# Squeeze Cement Treating Matrix: Improves Communication, Increases Efficiency, And Reduces Administrative Costs in Multi-Well Squeeze Project

*Henry Lopez, BJ Services, USA, and Dave Renshaw, PE, Chevron, USA Production Company*

**Abstract**

The Wickett Field in the Permian Basin, located 40 miles West of Odessa in Ward County, Texas, is a mature field where squeeze operations occur approximately once per week on each workover rig. Historically, squeeze designs and success ratios have been evaluated individually on a "job by job" basis; this has maintained squeeze cementing costs at a very high level for both the operator and the service company. These costs can include factors such as initial and repeated cement laboratory testing on varying cement slurries, on-site pumping services, cementing additives, surface and down hole equipment, administrative and engineering time of both the operator and service company personnel, rig time, and repeated costs with each squeeze attempt.

For some operators, additional factors can contribute to the complexity of this process such as limitations on a consistent methodology or organized approach to the operational aspects of a squeeze operation. Variations can exist within engineering, field supervisory, and service company personnel as to proper on-site pumping techniques, cement slurry design, or necessary volumes of cement for initial or subsequent attempts. Often times, a very limited established or organized method is in place for "looking back" on the success or failure of any particular cement slurry or operational technique. Finally, an overwhelming amount of selections are available in the design process concerning slurry design and operational techniques.

We will show how an operator, in close association with a service company can establish specific guidelines to manage these complex variations. We will present the methodologies that have reduced the complexity and increased the manageability of an ongoing process. Through these efforts, laboratory testing, administrative and engineering time commitment by the operating and service company personnel, and overall costs in remedial squeeze cementing have been reduced. In addition, these methodologies have improved communications, helped standardized operational considerations, and have increased the probability of successful squeezes on the first attempt[1].

**Introduction**

Chevron's Wickett Field is a mature field where 140 cement squeeze operations were completed from January 1996 through September 1997. This field is the object of this paper's study.

Cements are commonly used to: isolate zones, plug or squeeze abandoned zones[2,4,6-8],fill micro-annular space[2-4,6-8]; control unwanted production[2-4,14]; repair liner tops[2-4]; and repair casing caused by wear or deterioration[2-4]. Squeeze cementing historically has been an indistinct science[2], due to the many obscure variables[1] that effect cement squeezing. Many times the variables remain unidentified, undefined, or not fully understood. Hence, successful cement squeezing generally has been defined by the industry primarily through trial and error[8]. This methodology requires the accounting of many critical items that routinely vary from job to job. These include cement chemistries and volumes, surface and subsurface tools, and on-site pump methods and rates. Squeeze pressures[1-4,16] and "shut in" times[1,2,5,6] can also vary according to individual preference. Critical formation characteristics[1-3,5-12] often remains undefined.

Formation characteristics can include fracture pressures[1,14], fracture extension pressures[1,14] and the dynamic effect of various fluids under pressure. Other characteristics important in squeezing are formation permeability[1,14], pore pressure[1], fluid loss (coefficient) or leak-off characteristics[1-3,5-12], and bottom hole temperature[1,14]. The amount of formation exposure can be dictated by the size of treatment openings, repair sites, and fluid rate.

Cements can be modified to vary slurry properties such as density, total thickening times[1,5], fluid loss characteristics[1-3,5-12], rheological flow properties (to include thixotropic properties), free water content, etc.

The complexity and difficulty in constantly maintaining these records to assess successes and failures, coupled with the huge number of variables involved in squeeze cementing can significantly reduce the probability of obtaining a successful squeeze on the first attempt and can be a major factor contributing to the already high cost of squeeze cementing.

**The Management Process of a Mature Multi-Well Field Remedial Squeeze Program**
The management of aggressive program such as the Wickett remedial squeeze program required an equally aggressive and unique approach. First, the objectives of the program were clearly defined. The problems thought to most effect remedial squeezing were identified and addressed. Then a solution was proposed and systematically implemented. Finally, a method to track the success of the solution (metrics) was structured.

**Objectives.** Clear objectives were needed to assist the operator (and service company) in controlling the cost of remedial squeezing. Several key objectives were considered:

***Minimize Costs.*** The physical cost of cement squeezing should be minimized for the most effective return. The costs should be minimized by maintaining a high success ratio of first time squeezes while also reducing the engineering and administrative time commitment to the program by the operator and service company.

***Establish Methodology.*** Those factors[1] and principles[1] that have proven effective in successful first attempt squeezing should be firmly established. Further, establish operator interdepartmental and vendor conformity to those established principles through training, readably accessible information, and practical tools.

***Establish a Metric System for Effective Review.*** Establish a metrics system for the accounting of squeeze success and failure ratios. Identify and implement changes to cement chemistries, on-site techniques, practices and procedures, and tool applications as directed by success and fail ratios. Promote effective communications through meetings and review processes to identify, implement, and maintain the use of the most effective tools.

**Analysis: The Problem of High Costs and the Complex Process of Multiple-Well Squeezing.**
The shear complexity of the management of a squeeze cementing program for a mature multi-well field has historically held the costs of squeeze cementing at a high level for both the operator and the service company.

Total costs can include such factors as the rental of surface and subsurface tools and equipment, fluids and their transport costs, actual on-location squeeze work, chemical and material cementing costs, rig or coiled tubing rentals, pressure testing equipment, and the loss of production due to well downtime.

Other contributing factors can include a significant and continuous time commitment by administrative and engineering personnel (operator and service company), including the repeated laboratory testing of a significant number of varying cement slurries (from surface to 8,500 feet). Finally, multiples of each of the above can be repeated for multiple squeeze attempts.

**A Complex Process.** There are many variables that can contribute to the complexity and cost of squeezing.

***Flushes***[4,9,11,14]. The type and quantity of pre-job hole preparation used can vary tremendously. Effective flush chemistries, volumes, and placement techniques may not be consistently applied. Some common types of pre-flushes include fresh water, two-percent (by weight) potassium chloride water, sodium chloride brines formulated from 8.5 to 10.0 pounds per gallon, caustic soda pre-flushes, specialty flushes such as sodium acid pyrophosphate (SAPP) and sodium silicate (SMS) solutions, and many more.

***Slurry Design.*** Often times there is a very limited methodical or organized approach to slurry design. Slurry designs can vary a great deal. Preferred slurries which are effective under one set of condition may not be effective in other situations (even those under seemingly similar conditions); there may also be a great deal of variation in the volume of cement pumped, which generally tends to increase with each subsequent squeeze attempt.

***Discontinuity Between Formation Characteristics and Slurry Properties***[1,3]. Often times there is a very limited (or undefined) relationship between the formation to be squeezed and slurry designs. Normally, more considerations are given to bottom hole temperature, depth, and squeeze sites rather than critical formation characteristics.

***Matrix Rates.*** There is an inclination to fracture the formation in an attempt to establish an injection rate prior to squeezing, sometimes utilizing acids (spearheading). The formation may be unintentionally fractured if the hydrostatic pressure of well fluids such as innate fluids, slurries, and flushes are not considered.

Although generally prefered[1-5,7,12,15], matrix rates and pressures are often times not considered. Fractured formations generally require more cement[1] and can complicate the squeeze process.

***On-Site Pumping Procedure***[1-17]. The on-site pumping and other operational procedures can vary substantially, often times from well to well, engineer to engineer or foreman to foreman. The presence of an organized and consistent operational approach may be suspect.

***Tools and Techniques***[1,3,5,13,17]. Varying types of tools and techniques are used within a field. Consistency in tool application is often dependent on the individual's preference.

***Squeeze Failures***[1,5]. The first supposition often made is that a failed squeeze attempt is due primarily to the slurry design (chemistry). Subsequently, slurries may be changed and volumes increased with each squeeze attempt. A comprehensive investigation is seldom conducted on the cause of a failure. This may allow repeated failures due to undefined causes.

***Metrics.*** There are few established or organized methods for a "look back" (metrics) on the success or failure ratios of a particular cement slurry or operational technique other than on a well to well basis. Field studies on the effectiveness of squeeze techniques are rare. The information on effective techniques gained by the individual can be lost or not passed on. Operator interdepartmental and service company communications are often obscure.

***Multi-Well Squeezing.*** Administrative and engineering departments can be easily over-whelmed by the immense selection of cement additives available, tool options, operational techniques, and by the sheer number of on-going squeezes.

***Multiple Vendors.*** With each new participant entering the program the complexity of the program increases with the possible permutations at least doubling. For instance, if two service companies are used the cement chemistry doubles, as does the number of slurries. This is evident, if for example, each service company provides 20 of its most effective slurries. The slurries double and each with separate considerations. Each slurry must be considered and equated to the other service company's additives for each application ie., surface to 8500 feet for the Wickett Field. Although the slurry's designs may test equivalent, the actual down hole performance may vary due to additive chemical differences; thus each must be individually scrutinized. Therefore, any management system must be extended to encompass all new participants.

Given the variety of services and service providers available, the possibility of overburdening even a well-peopled, highly effective, and most organized management program is very real.

**The Solution: The Management Process**

To effectively manage such an aggressive squeeze program several key issues became apparent. Conformity to those principles and on-site procedures that were deemed critical were established and these principles would ultimately include the injection testing of each well prior to squeezing[1]; the selection of the proper cement chemistry based on the injection test (formation characteristics1[1]); the on-site pumping procedure; and the establishment of a metric system to track performance.

**Establish Conformity**. In order for the management process to be effective, all parties involved would need to conform to the principles and procedures established from proven techniques. Of primary importance was establishing continuity (link) between the formation and the slurry's properties.

***Formation Characteristics Evaluated by Injection Tests.*** The formation to be squeezed was characterized with respect to its capacity or affinity to accept fluid under pressure. Several methods [1,5] have proven to be effective in the past. In the Wicket field, an injection test was conducted at a constant one barrel per minute. The injection pressure may be perceived as an indirect measure of the conductivity and leak-off of the formation (with respect to the fluid pumped).

***Formation Characteristics (Injection Tests) Related To Slurry Properties***[1,5]. A relationship was then established from the injection profile to the performance of the slurry. When zero pressure formation characteristics (vacuum) were observed, slurries with thixotropic properties were considered.
Low pressure[1] characteristics (0 – 50 psi) were linked to slurries that exhibited high fluid loss values (little control). Finally, higher-pressure injection profiles (>500 psi) were matched with slurries exhibiting low fluid loss characteristics[1,5] (less than 100 cc/30 minutes). This information was placed in a matrix that relates the injection pressure to the specific cement slurry to be used at a given depth (Table 3,4).

Options to the use of a thixotropic slurry at zero pressure include a two-slurry approach[1]. The lead slurry is designed to exhibit a shorter total thickening time and higher fluid loss than the tail slurry ie., lead: 300 – 500 cc/30 minutes ; tail: 80-120 cc/30 minutes. The lead slurry dehydrates forming a base for the tail to squeeze against [1].

***Field Pumping Procedure.*** In most field applications the squeeze slurries were pumped under "hesitation squeeze" parameters. The slurry or slurries were pumped down the tubing to a point above the squeeze tool (packer or retainer); the tool set or stinger stabbed to force the slurry below the tool; and then the pump slowed to a minimum rate while the cement was squeezed into the formation. Often times, the pump would then be shutdown to allow the cement to dehydrate for an extended time frame. Then the cement pump would be restarted slowly while closely monitoring the pressure. This would be repeated until the desired squeeze pressure was attained.

***Squeeze Pressure - When to Start Displacement.*** The squeeze pressure can be defined by the observed pump pressure while the cement is entering the formation. It is thought that this pressure should be less than the pressure required to fracture the formation but more than the initial injection pressure while cement is first entering the formation. The squeeze pressure is expected to rise gradually as more cement is squeezed into the formation. Generally, the higher the fracture gradient the higher is the resulting squeeze pressure.

Squeeze pressure[1-6,8,11,16] is a function of formation integrity, conductivity, permeability, cement rheology, number of perforations, and the total flow area of the perforation (friction pressures in 2 3/8" and larger work strings are minimum at low pump rates). The depth and temperature of the formation will affect cement rheological properties. Longer pump times are required to get the cement to the formation and the temperature of the formation rises as the depth increases.

When one should stop pumping cement and start displacement is often subject to debate; an example is to start displacement when the squeeze pressure is 1.25 times the initial injection pressure at a constant pump rate.

***The Metrics System and Enhanced Communications.*** A program was instituted which assess the success or failure of each job (ie., a look back system). This program is in the initial stages of implementation. The program reviews the type of job (perforation or casing), the selection of the slurry as correlated to injection pressure, use of down hole tools, on site pumping procedures, and any unusual circumstances affecting the success or failure of the job. Operator morning reports and service company treatment records are an excellent source of information. Systematic communication with the work over foremen, engineers, and service supervisors on the well sites is vital to job assessments. Recommendations on repairs to the squeeze and operations procedure are made to the squeeze program manager.

**The Management Solution: The Cement Matrix and the Results of Its Use.**
A relationship was established between the injection pressures (1 bpm) and specific cement slurry properties that were observed to be effective in cement squeeze applications in the Wickett Field. A cement treating matrix was created that relates injection pressures to the specific cements yielding the desired slurry properties.

**The Matrix.** The matrix encompassed injection pressures incrementally from 0 psi to greater than 500 psi and depths from surface to 8,500 feet (Table 3,4). Cement slurries were then designed according to the desired slurry properties. Each slurry was tested primarily on a hesitation squeeze schedule[18] as modified by the operators specific test procedures[1]. The slurries were also tested on a running squeeze schedule[18]. Total thickening times on a hesitation squeeze schedule were limited to relatively short times, i.e., at 600 feet: 33 minutes, and at 8500 feet: 143 minutes (depths and temperatures were calculated according the greatest depth of each formation). The finished squeeze cement matrix was placed in key locations to enhance communications ie., the operator's central remedial division office; rig workover foremen, the service company's operation facilities; and the service company's central region laboratory.

**Results.** The use of the cement treating matrix has allowed the identification and the consistent application of a relatively few standardized primary cement slurries detailed to the various depths, bottom hole temperatures, and formation injection characteristics. By February 1997, the many and varied slurries, historically used (from surface to 8500 feet), were reduced to 13 highly specific slurries (Table 4). These were increased to 16 slurries in November 1997. The November matrix currently in use (Table 3).

The use of this cement matrix has also allowed the operator to establish a dynamic process that provides guidance for new engineers (both operator and service company); new foreman and consultants in the field; and allows for the continuous review and improvement of the cement slurries and field procedures based on successes or failures. In addition, the process provides for a review of the success or failure of each squeeze job performed in the Wickett Field.

The cement matrix has not only reduced the complexity of the project to a manageable entity but has also promoted and enhanced effective communications and helped to standardize and streamline operational considerations and procedures. The matrix has also promoted those conditions[1] affecting the success of first time squeezes while significantly reducing the administrative and engineering time commitment by the operator and service company. The matrix has reduced costs by substantially reducing the laboratory's time commitment to routine squeeze testing and overall costs in remedial squeeze cementing for both the operator and the service company.

**Wickett Field Remedial Squeeze Statistics.** The overall squeeze "Success Ratio" statistics for 1997 were based on 9 months while those for 1996 were based on 12 months. The laboratory data statistics were based on a 10.5-month period for 1997 while those for 1996 were based on a 13-month period (prior to the use of the cement matrix). Both were adjusted to represent a 12-month period. A further adjustment was made to equate the number of squeeze jobs performed in 1996 to

1997 since the squeeze activity affects the amount of testing required.

***1997 Success Ratios (of first time successful squeezes).*** A total of 63 squeezes were conducted in 1997, of which 57 were successful on the first attempt. The 1997 first time squeeze success ratio was 90.5% (Table 1).

***1996 Success Ratios (of first time successful squeezes).*** A total of 77 squeeze jobs were conducted in 1996, of which 70 were successful on the first attempt. The 1996 first time squeeze success was 90.9% (Table 1).

***1997 Engineering and Administrative Time Savings by the Operator and the Service Company.*** The operator time commitment, prior to the use of the matrix, was approximately 7.5 hours weekly or a total of 390 hours per year. The matrix has reduced this time by 90% for an annual saving of 351 hours. The service company alliance engineer time commitment, prior to the use of the matrix, was approximately 4.0 hours weekly or 208 hours per year. The matrix has reduced this time by 90% for an annual saving of 187.2 hours (Table 2).

***1997 Service Company Laboratory Testing Commitment Savings***. The service company laboratory time commitment, prior to the use of the matrix (1996), was 749.77 hours. The time commitment was reduced to 138.29 hours for 1997. (The research time commitment required to create the matrix was 199.5 hours and is not included). The total time commitment saving for 1997, including the time required to create the matrix, was 611.48 hours. The matrix has reduced the total time commitment by the laboratory by 81.56% (Table 2).

**The Next Step: Field Squeeze Procedure Matrix Conceptualized**

In a logical progression and extension of the cement matrix, a field squeeze procedure matrix is conceptualized. It is thought that this matrix would be one end product of the cement slurry matrix. The matrix would collect information on field procedures from the engineers, cement service supervisors, and rig foremen. This matrix would help identify and direct field proven "best practices" and reflect the most recent procedures that further the ratios of first time successful squeezes. It is thought that the matrix would relate the type of job, injection pressures and depths to cement pump rate procedures; types and volumes of pre-flush; when to start the displacement process; most effective squeeze pressures; and other factors which will result from further evaluation ie., types of tools and procedures.

By providing a permanent record of success ratios that could be cross-referenced to slurry design, slurry volumes, on-site pumping procedures, formation injection profiles, and tool use, it is hoped these variables can be converted to a more manageable format.

**Conclusions**

The effective management of a complex multi-well squeeze project such as Chevron's Wickett Field was necessitated by the enormous costs of remedial squeezing and the enormous time constraints and commitments placed on the administrative and engineering departments of both the operator and the service company(s). Further, characterization of the formation to be squeezed by injection testing in conjunction with the cement slurry matrix that relates injection pressures to slurry performance, has allowed the management of this program to meet the objectives which were established at the onset of the cement squeeze program for the Wickett Field.

It must be emphasized that the communication of squeeze results, sharing of best practices, and continuously improving the cement squeezing operation is a "process" not an end product. This process can become more efficient by employing quality tools such as flowcharts, diagrams, and matrixes which will help new and experienced workover foremen and service company cement service supervisors to better and more quickly understand the best squeeze practices for each zone in the field. A philosophy of continuous improvement and employing tools to communicate and effect this improvement is necessary to optimize cementing operations. Each participant is asked to contribute to the improvement of all aspects of the process.

A crucial function of the cement slurry matrix is thought to be as an educational tool. The data and experience contained within the matrix can be effectively communicated to new engineers (operator and service company), workover foreman, consultants, cement service supervisors, technical representatives, so that the lessons of the past are not so easily lost.

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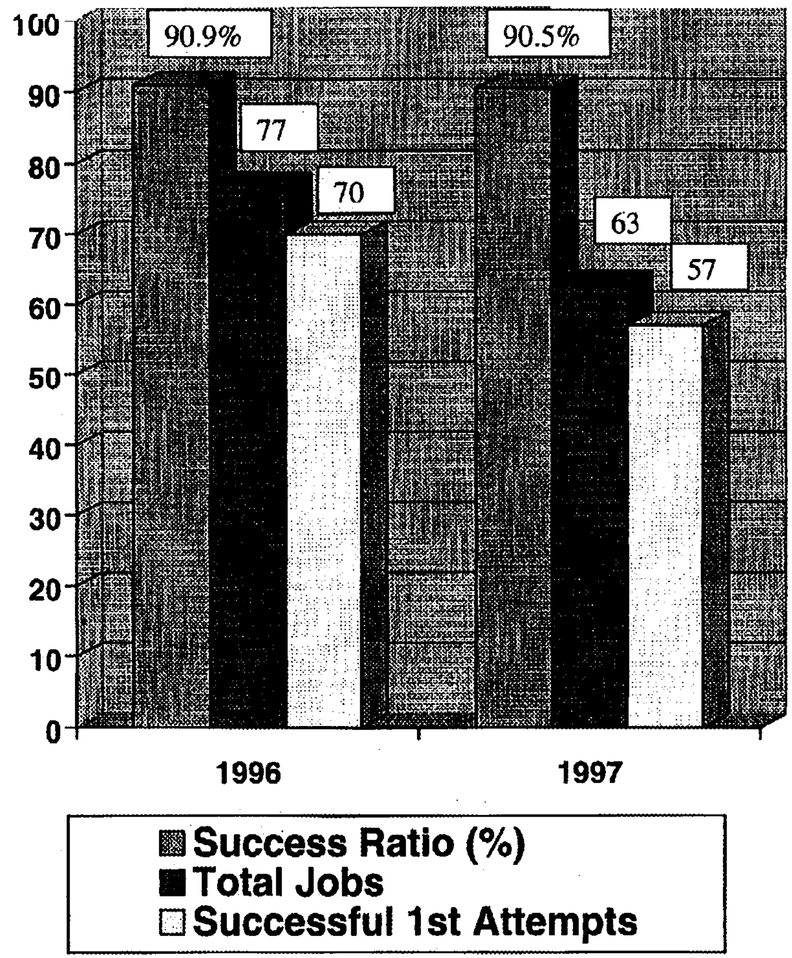
**SI Metric Conversion Factors**

| | |
|---|---|
| $cf^3$ X 2.832 | E + 02 = $m^3$ |
| °F X (°F-32)/1.8 | E + 00 = °C |
| gal X 3.785412 | E – 03 = $m^3$ |
| lbm X 4.535924 | E – 01 = kg |
| lbm/gal X 1.198 | E + 02 = $kg/m^3$ |
| psi X 6.894757 | E + 00 = kPa |
| sk X 94 | E + 00 = lbm |

**References**

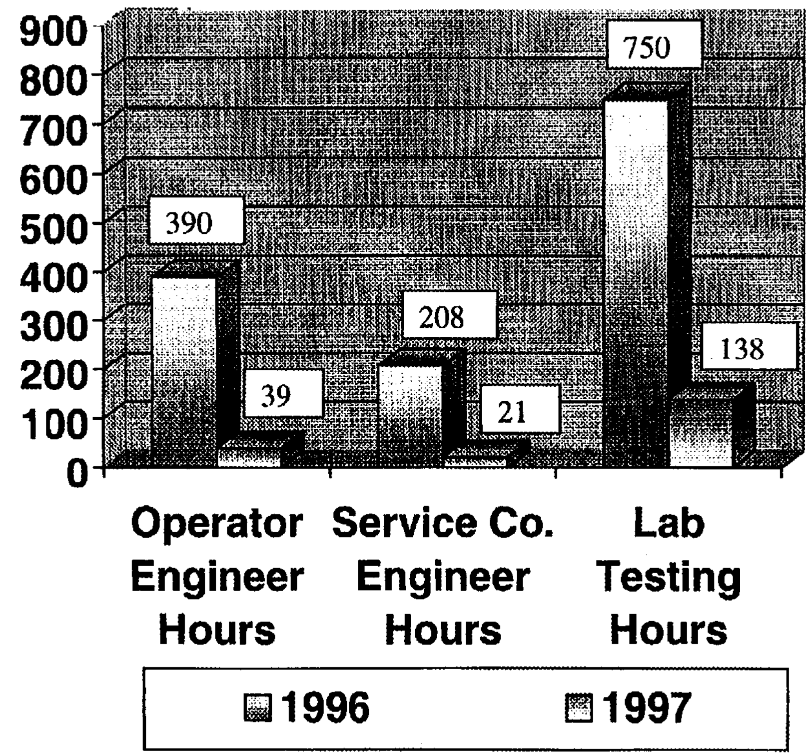
1. Grant Jr., W.H. and White, R.L.:" Successful Squeezing of Shallow and Low-Pressure Formations" paper SPE19937 presented at the 1990 IADC/SPE Drilling Conference, Houston, Texas, (Feb. 27-Mar. 2, 1990) 1.
2. Rike, J.L.:" Obtaining Successful Squeeze-Cementing Results", SPE4608 prepared for presentation at the 48th Annual Fall Meeting of the Society of Petroleum Engineers of AIME at Las Vegas, Nevada (Sept. 30-Oct 3, 1973), 2.
3. Shryock, S.H. and Slagle, K.A.: "Problems Related to Squeeze Cementing" paper SPE 1993 presented at SPE 38th Annual California Regional Meeting Las Anglos, Calif., (Oct. 26-27 1967) 801.
4. Toor, A.A. "Problems in Squeeze Cementing" paper SPEI 1499 presented at the Middle East Oil Technical Conference of the Society of Petroleum Engineers Manama, Bahrain (Mar. 14-17, 1983) 478.
5. Beach, H.J., O'Brien, T.B., and Goins Jr., W.C.: *"Formation Cement Squeezes by Using Low-Water-Loss Cements " The Oil and Gas Journal,* **Volume 62** (196 1) 1.
6. Rike, J.L.:" *Squeeze Cementing: State of the Art" Journal of petroleum Technology* (Jan. 1982) 39.
7. Goodwin, K.J.: "Principles of Squeeze Cementing" SPE 12603 presented at the Permian Basin Oil & Gas Recovery Conference Midland, Texas (Mar. 8-9, 1984) 234.
8. George, C.R.: "Understanding Squeeze Cementing: Process and Problems", Meeting Paper, presented at the Solution Mining Research Institute (SMRI), Fall Meeting, Houston Texas, (Oct. 13-16), 3.
9. Carter, L.G., Harris, F.N. and Smith, D.K.: "Remedial Cementing of Plugged Perforations," paper, SPE759 presented at the California Regional Meeting (Oct. 23-25, 1963) 1.
10. Beach, H.J., O'Brien, T.B. and Goins Jr., W.C.: "The Role of Filtration in Cement Squeezing" SPE presented at the Spring Meeting, Southern District, Division of Production, Shreveport, Louisiana (Mar. 1961) 29.
11. Harris, F. and Carter, G.: *"Use a Chemical Wash and a Low Fluid Loss Cement," Drilling,* **Volume 25,** No. 3, (Jan. 1964) 2.
12. Brinkley, G.W. and Dumbauld, G.K.: "Factors Affecting the Rate of Deposition of Cement in Unfractured Perforations During Squeeze Cementing Operations," paper T.P.8005 presented at the Annual Fall Meeting of the Society of Petroleum Engineers, Dallas, Texas (Oct. 6-9) 51.
13. Bradford, B and Reiners, B..- *"Analysis Gives Successful Cement Squeeze," Oil and Gas Journal* (April 1, 1985) 71.
14. Murphy, W.C.: *"Squeeze Cementing Requires Careful Execution for Proper Remedial Work" The Oil and Gas Journal,* **Annual** Issue (Feb. 16, 1976) 87.
15. Howard, G.C. and Fast, C.R.: "Squeeze Cementing Operations" Petroleum Transactions, AIME, **Volume 189** (1950) 53.
16. Patton, D.L. and Patton-Roberts, et. Al.: "Squeeze Cementing Made Easy," Petroleum Engineer International, (Oct. 1987) 46.
17. Harrison, T.W. and Blount, C.G.: "Coiled Tubing Cement Technique at Prudhoe Bay, Alaska," paper SPE 15104 (1986) 116.
18. "Specification for Materials and Testing for Well Cements", API Specification IO (Spec IO) Fifth Edition, (July 1, 1990) 60.

Table 1
Wickett Squeeze Statistics Success Ratio




(The cement matrix was in use February 1997 to November 1997).

Table 2
Wickett Squeeze Statistics Operator & Service Company Time Commitment




(The cement matrix was in use February 1997 to December 1997).

Table 3A

The Cement Matrix Published November 1, 1997

***Wickett Squeeze Slurries***

***SLURRY SELECTION BASED ON INJECTION PRESSURE***

| | | Wickett Slurry Selection Number — Injection Pressures @ 1 BPM | | | | Temperature Range (°F) | |
|---|---|---|---|---|---|---|---|
| Depth (ft) & Formations | Test Depth | < 50 psi | 50-200 psi | 200-500 psi | > 500 psi | Shallow | Deep |
| Surface – 600' | 600' | 1 | 2 | 2 | 3 | 76 | 79 |
| 600' – 1000' | 1000' | 2 | 2 | 2 | 3 | 79 | 82 |
| 1000' – 1800' | 1800' | 2 | 2 | 3 | 3 | 82 | 88 |
| 1800' – 2300' | 2300' | 2 | 2 | 3 | 5 | 88 | 91 |
| 2300' – 2600' Yates | 2600' | 2 | 4 | 5 | 5 | 91 | 93 |
| 2600' – 2900' 7 Rivers | 2900' | 4 | 4 | 5 | 5 | 93 | 95 |
| 2900' – 3200' Queen | 3200' | 4 | 4 | 5 | 5 | 95 | 97 |
| 3200' – 3300' Queen Dolomite | 3300' | 4 | 4 | 5 | 5 | 97 | 98 |
| 3300' – 3500' Grayburg | 3500' | 4 | 4 | 5 | 5 | 98 | 100 |
| 3500' – 3700' San Andres | 3700' | 7 | 7 | 6 | 6 | 100 | 101 |
| 3700' – 4000' Judkins | 4000' | 7 | 7 | 6 | 6 | 101 | 103 |
| 4000' – 4200' Intermediate | 4200' | 7 | 7 | 6 | 6 | 103 | 104 |
| 4200' – 4600' McKnight | 4600' | 7 | 7 | 6 | 6 | 104 | 107 |
| 4600' – 5100' Holt | 5100' | 7 | 7 | 6 | 6 | 107 | 111 |
| 5100' – 5700' Clearfork | 5700' | 7 | 7 | 6 | 6 | 111 | 115 |
| 5700' – 6200' Tubb | 6200' | 7 | 7 | 6 | 6 | 115 | 118 |
| 6200' – 7400' Wichita Albany | 7400' | 7 | 7 | 6 | 6 | 118 | 127 |
| 7400' – 7800' Wolfcamp | 7800' | 8 | 8 | 9 | 9 | 127 | 130 |
| 7800' – 8500' Penn | 8500' | 8 | 8 | 9 | 9 | 130 | 135 |

Table 3B

The Cement Matrix Published November 1, 1997

| CLASS "C" CEMENT | | | Mix Water | Den | Yld | FL | TTT (Run) | TTT (Hes SQZ) |
|---|---|---|---|---|---|---|---|---|
| Slurry No. | Cement Additives | | gal per sack | lbm per gallon | cuft per sk | cc per 30 min | hour: min | hour: min |
| Wickett # 1 | + 10% CaSO4 +.2% SMS + 2% CaCl2 (This is a Thixotropic Blend) | | 6.85 | 14.8 | 1.47 | 750 | 0:58 | 0:05 |
| Wickett # 2 | + 0% CaCl2 | | 6.32 | 14.8 | 1.35 | 1060 | 4:39 | 3:02 |
| | + 1% CaCl2 | | 6.32 | 14.8 | 1.35 | 820 | 3:03 | 1:48 |
| | + 2% CaCl2 | | 6.32 | 14.8 | 1.35 | 710 | 1:58 | 1:03 |
| | + 3% CaCl2 | | 6.32 | 14.8 | 1.35 | 625 | 1:14 | 0:33 |
| Wickett # 3 | 1% SALT + 3% KCl + .6% FLA + .5% Disp + .2% SMS | | 6.41 | 14.8 | 1.36 | 46 | 2:37 | 1:48 |
| Wickett # 4 | Lead | + .4% FLA + .2% CaCl2 | 6.32 | 14.8 | 1.32 | 502 | 1:03 | 0:33 |
| | Tail | + 3% KCL + .6% FLA + .5% Disp + .2% SMS | 6.37 | 14.8 | 1.35 | 84 | 2:09 | 1:33 |
| Wickett # 5 | + 3% KCL + 6% FLA + .5% Disp + .2% SMS | | 6.37 | 14.8 | 1.35 | 86 | 2:24 | 1:48 |
| Wickett # 6 | + 3% KCl + .6% FLA + .5% Disp + .2% SMS + .15% Retarder | | 6.37 | 14.8 | 1.35 | 92 | 2:09 | 1:35 |
| Wickett # 7 | Lead | + .4% FLA + .2% SMS | 6.30 | 14.8 | 1.33 | 520 | 2:10 | 1:35 |
| | Tail | + 3% KCL + .6% FLA + .5% Disp + .2% SMS + .15% Retarder | 6.37 | 14.8 | 1.35 | 90 | 2:09 | 1:35 |
| Wickett # 8 | Lead | + .4% FLA + .2% SMS + .25% Retarder | 6.32 | 14.8 | 1.32 | 546 | 2:48 | 2:23 |
| | Tail | 3% KCL + .6% FLA + .5% Disp + .2% SMS + .4% Retarder | 6.37 | 14.8 | 1.34 | 90 | 2:45 | 2:23 |
| Wickett # 9 | + 3% KCL + .6% FLA + .5% Disp + .2% SMS + .4% Retarder | | 6.37 | 14.8 | 1.34 | 90 | 2:45 | 2:23 |

CaSO4 = Calcium Sulfate (anhydrous); Disp = Surfactant Enhanced Cement Dispersant; FLA = Fluid Loss Additive; SMS = Sodium Metasilicate (anhydrous)

TTT (Run) = Total Thickening Time; API Spec 10 Squeeze Schedule

TTT (Hes SQZ) = Total Thickening Time; API Spec 10 Hesitation Squeeze Schedule (modified per Chevron, USA)

den = density; cc = cubic centimeter; cuft = Cubic Foot; °F = degrees Fahrenheit; FL = fluid loss; lbm = pound; min = minute; Sqz = Squeeze; Yld = Yield

Table 4A
The Cement Matrix Published February 13, 1997

| *Wickett Squeeze Slurries* *SLURRY SELECTION BASED ON INJECTION PRESSURE'* | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Wickett Slurry Selection Number Injection Pressure @ 1 bpm | | | | | |
| Depths (ft) & Formations | Test Depth | < 50 PSI | 50-200 PSI | 200-500 PSI | > 500 PSI | Temperature Range (°F) | |
| | | | | | | Shallow | Deep |
| Surface – 600' | 600' | 1 | 1 | 2 | 3 | 75 | 79 |
| 600' – 1000' | 1000' | 1 | 2 | 2 | 3 | 79 | 82 |
| 1000' – 1800' | 1800' | 4 | 2 | 2 | 3 | 82 | 88 |
| 1800' – 2300' | 2300' | 4 | 2 | 5 | 3 | 88 | 91 |
| 2300' – 2600' Yates | 2600' | 4 | 5 | 5 | 3 | 91 | 93 |
| 2600' – 2900' 7 Rivers | 2900' | 4 | 5 | 5 | 3 | 93 | 95 |
| 2900' - 3200' Queen | 3200' | 4 | 5 | 5 | 3 | 95 | 97 |
| 3200' - 3300' Queen Dolomite | 3300' | 4 | 5 | 6 | 6 | 97 | 98 |
| 3300' - 3500' Grayburg | 3500' | 4 | 5 | 6 | 6 | 98 | 100 |
| 3500' – 3700' San Andres | 3700' | 7 | 7 | 6 | 6 | 100 | 101 |
| 3700' – 4000' Judkins | 4000' | 7 | 7 | 6 | 6 | 101 | 103 |
| 4000' – 4200' Intermediate | 4200' | 7 | 7 | 6 | 6 | 103 | 104 |
| 4200' – 4600' McKnight | 4600' | 7 | 7 | 6 | 6 | 104 | 107 |
| 4600' – 5100' Holt | 5100' | 7 | 7 | 6 | 6 | 107 | 111 |
| 5100' – 5700' Clearfork | 5700' | 7 | 7 | 6 | 6 | 111 | 115 |
| 5700' – 6200' Tubb | 6200' | 7 | 7 | 6 | 6 | 115 | 118 |
| 6200 – 7400 Wichita Albany | 7400' | 7 | 7 | 6 | 6 | 118 | 127 |
| 7400' - 7800' Wolfcamp | 7800' | 8 | 8 | 9 | 9 | 127 | 130 |
| 7800' - 8500' Penn | 8500' | 8 | 8 | 9 | 9 | 130 | 135 |

Table 4B
The Cement Matrix Published February 13, 1997

| CLASS "C" CEMENT | | | Mix Water | Den | Yld | FL | TTT (Run) | TTT (Hes SQZ) |
|---|---|---|---|---|---|---|---|---|
| Slurry No. | Cement Additives | | gal per sack | lbm per gallon | cuft/ sack | cc/30 min | hour:min | hour: min |
| Wickett # 1 | + 10% CaSO4 +.2% SMS + 2% CaCl2 (This is a Thixotropic Blend) | | 6.85 | 14.8 | 1.47 | 750 | 0:58 | 0:05 |
| Wickett # 2 | + 5% KCL + 1% FLA + .4% Disp + .3% SMS + 2% CaSO4 | | 6.32 | 14.9 | 1.35 | 84 | 1:47 | 1:03 |
| Wickett # 3 | + 1% SALT + 3% KCl + .6% FLA + .5% Disp + .2% SMS | | 6.41 | 14.8 | 1.36 | 46 | 2:37 | 1:48 |
| Wickett # 4 | Lead: 125 Sacks | + .4% FLA + .2% SMS | 6.30 | 14.8 | 1.33 | 490 | 3:03 | 2:03 |
| | Tail: 50 Sacks | + 3% KCL + .6% FLA + .5% Disp + .2% SMS | 6.37 | 14.8 | 1.35 | 84 | 2:09 | 1:33 |
| Wickett # 5 | Lead: 75 Sacks | + .4% FLA + .2% SMS | 6.30 | 14.8 | 1.33 | 499 | 3:08 | 2:03 |
| | Tail: 75 Sacks | + 3% KCL + .6% FLA + .5% Disp + .2% SMS | 6.37 | 14.8 | 1.35 | 84 | 2:09 | 1:33 |
| Wickett # 6 | + 3% KCL + .6% FLA + .5% Disp + .2% SMS + .15% Retarder | | 6.37 | 14.8 | 1.35 | 92 | 2:09 | 1:35 |
| Wickett # 7 | Lead: 125 Sacks | + .4% FLA + .2% SMS | 6.30 | 14.8 | 1.33 | 520 | 2:10 | 1:35 |
| | Tail: 50 Sacks | + 3% KCL + .6% FLA + .5% DISP + .2% SMS + .15% Retarder | 6.37 | 14.8 | 1.35 | 90 | 2:09 | 1:35 |
| Wickett # 8 | Lead: 125 Sacks | + .4% FLA + .2% SMS + .25% Retarder | 6.32 | 14.8 | 1.32 | 546 | 2:48 | 2:23 |
| | Tail: 50 Sacks | + 3% KCL + .6% FLA + .5% Disp + .2% SMS + .4% Retarder | 6.37 | 14.8 | 1.34 | 90 | 2:45 | 2:23 |
| Wickett # 9 | + 3% KCL + .6% FLA + .5% Disp + .2% SMS + .4% Retarder | | 6.37 | 14.8 | 1.34 | 90 | 2:45 | 2:23 |

CaSO4 = Calcium Sulfate (anhydrous); Disp = Surfactant Enhanced Cement Dispersant; FLA = Fluid Loss Additive SMS = Sodium Metasilicate (anhydrous)

TTT (Run) = Total Thickening Time; API Spec 10 Squeeze Schedule
TTT (Hes SQZ) = Total Thickening Time; API Spec 10 Hesitation Squeeze Schedule (Modified)

den = density; cc = cubic centimeter; cuft = cubic foot; °F = degrees Fahrenheit; FL = fluid loss; lbm = pound; min = minute; Sqz = squeeze; Yld = yield