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AN EVALUATION OF FOUR SLURRY EXPLOSIVES
PROPOSED FOR USE IN EXPLOSIVE FRACTURING
OF OIL SHALE FORMATIONS

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Abstract

The oil shale fracturing experiment conducted by Sandia Laboratories and the Laramie Energy Research Center at Site 12 of the Rock Springs, Wyoming, oil shale experiment area required an understanding of the flow and detonation characteristics of the explosive slurry selected for insertion into preformed hydraulic fractures. A series of tests were conducted to evaluate those characteristics for four candidate explosive slurries considered for that experiment.

Two of the slurries flowed readily through medium (10/20 mesh) sand; two failed to flow through 10/20 sand but were capable of being pumped through coarse (8/12 mesh) sand. Tests were conducted which indicated that successful detonation can be achieved in cracks at least 1/8" thick; however, each of the explosives failed to detonate satisfactorily in 1/16" thick unfilled cracks, or sand filled cracks up to 3/8" thick.

<u>Detonation Tests</u>			
<u>Explosive Supplier</u>	<u>Flow Tests</u>	<u>Unfilled Fractures</u>	<u>Sand Filled Fractures</u>
TAL1005E Talley Energy Systems, Inc.	Flowed through coarse sand (8/12 or larger)	Failed to detonate in 1/16" thick cracks	Failed to detonate in sand filled cracks
Teledet Teledyne- McCormick Selph Company	Flowed through medium sand (10/20 or larger)	(Test not performed)	Failed to detonate in sand filled cracks
GOI-4 GOEX, Inc.	Flowed through medium sand (10/20 or larger)	(Test not performed)	Failed to detonate in sand filled cracks
PTC-4LT Petroleum Technology Company	Flowed through medium sand (10/20 sand or larger)	Low order detonation in 1/16" crack	Low order detonation in sand filled cracks

INTRODUCTION

An in situ shale oil extraction experiment, including the fracturing process, is in progress at Site 12 of the Laramie Energy Research Center test area west of Rock Springs, Wyoming. The objective of the fracturing experiment is to evaluate the formation fracturing and rubbing which results when a slurry explosive is inserted and detonated in two previously formed and sand propped hydraulic fractures.

During the planning phase of the experiment it was recognized that the resulting fracturing and rubblization¹ would depend upon the amount of explosive (thickness and density) which could be emplaced in a given area of each hydraulic fracture, and the successful high order detonation of the explosive. Questions existed as to whether the available slurry explosives could be satisfactorily extruded through the sands planned for use in propping open the hydraulic fractures, and whether, if emplacement were successful, a sustained high order detonation of the explosive would be achieved.

With these questions in mind, a series of tests was designed to evaluate the ability of the explosive slurry planned for use in the Site 12 Experiment (Talley Energy Systems, Inc. TAL1005E explosive) to be extruded through 20/40, 10/20, and 8/12 mesh propping sand. Tests were also planned to measure the degradation in detonation velocity attributable to contamination of the slurry by the propping sand. In addition, demonstration of the compatibility of the detonator/booster and the explosive slurry was required. The results of the first series of tests, strongly suggested subsequent testing of each of the other slurry explosives currently available for explosive fracturing. The other explosives tested were the GOI-4 produced by GOEX, Inc., a subsidiary of Gearhart-Owens Industries, Teledet produced by Teledyne-McCormick Selph Company, and PTC-4LT produced by the Petroleum Technology Company.

Test Description

General

The object of the explosive evaluation tests was to:

- a) observe the capability of the slurry to be extruded through simulated sand propped fractures,
- b) measure the degradation in detonation velocity caused by the propping sand,
- c) determine the approximate thickness at which the explosive fails to propagate a satisfactory detonation front,
- d) confirm the compatibility of the Site 12 explosive-detonator combination and
- e) for the PT-4LC explosive, determine if there is a noticeable difference in detonation characteristics between 45°F and 80°F.

Three similar test fixtures were used during the course of the tests. The fixtures all consisted of an aluminum plate, 1" thick, to which a thick (3/4" or 1") piece of plexiglas was bolted. In some tests the center of the aluminum plate was milled away to various depths to simulate the various crack thicknesses. In others the variable crack thickness was provided by rubber gaskets of various thicknesses. Since insertion pressures of up to 500 psi were anticipated, the early test fixtures were bolted together in the center as well as around the edges. The plexiglas plate permitted visual observation of the flow of the explosive through the sand.

Figure 1 shows the fixture used with the first tests and Figure 2 shows a modification made to permit variable explosive thicknesses. These fixtures were used primarily with the TAL-1005E explosive. The test fixture, was subsequently reduced in size and the center line of bolts deleted for use in the tests of the GOI-4 and Teledet materials. This fixture is shown in Figure 3. The PTC-4LT explosive was tested in the fixture shown in Figure 4 which deleted the booster well and contained a special slot across the end for the PTC initiation system.

Figure 5 shows a special fixture which was used with the TAL-1005 explosive to confirm the compatibility between the explosive and the intended detonator/booster assembly, and to determine the minimum crack width into which a detonation front would propagate from a simulated wellbore. This special fixture consisted of two sheets of plexiglas

Figure 1. Test Fixture Used With Early TAL 1005E Tests.

Figure 2. Test Fixture Used to Simulate Variable Thickness Crack

Figure 3. Test Fixture Used in GOI-4 and Teledet Tests

PTC 4LT Initiation Scheme

Figure 4. Fixture Used with PTC 4LT Tests

Figure 5. Booster/Detonator Compatibility Test Fixture

(4 feet by 4 feet) separated every several inches by spacer discs. The simulated wellbore was adhesively bonded to the upper plate. A hole in the upper plate the size of the simulated wellbore permitted the explosive to enter the space between the plexiglas sheet. With the exception of the tests of the PTC-4LT explosive, the tests were conducted at the supplier's plant with limited portable recording equipment. The PTC-4LT explosive was tested at Tracy Test Site of the Physics International Company.

Instrumentation

The early tests were designed to confirm the flow of the explosive through various sand proppants and to observe the detonation through the same propped sections. Instrumentation employed consisted of remote TV monitoring of the flow and the measurement of detonation velocities using velocity pins and SLIFER² cables.

Two types of velocity pins were used. Barium titanate stress pins were used in the testing of each explosive while ionization pins were also employed during the tests of the PTC-4LT material at the Physics International Test Facility. The stress sensitive pin employs a small crystal of barium titanate, a piezoelectric material, which generates an electric pulse when stressed by the passing shock. The barium titanate pins were .063" in diameter and about 2 inches in length. They were glued in place in holes drilled into the lucite cover plates. The tip of the pin was placed approximately 1/16" from the lucite/explosive interface. The times between the shock induced pulses were then recorded on fast counters and/or oscilloscopes.

The ionization pins supplied by Physics International were about .090" in diameter and approximately 2 inches in length.

²SLIFER is an acronym meaning Shorted Location Indicator by Frequency of Electrical Resonance. A SLIFER cable is a coaxial cable where the inductance between the inner and outer conductors is changed as the cable is collapsed (and shorted) by the moving shock. The change in inductance changes the resonant frequency of the cable which is measured continuously during the detonation. The measured resonant frequency is then used to infer a cable length versus time.

They consisted of a piece of rigid copper tubing enclosing a center conductor and solid dielectric. As the ionized shock front engulfed the end of each pin, it would conduct and the time-of-arrival of the shock at that pin would then be recorded with a counter and/or oscilloscope. The ionization pins were positioned similarly to the stress pins except that the holes they were placed in were drilled completely through the lucite and the pin was bonded in place flush with the inside surface of the lucite as shown in Figure 6. The piezoelectric pins are usually responsive to low level shocks. This was evident in the PTC tests where the low velocity disturbance was not sensed by the ionization pins. Care must be taken in interpreting the data that the arrival of a true detonation front is concluded rather than the arrival of an elastic wave in the plexiglas or explosive slurry from the detonator or explosive detonation ahead of the sand pack.

The SLIFER cables used during the TAL-1005E tests were used to record shock velocity. Three SLIFER cables were used with each of the test assemblies of Figure 5. Piezoelectric crystals were also used as time-of-arrival gages to indicate shock passage on the TAL-1005E tests shown in Figure 5.

Explosive Initiation

In the TAL-1005E tests, the explosive was detonated by Sandia; however, in each of the other tests, the explosive was detonated by the respective supplier.

At the Talley Energy Systems, Inc. (TESI) site, the tests which established the compatibility of the booster/detonator system (Figure 5) were detonated by an exploding bridgewire (EBW) detonator designated the SE-1. The SE-1 was expected to be used in the Rock Springs Site 12 experiment. The remaining tests at the TESI site were initiated by inserting an SE-1 detonator through a hole in the lucite plate as shown in Figure 7. A tetryl pellet surrounded by a mass of C-4 boosted the TAL-1005E.

The GOI-4 and Teledet tests used a supplier-furnished blasting cap inserted into a well which was machined into the end of the aluminum plate (see Figure 8). The well was included to provide a larger volume of the explosive around the detonator to improve the initiation.

Figure 6. Velocity Pin Installations

Figure 7. Detonation Scheme Used in TAL 1005E Tests

Figure 8. Detonation Scheme Use in GOI-4 and Teledet Tests

Figure 9. Detonation Scheme Used in PTC-4LT Tests

FIGURE 10-TAL 1005E TEST FIXTURE PRIOR TO TEST

The PTC test fixtures used yet another initiation scheme. The end of the aluminum and the lucite plates were slotted to provide an opening in the end of the assembly which was up to 3/8" thick by 1-1/8" deep over the width of the test fixture. A piece of Detasheet 1/4" thick by approximately 2" long and 4" wide was inserted in the slotted end of the fixture. The explosive flowed around the Detasheet filling the voids to the top of the fixture. The fixture was oriented so that the long (24") dimension was vertical and detonation occurred at the top of the fixture. A RP-88 detonator (similar to the SE-1) fixed to the detasheet booster initiated the explosive. Figure 9 depicts this detonation system.

Closed circuit television monitored the insertion of the explosive slurry during each of the test series except those performed at Physics International where the insertion was observed in person. Still photography documented the test setups. Post mortem examination of the aluminum plates confirmed the degree of detonation achieved as indicated by the measured detonation velocity.

Test Results

Summary

The TAL-1005E and GOI-4 slurries could not be pumped through simulated sand propped fractures while the Teledet and PTC-4LT flowed readily through similar fractures. A satisfactory detonation front was not sustained in any of the explosives tested as it entered the simulated sand propped section. A low order detonation was sustained by the PTC-4LT as it entered the sand and remained low order as it exited the sand back into the explosive. Low order detonation or failure to sustain a detonation front was observed for each explosive in 1/16" thick cracks.

The Sandia Site 12 experiment had to be changed, as a result of these tests, to eliminate nearly all the planned proppant and insert the explosive under pressures capable of opening the fractures to an acceptable thickness at the time of detonation.

The following paragraphs describe the results of the four groups of tests. A brief description and a summary of the results of each of the tests are contained in Table.1.

TAL-1005E Test Results

The TAL-1005E could not be pumped through 10/20 mesh or smaller sand with reasonable pressures (up to 250 psi), however, it did flow through #12 construction sand and 8/12 mesh propping sand under a pressure of about 40 psi. Since the #12 construction sand is highly irregular and contains some fines, the TAL-1005E flow was slowed somewhat as it proceeded through the sand and picked up the fines.

The TAL-1005E detonated satisfactorily in cracks of 1/8" thickness but did not consistently detonate in cracks 1/16" in thickness when initiated by a intersecting column simulating a central wellbore. The detonation front proceeded normally through a special fixture where the thickness of the explosive stepped from 3/8" to 1/4" to 1/16" and back to 3/8". Detonation velocities of about 6500 m/sec were measured where normal detonation was achieved. In the 1/16" cracks, the detonation velocities of 2500 to 3500 m/sec were measured. Since the acoustic velocity in plexiglass is about 2600 m/sec it is questionable whether the measured 2500-3500 m/sec is that of a low order detonation or the normal shock which would be observed in the plexiglass.

The failure of the explosive in the sand filled sections to detonate was obvious from the post-shot observation of the test fixture. In those instances only the detonation end of the fixture was damaged and the simulated fracture was still filled with the sand/slurry mixture. Figure 10 shows a test fixture prior to detonation and Figure 11 shows the same fixture after the test. Note the undetonated and unburned explosive/sand mixture.

GOI-4 Test Results

The GOI-4 slurry was pumped through simulated propped fractures with 10/20 mesh or larger sand. Figure 12 shows pin times plotted against distance for the two GOI-4 detonation tests. The detonation velocity in a simulated, sand-free fracture 1/4" thick was about 6000 m/sec. The detonation front failed to propagate from a sand-free crack into sand propped zones filled with 10/20 or 8/12 mesh sand as evidenced by the measured velocities being very close to the 2600 m/sec acoustic velocity in plexiglas. The pin responses resulted from the elastic wave being transmitted from the explosive in initiation end of the fixture to the pins by way of the plexiglas cover. Post-test evaluation confirmed that the explosive failed to detonate in the sand filled area.

TABLE 1. RESULTS OF EXPLOSIVE SLURRY TESTS

Test	Purpose of Test	Test Description	Results Observed
TAL-1005E Test No. 1 (1/25/77 to 2/4/77)	Explosive Insertion in fine (20/40) propping sand.		The explosive failed to enter the sand filled zone.
Test No. 2 (1/25/77 to 2/4/77)	Water insertion in fine (20/40) prop- ping sand. Com- parative test.		Water flowed readily through the sand filled zone. The sand was quickly washed out of the fixture when the water front reached the vent. The water flow test was conducted merely as a demonstration test to confirm that a low viscosity fluid could flow through the sand filled fixture.

Test	Purpose of Test	Test Description	Results Observed
TAL-1005E Test No. 3 (1/25/77 to 2/4/77)	Pump TAL-1005E thru open thin crack.	<p>1/16"</p> <p>OPEN</p>	The TAL-1005E flowed thru the open 1/16" crack with a maximum pressure build-up of 20 psi.
Test No. 4 (1/25/77 to 2/4/77)	Explosive insertion in 3/8" crack with propped zone of #12 sand.	<p>3/8"</p> <p>#12 construction sand</p>	The TAL-1005E moved smoothly if slowly through the #12 sand.

Test	Purpose of Test	Test Description	Results Observed
TAL-1005E Test No. 5 (1/25/77 to 2/4/77)	Explosive insertion in 1/4" crack with propped zone of #12 sand.		The TAL-1005E flowed to the middle of the sand filled zone quickly at which time the flow slowed to about 4-1/2 in/minute at 40 psi. A line of fine sand was accumulated at the leading edge of the fluid tending to block the flow.
Test No. 6 (1/25/77 to 2/4/77)	Explosive insertion in 3/8" crack with 10/20 mesh sand.		The TAL-1005E flowed into the sand pack approximately 2 inches when the flow was stemmed. Pressure was allowed to build to 200 psi without additional flow.

Test	Purpose of Test	Test Description	Results Observed
TAL-1005E Test No. 7 (1/25/77 to 2/4/77)	Explosive insertion in 3/8" crack filled with 50-50 mixture of 8/12 and 10/20 sand.		The TAL-1005E proceeded about 5" into the sand at which time it bridged and flow stopped.
Test No. 8 (1/25/77 to 2/4/77) and Test No. 9 (1/25/77 to 2/4/77)	Compatibility between detonator/booster system and the TAL-1005E in the wellbore configuration.		High order detonations were achieved on both tests demonstrating the compati- bility of the detonator/ booster assembly with the TAL-1005E explosive.

Test	Purpose of Test	Test Description	Results Observed
TAL-1005E			
Test No. 10 (1/25/77 to 2/4/77)	Propagation of detonation front in well-bore to 1/4" crack intersecting well-bore.	<p>Detonator/Booster Assembly</p> <p>SLIFER Cables</p> <p>Time-of-Arrival Gages</p> <p>Typical Spacer</p> <p>1/4" Plexiglas Plates</p> <p>1/4"</p>	Detonation propagated into 1/4" crack. Average detonation velocity = 6930 m/sec.
Test No. 11 (1/25/77 to 2/4/77)	Propagation of detonation front from well-bore to 1/8" crack intersecting well-bore.	<p>Detonator/Booster Assembly</p> <p>SLIFER Cables</p> <p>Time-of-Arrival Gages</p> <p>Typical Spacer</p> <p>1/4" Plexiglas Plates</p> <p>1/8"</p>	Detonation propagated into 1/8" crack. Average detonation velocity = 6431 m/sec.

Test	Purpose of Test	Test Description	Results Observed
<p>TAL-1005E</p> <p>Test No. 12 (1/25/77 to 2/4/77)</p>	<p>Propagation of detonation front from wellbore to 1/16" crack intersecting wellbore</p>	<p>The diagram shows a 3D perspective of the experimental setup. A cylindrical 'Detonator/Booster Assembly' is positioned on a stack of '1/4" Plexiglas Plates'. 'SLIFER Cables' are connected to the assembly. A '1/16"' crack is shown intersecting the plates. 'Time-of-Arrival Gages' are placed along the crack, with a 'Typical Spacer' between them.</p>	<p>The detonation failed to propagate in 1/16" crack.</p>
<p>Test No. 13 (1/25/77 to 2/4/77)</p>		<p>This diagram is identical to the one for Test No. 12, showing the 'Detonator/Booster Assembly', 'SLIFER Cables', '1/4" Plexiglas Plates', '1/16"' crack, 'Time-of-Arrival Gages', and 'Typical Spacer'.</p>	<p>The detonation failed to propagate at normal velocity in the 1/16" crack. The average velocity measured about 2532 m/sec. This is very close to the sound speed in Plexiglas and therefore should be interpreted as the measurement of a shock in the Plexiglas from the detonator/booster explosion.</p>

Test	Purpose of Test	Test Description	Results Observed
TAL-1005E			
Test No. 14 (2/28/77 to 3/3/77)	Confirm results of No. 11, 12.		A detonation was not obtained in the 1/16" crack. Average of the velocities recorded was 2903 m/sec., very near the acoustic velocity in the Plexiglas.
Test No. 15 (2/28/77 to 3/3/77)	Propagation of detonation front from wellbore into 1/16" crack intersecting wellbore.		Same as test No. 14 except average velocity recorded was 3458 m/sec.
Test No. 16 (2/28/77 to 3/3/77)	Confirm that detonation front would propagate from wellbore into 1/8" crack intersecting the wellbore.		Detonation propagated successfully from the wellbore into the 1/8" crack at a velocity of about 6500 m/sec.

Test	Purpose of Test	Test Description	Results Observed
<p>TAL-1005E</p> <p>Test No. 17 (2/28/77 to 3/3/77)</p>	<p>Measure the detonation velocity as the detonation proceeds from explosive into sand and back into the explosive.</p>	<p>The diagram shows a rectangular block with a top layer of explosive (4" thick) and a bottom layer of 8/12 Sand and TAL 1005E Mixture (1/4" thick). The total length is 2". The bottom layer contains piezoelectric pins (marked with asterisks). The right end is labeled 'Initiation End'.</p>	<p>Detonation front proceeded at a velocity of 6661 m/sec in the initial volume of explosive. The detonation stopped as it arrived at the first sand/explosive interface.</p>
<p>Test No. 18 (2/28/77 to 3/3/77)</p>	<p>Measure the detonation velocity in the sand/explosive mixture.</p>	<p>The diagram shows a rectangular block with a top layer of explosive (1/4" thick) and a bottom layer of 8/12 Sand and TAL 1005E Mixture (1/4" thick). The total length is 1/4". The bottom layer contains piezoelectric pins (marked with asterisks). The right end is labeled 'Initiation End'.</p>	<p>The detonation front stopped at the sand/explosive interface.</p>

Test	Purpose of Test	Test Description	Results Observed
<p>TAL-1005E</p> <p>Test No. 19 (2/28/77 to 3/3/77)</p>	<p>Measure the detonation velocity as the front proceeded through variable crack thicknesses.</p>	<p>4"</p> <p>3/8"</p> <p>1/16"</p> <p>1/4"</p> <p>3/8"</p> <p>Initiation End</p> <p>*-Piezoelectric Pins</p>	<p>The detonation front proceeded normally from one end of the fixture to the other.</p>

Test	Purpose of Test	Test Description	Results Observed
GOI-4 Test No. 1 (4/4/77)	Observe the ability of the GOI-4 to be pumped and detonated through 10/20 sand.	<p>The diagram shows a cross-section of a rectangular container. At the top, two 'Piezoelectric Pins' are shown, each with a 9" dimension. Below them is a 'Booster Well' containing a '10/20 Sand and GOI-4 Mixture'. The bottom of the container is labeled '1/4"'. The right side of the container is labeled 'Initiation End'.</p>	<p>The GOI-4 explosive flowed through the 10/20 sand pack. The detonation front stopped as it arrived at the sand/explosive interface. The detonation velocity in the explosive was 6020 m/sec. See Figure 10.</p>
Test No. 2 (4/4/77)	Observe the ability of the GOI-4 to be pumped and detonated through 8/12 sand.	<p>The diagram shows a cross-section of a rectangular container, similar to the one above. It has 'Piezoelectric Pins' at the top with 9" dimensions, a 'Booster Well' containing an '8/12 Sand and GOI-4 Mixture', and a bottom labeled '1/4"'. The right side is labeled 'Initiation End'.</p>	<p>The GOI-4 explosive flowed through the 8/12 sand pack. The detonation front stopped as it arrived at the sand/explosive interface. The detonation velocity in the explosive was 6280 m/sec. See Figure 10.</p>

Test	Purpose of Test	Test Description	Results Observed
<p>Teledet</p> <p>Test No. 1 (4/11/77)</p>	<p>Observe the ability of the Teledet explosive to be pumped and detonated through 10/20 sand.</p>	<p>The diagram shows a cross-section of a rectangular container. At the top, a layer of 'Piezoelectric Pins' is shown with a thickness of 1/4". Below this is a layer of '10/20 Sand and Teledet Mixture' with a thickness of 1/4". The container has an 'Initiation End' on the right and a 'Booster Well' on the left. The length of the container is marked as 9" on both the top and side views.</p>	<p>Although the Teledet appeared to be quite viscous before pumping, it was thixotropic and flowed through the sand pack very readily under pressure. The detonation front stopped at the explosive sand interface.</p>
<p>Test No. 2 (4/11/77)</p>	<p>Same as test No. 1</p>	<p>The diagram shows a cross-section of a rectangular container, similar to Test No. 1. It has a top layer of 'Piezoelectric Pins' (1/4" thick) and a bottom layer of '8/12 Sand and Teledet Mixture' (1/4" thick). The container has an 'Initiation End' on the right and a 'Booster Well' on the left. The length is marked as 9" on both the top and side views.</p>	<p>Same as for test No. 1</p>

Test	Purpose of Test	Test Description	Results Observed
PTC-4LT Test No. 1 (2/14/78)	Measure detonation velocity in 8/12 sand at 80°F.	<p>3"</p> <p>Initiation End</p> <p>8/12 Sand/Explosive Mixture</p> <p>Ionization Pins</p> <p>1/4"</p> <p>Temperature = 88°F</p>	The explosive flowed easily through the sand. The detonation velocity approaching the sand was about 7500 m/sec. The detonation velocity through the sand and in the explosive following the sand was about 2180 m/sec.
Test No. 2 (2/14/78)	Measure detonation velocity in 10/20 sand at 80°F.	<p>3"</p> <p>Initiation End</p> <p>10/20 Sand/Explosive Mixture</p> <p>Ionization Pins</p> <p>Piezoelectric Pins</p> <p>1/4"</p> <p>Temperature = 80°F</p>	The explosive flowed easily through the sand. The detonation velocity approaching the sand was about 7500 m/sec. The detonation velocity through the sand and in the explosive following the sand was about 1900 m/sec.

Test	Purpose of Test	Test Description	Results Observed
PTC-4LT Test No. 3 (2/15/78)	Measure the detonation velocity in a 1/16" wide crack at ~45°F.	<p>Temperature = 50°F</p>	A high order (~6000 to 8000 m/sec) detonation was not achieved. A "burn" front propagated at an initial velocity of about 1385 m/sec increasing to about 1905 m/sec after about 6" of run.
Test No. 4 (2/15/78)	Measure the detonation velocity in a 1/16" wide crack at 80°F.	<p>Temperature = 78°F</p>	A high order detonation was not achieved. A "burn" front propagated at a velocity of about 1905 m/sec.

Test	Purpose of Test	Test Description	Results Observed
PTC-4LT Test No. 5	Measure the "burn" propagation velocity in sand.	<p>Temperature = 69°F</p>	A velocity of about 1900 m/sec was measured in the sand. Unsatisfactory boosting of the PTC-4LT (upstream of the sand pack) was indicated by the lack of spall at the initiation end of the aluminum plate. On all other tests, the back surface of this plate was spalled in the areas where the PTC-4LT was not contaminated with sand and a high velocity detonation was measured.
Test No. 6	Repeat of Test No. 5 with a slightly longer section of pure explosive.	<p>Temperature = 70°F</p>	A detonation velocity of 7250 m/sec was measured in the pure explosive sector decreasing abruptly to 1690 m/sec in the explosive/sand mixture.

Test	Purpose of Test	Test Description	Results Observed
PTC-4LT Test No. 7	Measure the detonation velocity in pure explosive after the detonation front exits a sand pack.	<p>Initiation End</p> <p>8/12 Sand and PTC 4LT Mixture</p> <p>2-3/8"</p> <p>1/4"</p> <p>•-- Ionization Pins ▲ Piezoelectric Pins</p>	A "burn" velocity of about 2000 m/sec was measured in the pure explosive following the short sand pack.

Teledet Test Results

The Teledet slurry exhibited the characteristics of a classic thixotropic material during the pumping test. Although it was a thick slurry at rest, it flowed quickly through cracks filled with 10/20 mesh and 8/12 mesh propping sand when pressure was applied. Figure 13 is a plot of the pin times for the Teledet explosive. The measured detonation velocity of the Teledet slurry in a simulated, sand-free crack was about 6300 m/sec. Like the TAL-1005E and GOI-4, the detonation front ceased to propagate upon encountering a zone propped with 10/20 or 8/12 sand as was shown by visual inspection of the fixtures after the test. The velocity measured in the sanded area is very close to the acoustic velocity of plexiglas in the first plot; however, that shown in the second plot is considerably less than that of plexiglas.

PTC-4LT Test Results

The PTC-4LT explosive was a very low viscosity slurry which flowed readily through simulated sand propped cracks filled with 10/20 or 8/12 mesh sand under very low pressure. The test fixtures were filled from the bottom while standing on end by pouring the explosive into a vertical fill tube. The total head height was less than a foot above the top of the fixture.

Figures 14 through 20 show the pin times versus distance recorded for each of the PTC-4LT tests. The PTC-4LT detonated in sand-free 1/4" thick cracks at a characteristic detonation velocity of ~7500 m/sec. The detonation velocity reduced to ~2000 m/sec upon encountering the sand-filled sections or when initiated in a crack 1/16" thick. After emerging from the sand, the decomposition front velocity remained at ~2000 m/sec over the remaining length of the test fixture. Sound speed in explosive slurries of this type is in the range of 2000 m/sec. The sand contamination of the explosive layer and the thin layers of explosive (e.g. 1/16" thick cracks) would both contribute to the dissipation of the normal detonation velocity of the explosive. The slower than normal velocity measured in the sand filled and thin sections is therefore not surprising.

As the velocity of detonation front slowed in the sand and thin crack regions, the ionization pins failed to short and indicate from arrival. Piezoelectric pins were then employed to record the arrival of the decomposition front.

Figure 12. Pin Actuation Times Observed During GOI-4 Tests

Figure 13. Pin Actuation Times Observed During Teledet Tests

Figure 14. Pin Actuation Times for PTC Test No. 1
(1/4"/88°F - 8/12 sand)

Figure 15. Pin Actuation Times for PTC Test No. 2
(1/4"/80°F - 10/20 sand)

Figure 16. Pin Actuation Times for PTC Test No. 3 (1/16"/50°F - no sand)

Ionization Pins Group B

Figure 17. Pin Actuation Times for PTC Test No. 4 (1/16"/78°F - no sand)

Figure 18. Pin Actuation Times for PTC Test No. 5
(1/4"/69°F - 8/12 sand)

○ Ionization Pins Group A

□ Ionization Pins Group B

Figure 19. Pin Actuation Times for PTC Test No. 6
(1/4"/63°F - 8/12 sand)

Figure 20. Pin Actuation Times
for PTC Test No. 7
(1/4"/63°F - 8/12 sand)

Although there is some scatter in the arrival times, especially in the sand-filled areas, the times observed and velocities so indicated are well within the accuracy desired to infer the occurrence of either a high order detonation or a low order deflagration caused by thin cracks or sand packed areas.

Conclusions and Recommendations

The tests planned and conducted in this series were not designed to completely characterize the four explosives tested (e.g. measuring total energy output), but to determine their immediate applicability to the Rock Springs Site 12 experiment. The following conclusions are therefore made in reference to that experiment.

The failure of the TAL-1005E to flow through 10/20 mesh sand, and the sluggishness with which it flowed through 8/12 sand and the GOI-4 flowed through both 10/20 and 8/12 sand, raised questions regarding the planned procedure of emplacing these explosives in previously formed and sand propped hydrofrac. Specifically, it appeared certain that the emplacement of the explosive into sand propped fractures according to the original plan would have resulted in a wellbore full of explosive which could not have been forced into the formation without further hydraulically fracturing the formation with the explosive. The Site 12 experiment was thereby changed to permit the explosive to be emplaced in hydrofracs relatively free of sand (i.e., with a partial monolayer of 6/8 sand).

It is further concluded that because of the observed failure of any of the four explosives to propagate a detonation into the simulated sand filled cracks, it would be inappropriate to assume that the explosive would detonate in the configuration originally planned for the Site 12 experiment. In addition the possibility that past gas and oil well stimulation efforts which may have been unsuccessful in the past in stimulating production may have been unsuccessful simply because the explosive failed to detonate and produce a stress wave capable of fracturing the rock. Visual observation of large amounts of combustion gases from the wellbore could have been erroneously interpreted as an indication of a normal detonation. Existing fractures would have been merely extended and a limited number of new fractures formed by the relatively low pressures created by the combustion gases formed by burning the explosive.

The results of at least the TAL-1005E tests should not have been a surprise to those familiar with the fact that the minimum detonation radius had previously been determined to be .012" and the manner in which such tests are typically performed. The spaces around the grains of sand in a zone filled with 8/12 mesh (.080" to .125" diameter) sand are of the order of .010" to .020". Therefore to TAL-1005E or any other explosive with a minimum detonation radius in that range should not have been expected to sustain a detonation front. Since the PTC-4LT displayed a reluctance to detonate high order in a 1/16" thickness, its ability to sustain a detonation front in the thin spaces between the sand grains would be questionable.

Surface tests simulating downhole explosive configurations should be conducted for any experiment or operation using explosive slurries to confirm the expected performance or to reveal unexpected problems. Care should be taken in interpreting and applying general explosive performance tests such as traditional minimum detonation thickness tests to field operations.

References

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