A cementing squeeze operation is normally defined in the industry as the placement, under pressure, of a portion of cement slurry to a predetermined location of a well to cause a seal. This definition is fine but limited in scope, particularly when viewed in the light of the current needs of our industry. It implies potential success of the operation without considering the main reason we drill wells: the production of hydrocarbons. What if the squeeze operations is drastically reduced. Was the squeeze operation a success? The answer to this question has to be a definite no! In this new light, perhaps a better definition of a successful squeeze cementing operation may be: the placement, under pressure, of a controlled volume of cement slurry at a predetermined location of a well, to cause an effective seal, with minimum damage to the well’s future productivity. This revised statement connects the squeeze operation directly to the well’s future performance.

Main Causes of Loss of Well Productivity After a Squeeze Operation

The well’s future productivity may be negatively impacted during the squeeze job mainly from four different directions:

**Damage from Fluids Pumped Ahead of the Cement Slurry:** It is well known that well bore fluids such as mud injected ahead of the cement slurry into a potential pay zone may drastically affect the well’s future performance. Flushes often used ahead of the cement to help open the plugged perforations should also be tested to make sure that they will not impair the permeability of nearby productive intervals.

**Damage from Cement itself:** It is well known that typical cement particles themselves cannot penetrate the pore spaces of normal formations. Cement particles likely cannot penetrate normal natural fractures to any appreciable depth either, but the potential exists for some invasion and plugging of some natural hydrocarbon-producing fractures opened during pumping of a squeeze job conducted to, for example, shut-off water production from a nearby set of perforations.

**Damage from the Cement Filtrate:** Cement filtrate is the most likely cause of formation (production) damage from a cement squeeze operation. Filtrate from the cement is fully capable of penetrating the natural formation permeability via pore spaces and/or natural fractures. It has a high pH (around 12.5) and it is loaded with ions that can easily react within the permeability of the rock to produce damage by precipitation, swelling etc. One of the main reasons Amoco prefers low pressure cement squeezing and good fluid loss control in the cement slurry whenever applicable is to try to minimise the potential formation damage caused by excessive amounts of cement filtrate penetrating the nearby pay zones.

**Mechanical Damage to the Well:** This can happen if during the squeeze job, a zone is fractured into water, etc.
Recommendations

This deliverable contains a great deal of information regarding squeeze cementing. The full impact of the technical and practical knowledge covered cannot be captured by just reading the conclusions or selected sections of the document. Since the report can be very enlightening and useful to field personnel dealing with squeeze cementing, for those individuals, detailed reading of the entire document is highly recommended.

Conclusions

1. The main practices that lead to failure of a squeeze cementing operation are given below. These practices need to be avoided as much as possible.
   
   a) Improper slurry design and/or testing for the given squeeze situation, for example. Too much or too little fluid loss control.

   b) Cement slurry contamination with well bore fluids during placement, or with well bore and/or mud formation fluids during the squeeze operation itself.

   c) Mud or ‘dirty’ work over fluids across interval to be squeezed. For example, injection of dirty fluids into the interval to be squeezed prior to the squeeze operation.

   d) Interval to be squeezed not fully open to receive cement slurry. For example, existing permeability impairment and/or unprepared perforations, fractures, etc.

   e) Improper placement practices for the given situation. For example, extreme pump rates, unnecessary fracturing of the zone, slurry not exposed to the entire interval, etc.

   f) Not enough time allowed for dehydration of the slurry.

   g) Premature pressure reversal (differential from the formation applied too soon after cement dehydration).

   h) Art sometimes replacing the use of sound engineering design and execution practice, generating the use of techniques that are not always the best ones for the given application. For example, fast pump rates, large volumes of cement. Etc.

2. The main practices that lead to success of a squeeze cementing operation are given below. Serious consideration must be given to these practices to help improve our cement squeeze successes:
a) Proper consideration to well conditions and characteristics of the zone to be squeezed (type of formation, permeability, existing fractures, cavities, etc) in the design of the cement slurry.

b) Serious effort to deliver uncontaminated cement slurry across the interval to be squeezed (i.e. not placing retainer too high above perforations, etc).

c) Use of clean, non-wall building completion/work over fluids across the interval to be squeezed.

d) **Pre-squeeze treatment of the zone to open and clean entire interval to be squeezed** (use of the perforations “surge” technique and/or use of acid, surfactants, etc. Combination of the two methods should yield the best results.

e) Use of proper placement techniques to place the cement slurry where it needs to go across the interval to be squeezed.

f) Proper dehydration of the cement slurry inside the interval: perforations, fractures, etc., to minimise movement after placement, during reverse out and during WOC time.

g) Maintenance of positive differential (into the formation) during reverse out and WOC time.

h) Application of sound engineering practices to the entire squeeze cycle: from design to execution, and after job, to assure minimum damage to the well’s future productivity.

3. Low fluid control slurries will penetrate further into a perforation than high fluid loss cements. However, if the fluid loss control of the slurry is too low, dehydration in the perforation will be difficult, particularly across the permeability zones. On the other hand, slurries with high fluid loss values may not fully fill the perforations across high permeability zones. If the high fluid loss slurry has a low viscosity, it has better chance of filling the performance than if its viscosity is high.

4. A mathematical model to analyse the deposition of cement in unfractured, permeable perforations during low pressure, squeeze-cementing operations is now available in a spreadsheet to help design squeeze jobs. From the model, the primary factors affecting deposition of the cement filter cake are: the properties of the cement slurry, the geometry (size) of the perforations, and the dehydration time. When compared to experiments, the model predicted the deposition of the cement slurries tested quite well. Copies of the spreadsheet for field use can be obtained from the Cementing Technology Team in Tulsa.

5. Experiments conducted to remove drilling fluid from plugged perforations by the use of chemical washes showed that partially
plugged perforations will not accept as much cement as open perforations during squeezing.

6. The rate of filter cake build-up is perhaps the most important factor to be considered in squeeze cementing. This rate depends on the fluid loss control properties of the slurry, the differential pressure, the formation permeability and the placement technique. Fluid loss additives reduce the permeability of the filter cake, and thus control the dehydration rate of the slurry.

7. The use of high pressures (late during the squeeze operation like Amoco Argentina does) needs to be seriously considered to help open closed or “dirty” perforations, to get them to accept cement slurry. Whenever possible, application of the high pressures should be done late during the squeeze operation, to minimise unnecessary fracturing of the zone.

8. Experiments were conducted to evaluate the use of injection of CaC$_2$ solutions (5-10%) into cement filter cakes squeezed inside perforation. The experiments suggested that this procedure deserves further investigation and consideration for use in the field to reduce the WOC time before resuming normal well operations.

9. In tests conducted using man-made perforations, unset cement filter cakes did not hold near as high negative pressures as cakes that were allowed to set.

10. Extended deposition times (time holding the positive pressure during dehydration of the slurry) helped to bond the cement cake to the walls of the perforation. In other words, enough dehydration time needs to be provided for the cement cake to properly dehydrate in the perforation and closely adhere to the core walls.

11. During “washing through” of the excess cement, and/or during reversing out after the squeeze job, the pressure in the well bore needs to be maintained positive (into the zone), or only very slightly negative. Thus, the pore pressure of the zone being squeezed needs to be considered when planning the operations after releasing the squeeze pressure.

12. Better bonding of cement cakes to the perforation walls was observed with moderate fluid loss slurries than with low fluid loss slurries. Good bonding is apparently related to the cake’s ability to allow flow (dehydration) to take place through the carrot (very low permeability cakes do not seem to bond well because they do not allow enough dehydration to take place). We do not know at this point to what extent this behaviour may be related to damage to the permeability of the formation by the cement filtrate.
13. Complete sealing of perforations is not a sure thing even with clean, open perforations. Our tests suggested that it is possible to have a perforation completely full of dehydrated set cement and still have the perforation produce some fluid (leakage) once the pressure is reversed.

14. Since cement does not bond to oily surfaces, oil wet perforations may be hard to keep squeezed-off, unless the surfaces are treated with surfactants to water wet them.

15. The use of silicate preflush ahead of the cement slurry was tested and showed potential. The silicate reacted with the brine and the cement slurry to seal off the permeability of the formation behind the cement, to minimise flow from the well bore, and therefore, to prevent dislodging of the cement carrot (cake) by high negative pressures, even before the cement was fully set. The cement was able to dehydrate against the sandstone after the injection of the preflush, suggesting that the permeability of the core was not affected until the cement filtrate contacted the silicate-filled pores of the core. On the other hand, if the silicate would have heavily reacted with the brine, it may have prevented the cement from dehydrating in the perforation.

16. Our tests showed that the use of expanding additives may help in keeping the cement carrot firmly trapped inside the perforations, and may also assist in minimising leakage from the zone, even under large pressure differentials from the formation.

17. A 12.8 lb/gal slurry consisting of 65% H + 35% Poz A with moderate fluid loss control performed very well in sealing off water-out clean perforations. We suspect the reason this low-density slurry worked so well is that the combination of the Class H and the Poz caused a larger particle size distribution in the system that may have contributed to the dehydrated cement to bond very well to the face of the sandstone. This is just a possible explanation, and therefore it needs to be further investigated.

18. In some of the tests, water leakage from the perforations started after the cement node was removed (broken) from the pipe inner wall. This suggests that it is desirable to preserve (protect) the nodes formed during the squeeze job. This may also suggest that the best thing to do may be to perform a good squeeze job (node building), and then wait through, instead of waiting until the cement sets and then drill out (in this case no nodes are left). However, more tests need to be conducted to check this.

19. From tests conducted with perforations “dirty” with a water-base drilling mud, we learned that complete cleaning of perforations does not occur from “surging” them. Our tests suggested that once “breakthrough” of flow from the formation occurs during “surging” debris is left inside the perforations.
20. As expected, we found that partially cleaned “dirty” perforations (even after surging) are harder to shutoff than cleaned perforations. In fact, perforations filled with mud even at low differential pressures may need to be fractured to have a chance of shutting them off.

21. Our tests confirmed that the permeability of set cement inside a perforation is lower than the permeability of the undehydrated cement.

22. Similarly, dewatering a cement slurry (forming of filter cake) decreases the set time and increases the rate of compressive strength development of the cement.

The Process of Squeezing Perforations

Squeeze cementing is a very complex operation. Many factors need to be considered and need to be brought into play to have a reasonable chance of achieving success in the field. This may be illustrated by following in our minds, a squeeze cementing operation to squeeze off perforations.

Assuming that the cement slurry was properly formulated, blended and mixed at the surface, and assuming that good practices were followed to assure minimum contamination of the slurry on its way to the interval to be squeezed, once the slurry is spotted across the perforations, it is required that it penetrates all the perforations in the desired interval. For the slurry to accomplish this, the perforations must be open to receive the slurry. Normally, not all the perforations are open, particularly if the well has been producing hydrocarbons or has been used as an injection well for any length of time. Let's assume that the interval has been properly prepared for the squeeze (perforations have been surged and/or treated with fluids: acids, surfactants, etc., to open all the perforations).

With open perforations, a pressure differential from the well bore will be required to inject the cement inside the entire length of the perforations. Once inside the perforation, a filtration process must take place for the cement to become immobilised (dehydrated) inside the perforation.

Dehydration is necessary to seal the perforations and to make sure the perforations remain plugged until the cement sets and develops enough strength to prevent it from being dislodged from the squeezed perforations when the pressure differential is reversed (for example by placing the well back on production).

For dehydration to take place, the cement slurry must possess the ability to dehydrate across the permeability of the rock in the perforation and not before being injected into the perforation (controlled fluid loss).

Dehydration is controlled by the ability of the cement slurry to release its filtrate. In addition, dehydration is controlled by the pressure differential applied, and by the permeability of the rock receiving the filtrate from the
cement slurry. Another important variable affecting dehydration is time. Time must be enough for the entire perforation to become filled with dehydrated cement, and for a node of dehydrated cement to form across the perforation, on the internal surface of the casing. If the differential pressure is not applied long enough for complete dehydration inside the perforation to occur and for the node to form, the wet slurry closer to the well bore may leak out of the perforation, leaving the perforation open.

Once the cement slurry becomes dehydrated inside the perforation, it must stay in there until it can support the required negative differential pressure (pressure from the formation).

The dehydrated cement will support a certain amount of negative differential pressure once dehydrated, but it will support much once it is set. The dehydrated cement will be able to withstand higher negative pressure differentials across low permeability zones than across high permeability zones (under balanced pressure needed to obtain clean perforations during perforating has been shown to decrease with increasing permeability of the reservoir\(^4\)). This means that during “washing through” of the excess cement, and/or during reversing out, the pressure in the well bore needs to be maintained positive (into the zone), or very slightly negative. Thus, the pore pressure of the zone being squeezed needs to be considered when planning the operations right after releasing the squeeze pressure. Since the set cement should be able to withstand large negative pressure differentials, normally, well operations are not resumed until the cement has had time to set (WOC time). If for a given operation the WOC time is considered excessive, some things may be tried to shorten it (more on this later).

All the mechanical operations, planning processes, execution practices, etc., associated with the squeeze operation must be directed to achieve the steps that we went through (application of sound engineering practices to the entire squeeze cycle). An excellent description of those operational aspects of a squeeze operation was written by Cowan and Bradford 11: AP1 Worldwide Cementing Practices, Chapter 6; Remedial Cementing. It is highly recommend that their work be studied by all field personnel involved with squeeze cementing. For their convenience, the entire chapter is reproduced in Appendix 1 of this report.