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EVALUATING CANDIDATE LOST CIRCULATION MATERIALS FOR GEOTHERMAL DRILLING

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ABSTRACT

Sandia National Laboratories' Geothermal Technology Development Division is working to advance the state of the art of lost circulation prevention and control. For this purpose, a large-scale Lost Circulation Test Facility was designed and built. This paper addresses the evaluation of candidate lost circulation materials using this facility and also using the recommended practice of API RP 13I. Test results from these facilities are compared and discussed for the materials tested.

INTRODUCTION

The problems associated with lost circulation in the well drilling industry are well known. Much has been written and many solutions have been applied, but lost circulation remains as one of the primary problems in drilling a geothermal well (Pye, Caskey 1985). Conventional materials and techniques used in oil and gas drilling have been tried in geothermal wells but have been mostly unsuccessful because of the hostile geothermal wellbore environment where the temperature can far exceed the tolerance level of commonly used cellulosic materials (Goodman, 1981). A Lost Circulation Technology Workshop held in October 1984 pointed to the need for research and development to provide lost circulation behavior and control theory and, to provide improved testing standards for materials evaluation and development (Caskey, 1984). The workshop report includes a bibliography on lost circulation.

Sandia National Laboratories, which manages the U. S. Department of Energy's Geothermal Technology Development Program is actively pursuing a program to advance the technology of lost circulation prevention and control (Caskey, Loeppke, and Satrape, 1985). Understanding and modeling the behavior of fluid/particle flows in the wellbore loss zone address one facet of this work (Givler, 1985).

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This paper addresses another part of this work; the evaluation of lost circulation materials (LCM's) that appear to be good candidates for geothermal applications. Tests were performed both with a modified version of the API 13I test cell and with a large scale facility designed and built at Sandia that evaluates the performance of LCM's in a simulated wellbore environment (Loeppke and Caskey, 1983).

TESTING DESCRIBED

There are several types of loss zones where the loss of drilling fluid can be encountered but those most common in geothermal drilling are vugular or fractured zones and fragile underpressured formations where fractures can be induced by the drilling operation. For this reason, the tests described here were conducted using a "slot"[1] that represents the fracture. This slot used in the test cell and the cell are the same as that described in the recommended practice of API 13I except that the depth of the slot has been increased from 0.25 inches to 6.0 inches. This design is used for all slot sizes and is also used in the large-scale Lost Circulation Test Facility (LCTF). The purpose for the large facility can be appreciated by examining the differences between it and the modified API test cell which is shown in Figure 1. The LCTF is designed to simulate the mud rheologies, flow patterns and temperatures of the wellbore environment whereas the API test is essentially a static test. The LCTF uses a 10 foot long section of 8 inch pipe with a smaller 4.5 inch pipe (plugged on the ends) inside it. The "drilling mud with LCM" is pumped through the annular space between these pipes through a center section where the slot described above is mounted at the outer surface of the annular space. This test vessel is shown in Figure 2. A seven barrel mud/LCM batch is circulated in a closed loop through the test vessel at rates up to 200 feet per minute. A heat exchanger can be included in the pumping loop so that the LCM can be tested at temperatures up to 400°F. A

[1] Slot dimensions used in this work: The "depth" represents the distance into a fracture and the "size" represents the fracture width.

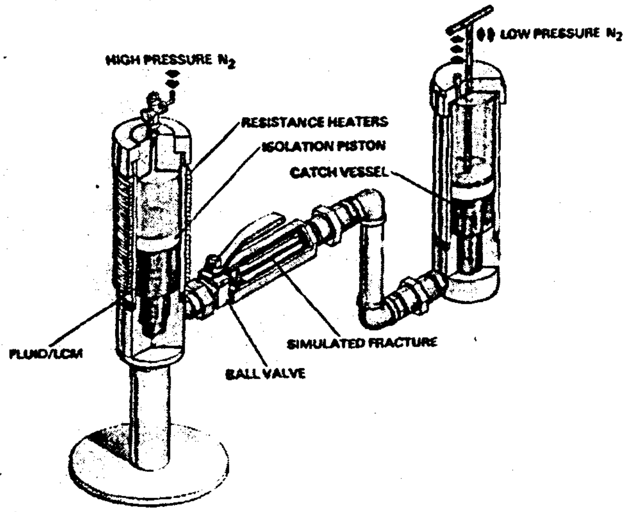

Figure 1. Modified API 13I Test Cell

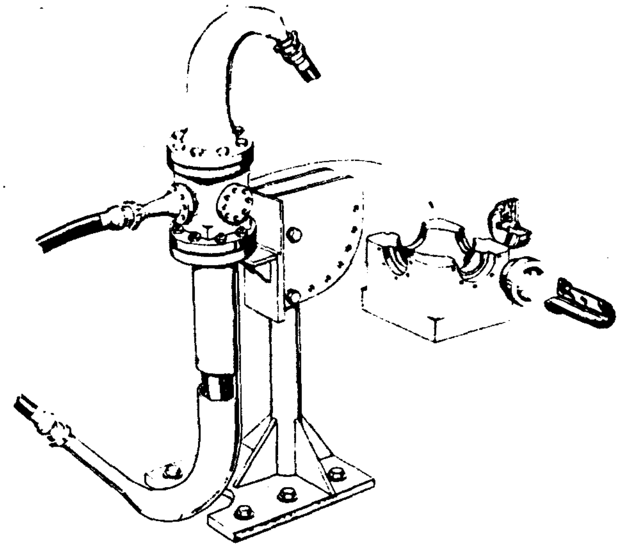

Figure 2. Lost Circulation Test Facility Test Vessel showing a cut-away of the center section and the simulated fracture.

test is conducted by imposing an increasing pressure differential across the slot in much the same way as the API test is performed. The API test cell is not designed to test heated materials nor does it allow crossflow circulation over the face of the slot. Another notable contrast that no doubt accounts for most of the difference in the results that are presented is the difference in the filtrate capacities. The useable capacity of the API test cell is about 3000 ml, whereas the capacity of the LCTF is almost 100 times as much. If the same slot dimensions are used in the LCTF, the opportunity for a plug to form is greatly enhanced. The dynamic test and greater filtrate capacity provide the rationale for the more repeatable results attained with the LCTF. Hinkebein et al concluded after conducting experiments to isolate the cause of the wide data scatter from the API test cell that the probable cause was the plug formation mechanics in the test cell (Hinkebein 1982). By using the same slot design, data has been gathered to show the effect of these different test methods.

The objectives of these tests were:

1. To evaluate candidate LCM's at elevated temperatures,
2. To compare performance of LCM's tested in the API test cell and in the large scale facility, and
3. To experiment with combinations of different LCM types to determine if performance could be improved.

A particle size distribution analysis was performed on each material. This is essential for comparing the performance of different LCM's. Since each material will test differently according to its attributes (e.g., maximum particle size and size distribution) a common basis is needed to make an equitable comparison of LCM's of different size ranges. This is accomplished by plotting the ratio of the slot (fracture) size to the maximum particle size of a material. Test results can then be compared or plotted together for different LCM's. The method used in this work is to plot this ratio verses the material concentration tested. The plot is a summary of all tests performed for an LCM and shows what concentrations can be expected to form a seal in a given fracture size and hold a pressure differential of 1000 psi. The maximum particle size used in the ratio is fixed at 95% (95% of the LCM is smaller than that size).

In order to minimize the effect of the mud used in the tests, a standard formulation was used for all tests. The formula was a 50% bentonite/50% sepiolite water-based mud with additives used to control viscosity and gel strength for elevated temperature tests.

Materials Tested

From a number of materials screened for temperature stability, three were evaluated in the tests discussed here. They were thermoset rubber (processed from salvaged auto battery cases), coal, and mineral fiber. The suppliers (and trade names) for these materials are shown in Table 1.

TABLE 1. LCM's Evaluated

LCM Type	Supplier	Trade Name(s)
Thermoset Rubber (particles)	Western Company	Hi-Seal, now Mud Save (Fine)
Thermoset Rubber (particles & flakes)	Poly-Cycle Indus.	Wes-Bridge Super Wes-Bridge SANI Flake
Ground Coal	Dowell	Kolite
Ground Coal	McCabe-Woody	Kol-Seal
Mineral Fiber	Rockwool Indus.	StrataWool

TEST RESULTS

Results of the tests conducted both with the modified API Test Cell and the Lost Circulation Test Facility (LCTF) are shown in the accompanying graphs. The test facility and conditions are noted for each figure.

DISCUSSION

Thermoset Rubber

Earlier tests of thermoset rubber LCM using the modified API test cell showed this material to be superior to several cellulosic materials that were also tested (Hinkebein, 1982). Tests conducted in this series using the same test cell showed the performance actually improved somewhat after the mud/LCM mix was exposed to 400°F for 4 hours in a roller oven (see Figure 3). However, when the material was tested at elevated temperature in the large-scale LCTF, its performance suffered noticeably as the temperature was increased (see Figure 4). Although there was very little evidence of melting when the bulk material was heated to 500°F in the screening tests, these tests show that the material does soften which is manifest by its reduced ability to hold a seal at high temperatures and high pressure differentials. The plastic nature of the material is actually one of its best attributes at temperatures below 200°F, since it will deform under pressure and temperature without fracturing. This was evident by examining the plugs formed in these tests. A more rigid material will fall away from the face of the slot (fracture) when the differential pressure is releived whereas the theremoset rubber remains wedged in place. Also, because of its good particle stability, there was no dramatic increase in mud viscosity with temperature as can be expected with materials that decompose (e.g. cellulose) at high temperature. Figure 5(API RP 13I test) and Figure 6 (LCTF Test) show the test results for this material plotted in the slot/particle size ratio format described earlier.

Ground Coal

Two brand names for the same product (Kolite and Kol-Seal) were used for these tests because of availability. There was some difference in particle size distribution of the samples tested so the slot/particle size ratio plot has been used here where comparisons are made. The ground coal demonstrated good temperature stability in both the API tests (Figure 7) and the LCTF tests (Figure 8). However, as can be seen in Figure 7 and 9, the material did not plug a slot size comparable to its largest particle size. This is believed due to the brittle nature of the material which appeared to break up in the LCTF test. Notice that the slot/particle ratio for an "always plugs" condition at 20 lbs. concentration for the API test (Figure 7) was 0.8, whereas for the LCTF test (Figure 9) the ratio is about 0.7. Further evidence of this effect in the LCTF tests was the significant viscosity increase in the mud/LCM mix that turned a charcoal grey color. Because of this phenomenon, a new mud/LCM batch was mixed for each concentration and temperature tested. Since the mud/LCM is continuously pumped in a closed loop for several minutes during an LCTF test, it can be argued that the test is more realistic or perhaps too severe. Regardless of the point of view, the brittle material does not perform as well in the slot test.

Mineral Wool

It is well known that a wide particle size distribution and a variety of shapes makes the best LCM (Messenger, 1981). While a fiber material alone is effective for stopping loss in permeable formations, it is much less effective in fractures. When a fiber LCM is tested alone in the API test cell a degree of control over fluid loss can be achieved but a high pressure seal cannot. A series of tests was run using the API test cell to evaluate different blends of mineral wool (Stratawool) and a particle LCM (Hi-Seal/-Thermoset Rubber) to determine the performance of the combined materials. The results, plotted in Figure 10, show a significant improvement in filtrate loss before a seal was achieved by adding the StrataWool mineral fiber to the Hi-Seal particle LCM at a ratio of 1 to 2 by weight. Further tests are planned for the LCTF.

Combined LCM Shapes (Thermoset Rubber)

A range of sizes of irregular shape flakes were gleaned during the processing of the salvaged battery cases and were used in an experiment to determine what performance improvement could be made by adding flake material to the particle LCM, Hi-Seal. A plot summarizing the results of these tests is shown in Figure 11. It shows a 50% improvement was attained by using a flake size distribution twice the size of the particle size distribution at a 4 to 1 (particle to flake) weight ratio. The combined material size distribution, plotted in Figure 12, was then tested in the LCTF. Those results, plotted in

Figure 13, show a 2.4 slot/particle ratio at "20 lbs concentration/always plugs" compared to about 1.1 (Figure 6) for Hi-Seal alone. However, the temperature sensitivity of this material above 200°F is more pronounced in the larger fracture/slot sizes than is Hi-Seal alone because of the flexible nature of the flakes. A blend of particles and flakes called Super Wes-Bridge which has a material distribution of larger particle and flake sizes (Figure 14) was mixed 1 to 1 (by weight) with Hi-Seal and tested in the API test cell. Those results, plotted in Figure 15, show a slot/-particle ratio (at 20 lbs concentration/always plugs) of 0.9 which can be compared to Hi-Seal alone (Figure 5) of less than 0.8.

TEST RESULTS COMPARED

Figures 16, 17, and 18 show a comparison of results for the different materials tested and for the two test methods used. The ability of a given material to plug almost a 50% larger slot when tested in the LCTF is shown in Figure 16. Figures 17 and 18 are comparisons of the material combinations tested in the two facilities (API test cell and the LCTF). The important findings shown here are:

1) If a particle LCM is used, it is of little benefit to use concentrations of more than 20 lbs/bbl. In fact, the same size fracture can be plugged with 5 lbs/bbl but the filtrate loss and the time to plug is much greater.

2) If an LCM with a combination of shapes is used, concentrations as high as 30 or 40 lbs/bbl may be practical.

3) Larger fracture sizes are best sealed using larger particle LCM's or by combining particles and flakes or fibers for more effective seals.

CONCLUSIONS

Thermoset rubber LCM (ground battery casings) was tested at elevated temperatures in a large-scale facility. The plastic nature of the material makes it an excellent plugging material at temperatures below 200°F but at higher temperatures the material softens and its ability to seal at high pressure differentials is reduced. Ground coal performs essentially the same at all temperatures; but, because it is a brittle material it does not plug fractures as well as thermoset rubber. StrataWool, a mineral fiber, added to the particle LCM (Hi-Seal) made the greatest performance improvement of the materials tested but is yet to be tested at high temperature in the large facility. Tests using the large-scale Lost Circulation Test Facility show there is little benefit in using particle LCM concentrations above 20 lbs/bbl; but, if an LCM with a combination of shapes is used higher concentrations can be beneficial. LCM's perform better in the large-scale facility which has a larger filtrate capacity and where the mud/LCM is circulated through the test vessel across the face of the slot or fracture.

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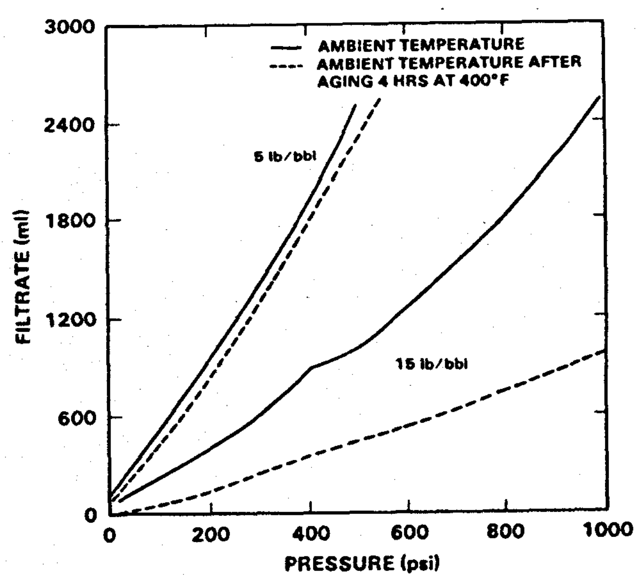


Figure 3. API Test Cell results showing the effects of temperature aging Hi-Seal (Thermoset Rubber). Slot size = 0.08 inches.

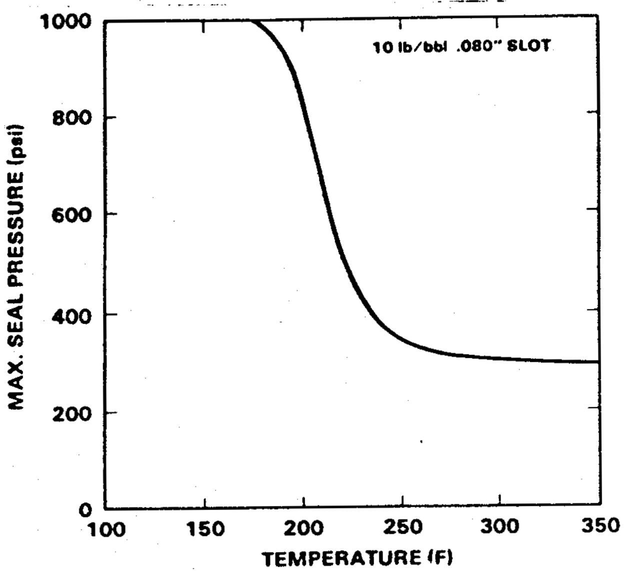


Figure 4. LCTF test results showing the effect of testing Hi-Seal (Thermoset Rubber) at elevated temperature.

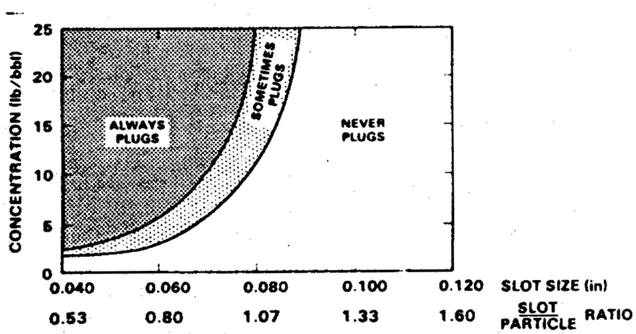


Figure 5. API Test Cell results showing the plugging ability of Hi-Seal (Thermoset Rubber) at ambient temperature and 1000 psi pressure differential.

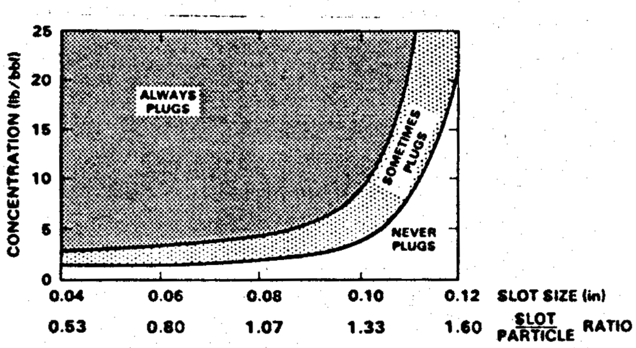


Figure 6. LCTF test results showing the ability of Hi-Seal (Thermoset Rubber) at ambient temperature and 1000 psi; pressure differential.

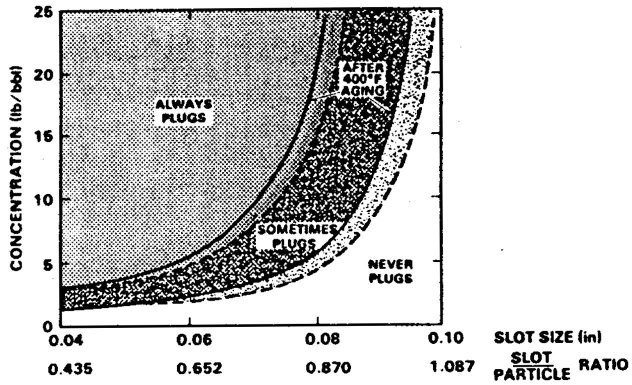


Figure 7. API Test Cell results showing the plugging ability of Kolite (ground coal) at 10000 psi; pressure differential and ambient temperature and, after temperature aging 4 hours at 400 F.

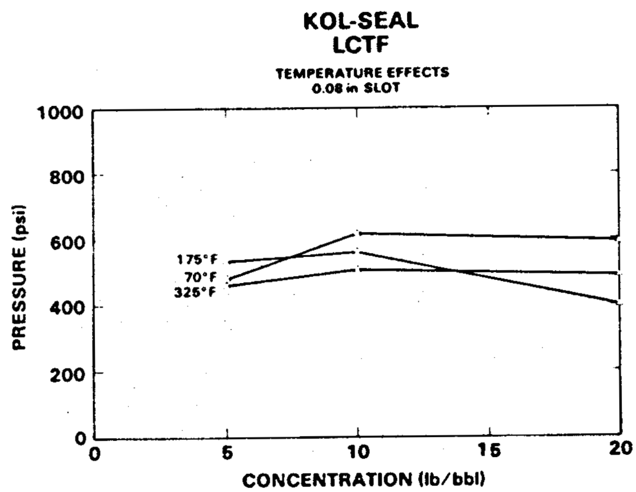


Figure 8. LCTF test results showing the performance of Kol-Seal (ground coal) using a 0.080 inch slot at elevated temperatures.

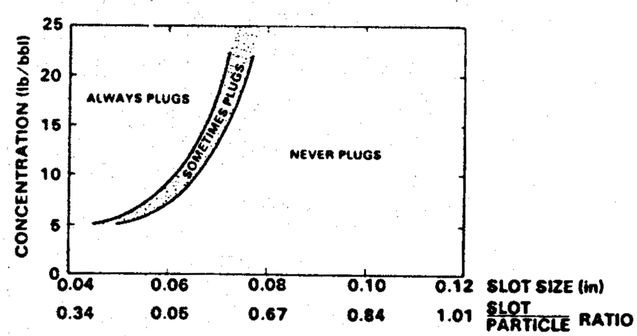


Figure 9. LCTF test results showing the plugging ability of Kol-Seal (ground coal) at ambient temperature and 1000 psi pressure differential.

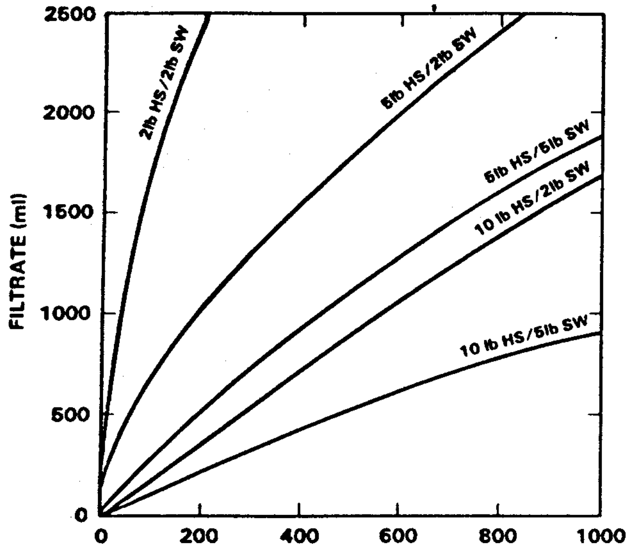


Figure 10. API TEST CELL results showing the effect on fluid loss by combining a fiber LCM (SW/ Strata Wool) with a particle LCM (HS/Hi-Seal), 0.080 inch slot and ambient temperature.

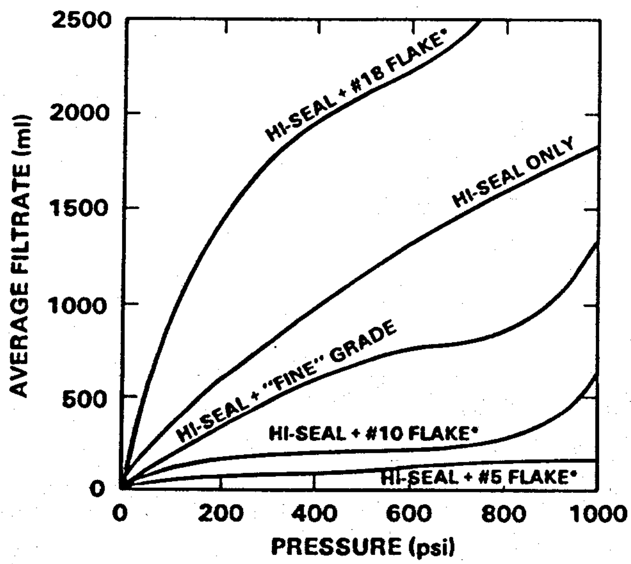


Figure 11. API Test Cell results showing the effect on filtrate loss using a 5 lb/bbl concentration of different sizes of flakes combined with the particle LCM Hi-Seal (1:1 by weight) compared to Hi-Seal only, 0.808 inch slot and ambient temperature.

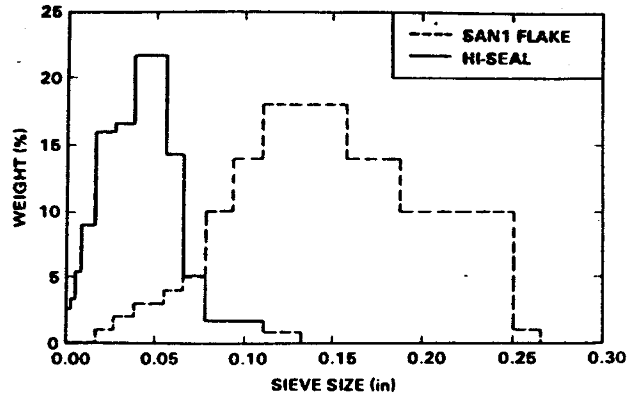


Figure 12. Material size distribution for Hi-Seal (particle LCM) and Sanl (flake LCM) sized for best performance with Hi-Seal when combined 1:4 (by weight).

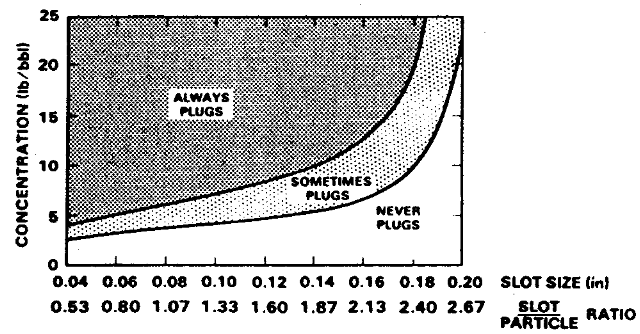
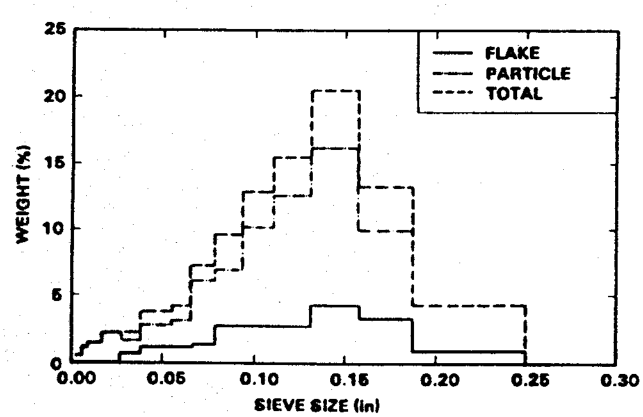


Figure 13. LCTF test results showing the plugging ability of a combined LCM (Sanl flake + Hi-Seal/1:4 by weight) at ambient temperature and 1000 psi pressure differential.



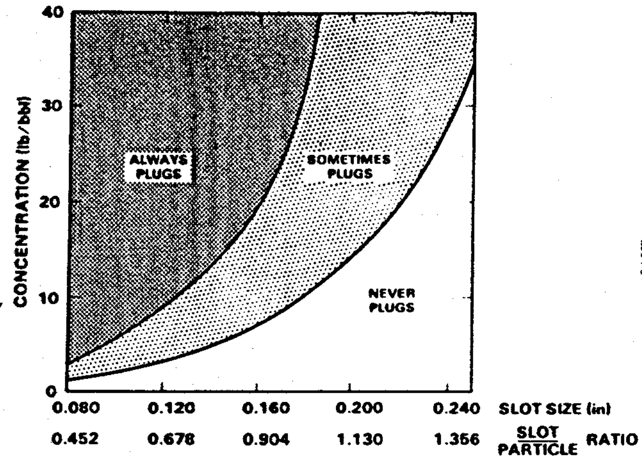


Figure 15. API Test Cell results showing the plugging ability of Super Wes-Bridge and Hi-Seal combined (1:1 by weight) at ambient temperature and 1000 psi pressure differential.

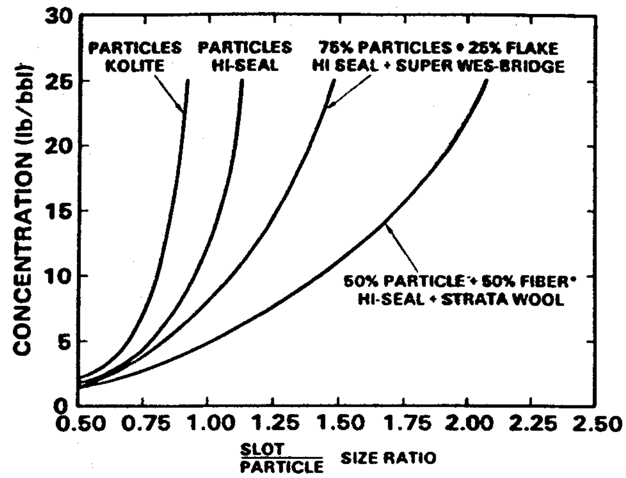


Figure 17. API Test Cell results for different LCM's compared, flake or-fiber size was not considered in the slot/particle size ratio calculation, tests at ambient temperature and 1000 psi pressure differential.

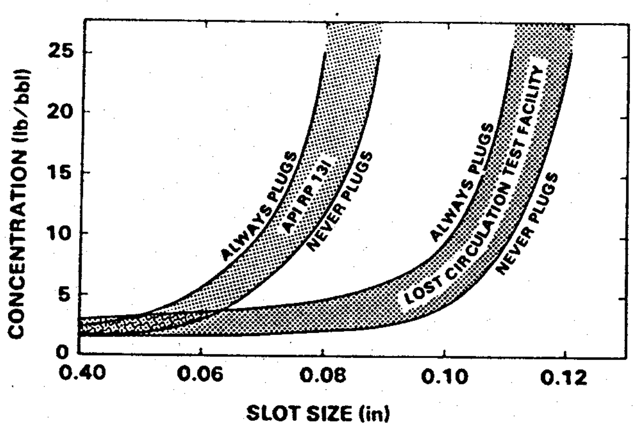


Figure 16. The test results for Hi-Seal LCM compared from the API RP 13I Test Cell and the Lost Circulation Test Facility test at ambient temperature and 1000 psi pressure differential.

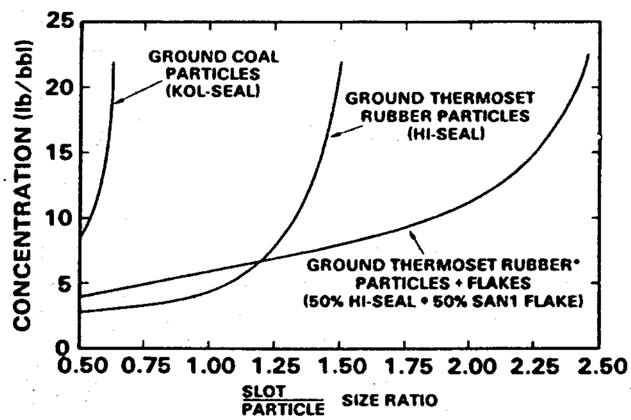


Figure 18. LCTF Test results for different LCM's compared, flake size was not considered in the slot/particle ratio. Tests at ambient temperature and 1000 psi pressure differential.