Pressure limitations during initial pumping and in final stages of the squeeze job are subjects of controversy.

Literature cautions against "fracturing pressures".[3] This is very sound reasoning in the realm of squeezing permeable sandstones. There the emphasis is on dehydration of the slurry against a permeable background to build a high-strength filter cake. Nothing is gained by parting the formation.

In the case of low-permeability carbonate formations, a different set of conditions exist. In fact, the formation is probably already fractured. Preoccupation with fracturing pressures may be unrealistic. A full column of cement in the tubing may itself create fracturing pressures. The use of accelerated spearhead slurries conveniently overlooks the fracturing pressure. Here the immediate concern is the placement of the slurry below the squeeze tool within safe limits of its reduced pumping life. Very little concern exists in actual field practice over pressure criteria while pumping the hazardous accelerated cement.

Extremely high squeeze pressures in the range of 4000 to 8000 psi are not necessary under ordinary squeeze applications; however, they are not necessarily detrimental.

A rule-of-thumb is attainment of 500 to 1000 psi standing pressure above initial pump-in pressure. If the pressure continues to bleed off, it may be necessary to raise the pressure intermittently for ultimate lockup. This may occur at a value higher than originally designed. It is of prime importance at the end of the squeeze that no bleed-off occurs. Bleed-off is an indication that the network is not filled; additional slurry is needed.

If the formation continues to take fluid at the exhaustion of slurry reserve in the pipe, it should be cleared in preparation for a second stage.

Ultimate squeeze pressure is unique to an individual squeeze job. Lockup can usually be achieved below 3000 psi.

SQUEEZE PACKERS AND PACKER SETTINGS

Two basic squeeze tools are available in the industry, retrievable and drillable.

The retrievable packer affords the advantage of convenient repositioning and removal. The well can be selectively tested and squeezed in one trip. The disadvantage is the lack of control over pressure differentials. Recovery of the tool may become difficult in event of downhole problems.

The drillable packer contains a back-pressure valve which helps guard against slurry flow-back into the casing during reversing of excessive slurry. Some types contain a sliding valve which can be closed against a pressure differential from above or below. This permits removal of the hydrostatic head from the slurry at job conclusion. The drillable type may be set much closer to the interval, due to its drillability and added control.

Proper selection of squeeze packers is as much a part of proper squeeze design as materials. Using the correct packer can simplify the entire operation.

Careful consideration should be given to the setting of the squeeze packer. A close setting provides minimum cement drillout. This is of major importance where densified slurries with sand are utilized in the squeeze operation. This type cement is particularly hard to drill. However, the close setting does not provide optimum clearing of the tubing of cement slurry early in the squeeze operation. A remote setting facilitates better displacement of slurry below the tool. With all the slurry below the tool, the squeeze operation may be completed with comparative ease.

Job conditions dictate choice and positioning of the tool. In most cases, the close setting becomes a poor risk due to added recovery operation hazards at the gain of less cement drillout.

CONCLUSIONS

1. Carbonates require special squeeze techniques.
2. Greater emphasis is on cement fill in fractures and/or channels.
3. Lost circulation materials, densification, moderate fluid loss control, and accelerated slurries improve job performance.
4. Squeeze pressures should not be governed by fracture gradient.
5. A study of well conditions and pre-job planning improves success.
6. Proper selection of squeeze tools and precaution in job mechanics reduce job hazards.

REFERENCES

1. Gibbs, M: Primary and Remedial Cementing in Fractured Formations. Twelfth Annual Southwestern Petroleum Short Course, Texas Technological College, April 1965
2. Goolsby, J. L.: A Proven Squeeze Cementing Technique in a Dolomite Reservoir. Society of Petroleum Engineers of AIME - SPE 2473, **1969**
3. Beach, H. J., O'Brien, T. B., and Goins, W. C. Jr.: The Role of Filtration in Cement Squeezing, Drill and Prod. Prac., API, 1961, 27-35.

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