Production Improvement from Increased Permeability Using Engineered Biochemical Secondary Recovery Methodology in Marginal Wells of the East Texas Field

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By

Dr. R.L. Bassett, President
TENECO Energy, LLC
and

William S. Botto, President
MICRO-TES, Inc.

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Submitted by:

TENECO Energy, LLC, 3760 Vance St. Suite 200, Wheat Ridge, CO 80033-6275, and

MICRO-TES, Inc., 12500 Network, Suite 201, San Antonio, TX 78249-3307

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ABSTRACT

A regenerating biochemical mixture and organic surfactant has been applied to wells in the East Texas Field with the goal of restoring permeability, reversing formation damage, mobilizing hydrocarbons, and ultimately increasing production. Initial work in task 1 was designed to open the perforations and remove blockages of scale, asphaltene, and other corrosion debris. This was accomplished on three wells that produce from the Woodbine, and was necessary to prepare the wells for more substantial future treatments. Secondly, in task 2, two wells were treated with much larger quantities of the biochemical mixture, e.g. 25 gallons, followed by approximately 140 barrels of a 2% KCl solution that carried the active biochemical solution into the near wellbore area and into the producing reservoir. After a 7 to 10 day acclamation and reaction period, the wells were put back into production. The biochemical solution successfully broke down the scale, paraffin and other binders blocking permeability and released significant debris which was immediately produced into the flowlines and separators. Oil production was clearly improved and the removed debris was a maintenance issue until the surface equipment could be modified. Next steps include larger treatments and tracer tests to better understand the fluid flow dynamics.

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1.0 INTRODUCTION

This research project has as its objectives: 1) the testing and evaluation of a method for increasing oil production by implementing innovative technology using a multi-dimensional biochemical secondary recovery treatment engineered to remove permeability impediments, e.g. paraffin, asphaltene, inorganic scale, iron corrosion, and mobilize residual frac gels, etc., accumulated over the 70 year production history of the East Texas Field. 2) to devise a protocol that has the significant environmental advancement that no petroleum based solvents or additives are required; consequently, permits, remediation and spill cleanup are avoided.

The project is using regenerating biochemicals produced by certain species of microbes i.e. Pseudomonas and related species to mitigate the aforementioned formation damage, thus restoring permeability and increasing recovery by reducing the surface tension of the oil in-place to the reservoir rock. The work is proceeding as three well-defined tasks. The initial task is to select prospective wells and use the biochemical treatment to open the perforations and clean up the wellbore, removing scale, paraffin, and other corrosion related residual material. The initial task is essential because debris and residual material mobilized by subsequent treatments in tasks 2 and 3 must be removed through the perforations and thus obstructions need to be removed. The second task is to clean outside the wellbore and break down the permeability barriers within the producing reservoir in the near well bore environment. The final task is to extend the biochemical suspension as far as is practical into the reservoir, either as an injection/withdrawal experiment, or as a well to well tracer test, if travel times are sufficiently fast to allow for breakthrough in an adjacent well.

To date the first task is completed and the second task will be completed in the very near future. The third task will begin by the summer of 2004.

2.0 EXECUTIVE SUMMARY

A regenerating biochemical mixture and organic surfactant has been applied to wells in the East Texas Field with the goal of restoring permeability, reversing formation damage, mobilizing hydrocarbons, and ultimately increasing production. The biochemical solution is added to the well annulus by gravity feed, and the solution can be mixed at the well site. Three wells with known well bore characteristics and perforation depths were treated, and all three wells evidenced an improvement either by increased production volume or the pumping of sand, scale, and other debris with the produced water.

Operations are affected at least two ways by the mobilized debris, first the mobilized debris interferes with pump action and may requires pump removal, and redressing, or secondly, scale and paraffin may be removed by the biochemical solutions exposing corrosion holes that were protected by the coatings of scale and paraffin. The use of cup-type tubing pumps significantly improves the capability of the pump to lift and discharge the mobilized debris with the produced fluid. The identification of weak or damaged tubing simply allows for proactive maintenance of tubulars.

Two wells were selected for the more substantial biochemical treatment in task 2. The treatment consists of at least 25 gallons of the biochemical solution and 25 gallons of nutrient solution, and approximately 140 barrels of carrier 2% KCl water. The biochemical solution is transported in drums and added directly to the annulus of the well, and the 2% KCl solution is brought in by truck to the well site. Addition of the solution is rapid and the only time constraint is the delivery time for trucking. Wells are left shut-in for 7 to 10 days for the microbes to acclimate and react. Wells are then placed back into production. Well No. 9 was successfully improved: oil production increased from about 0.3 BOPD to 1.5 to 2.5 BOPD. Water production increased only slightly indicating that the treatment may be impacting and improving the oil wet permeability more than the water wet permeability. Well No. 8 was also successfully treated evidenced by the increase in gas pressure and the increase in oil percent. This well does not produce a total fluid volume that is sufficient to remove the mobilized material and at present is still cleaning up.

Lessons learned to date that will benefit other operators in the future include the following. The quantity of material that is mobilized is significant. Flow lines, separators, and valves all become clogged with the debris and pressure actuated valves fail. A large gunbarrel performs effectively in separation of oil and water in the presence of the mobilized sediment and debris. By using a cup type tubing pump and gunbarrel the movement of debris ceases to be a problem.

3.0 EXPERIMENAL

Task 1 - Application of the Biochemical Product (Well Bore Environment).

Wells in The East Texas Field are approximately 3300 feet in depth and production over the life of these wells has been from the main Woodbine sand and from a lower sand stringers at the base of the Eagle Ford section. The wells in The East Texas Field may contain paraffin, asphaltene and scale inside the wellbore. It is therefore necessary to cleanup the immediate well bore area first.

Experimental Procedure: This treatment consisted of approximately 5 gallons of the biochemical product, 5 gallons of nutrient water, and 3 to 4 barrels of flush water. Samples of the produced water were collected prior to treatment for analysis of the existing microbial populations. The purpose of the initial microbial analysis was to determine if any species of Pseudomonas were present that would provide false indications of breakthrough in tracer test scheduled for task 3; none were identified. To the extent possible, care was taken not to introduce destructive microbes not already active, such as sulfate reducing bacteria; consequently, the flush water was either produced water from this lease, or purchased 2%KCl water. This treatment was designed to effect a cleanup of the immediate well bore environment i.e. perforations, etc. by mobilizing/solubilizing the scale, rust, corrosion by-products, paraffin, and aphaltenes.

Well nos. 1, 5, 8, and 9 have been treated with the biochemical product to clean the immediate well bore environment. The product and flush were introduced down the casing side of the well and the well was shut-in for at least 1 to 3 days. Subsequently, the wells were are placed back on pump to remove the debris created by the treatment, and to observe any change in production as a result of the clean-up treatment..

Task 2.0 - Biochemical Squeeze Treatments (Production Stimulation).

The “biochemical squeeze” treatment is designed to force the biochemical slurry through the previously cleaned perforations to treat outside the well bore and penetrate into the formation to liquefy blockage in the reservoir sands due to tar mats, and inorganic material. The biochemical solution is also designed to reduce surface tension of the oil/rock matrix interface thus mobilizing more recoverable oil.

Calculations were made to determine the optimum amounts of the biochemical product, nutrient package, and flush needed to deliver the product package to the formation based on fluid levels, number of feet of perforations and the volume of annulus. The No. 8 and No. 9 wells were selected for the “squeeze treatments” principally because the locations and producing sands were well defined and in the same horizon. This would allow for a test of the lower stringer sands, in two adjacent wells and would allow us to evaluate whether these wells would be appropriate for the well to well test designed for the next task.

It was determined for well No. 8 that the optimum solution was 25 gallons of the biochemical solution, 20 gallons of nutrient, 40 barrels of 2% KCl flush water with 2% nutrient solution added, and 140 barrels of flush water consisting of 2% KCl solution.

For well No. 9, the optimum solution was 25 gallons of the biochemical solution, 20 gallons of the nutrient solution, 40 barrels of 2% KCl flush solution with 2% nutrient solution added followed by 140 barrels of flush water. To maximize the distribution of the solution, re-circulating loop was installed on the wellhead that allow us to re-circulate produced water back down the annulus for at least 4 hours during the shut –in period.

The wells were left shut-in for at least 7 to 10 days to allow the microbes to become established and break down the paraffins, asphaltenes, and tar mats. Wells were then turned on to evaluate the production and remove the residual mobile debris.

4.0 RESULTS AND DISCSSION

The East Texas Field was discovered on October 5, 1930. This field is a classic stratigraphic trap comprising over 140,000 acres. Production is primarily oil with over 5-billion barrels of production to date. The woodbine sands, including the Lewisville and Dexter are the primary producing horizon within the field. These sands are both massive and stringer in nature, and have high porosity and permeability. The drive mechanism is primarily water with significant solution gas also contributing. To date over 30,000 wells have been drilled in this field. It was a "giant" oil field even by today's standards. Primary recovery under optimum conditions is 18% to 20% of the oil in place.

Based on our historical research, the existing wells in the East Texas Field were subjected to every type of treatment that became popular over the last 70 years. Many of these treatments resulted in significant formation damage i.e. asphaltene and paraffin precipitation in the pore throats thus reducing permeability, acid treatments causing inorganic materials such as iron sulfide to precipitate within the reservoir.

In addition, the rapid production and over-drilling could have caused paraffin and asphaltene to precipitate in larger quantities forming tar mats and creating major permeability barriers within the reservoir. Coning of water would also have occurred bringing dissolved inorganic material into the existing oil leg of the formation causing emulsion blocks and other resulting formation damage.

The regenerating biochemical solution used in this research project contains species of microbes i.e. Pseudomonas and related species, to mitigate the aforementioned formation damage thus restoring permeability and increasing recovery by reducing the surface tension of the oil in-place to the reservoir rock. Certain species of Pseudomonas and related bacteria produce enzyme-based surfactants that reduce the interfacial tension of the oil to the rock grain causing the oil to become more mobile. Emulsion blocks are broken in much the same way with the enzyme-based surfactants causing surface tension reductions thus allowing oil and water to separate based on density. Since the bacteria are heterotrophic, they need external sources of carbon. Pseudomonas species are chosen and adapted through forced natural selection to remove carbon selectively from the higher molecular weight hydrocarbons i.e. paraffin and asphaltene thus breaking the larger molecules into smaller molecules and increasing solubility. Additional molecular changes have also been observed in the microcrystalline wax fraction that would increase the solubility of the high molecular weight hydrocarbon into the lighter hydrocarbon fraction. Plugging by organic solids such as iron sulfide can also be solved using a similar process. The bacteria need soluble forms of iron and sulfur for their intracellular processes and as such they produce enzymes and other biochemicals to resolubilize these inorganic compounds to make them more bio-available.

In order to survive in the reservoir environment the species of bacteria used must be able to withstand high temperature and salinity. The species employed in this procedure are both thermophillic and halophillic. Since the bacteria are introduced into the reservoir environment with a nutrient package that contains nitrate, the species must be able to use nitrate as an electron receptor. Pseudomonas and related species used in the process are facultative i.e. able to metabolize with or without oxygen. The selected bacteria with their nutrient package undergo logarithmic growth within 20 to 30 minutes after being exposed to the nutrient. This rapid growth occurs after the bacteria are injected into the producing formation and further helps acclimate the various species to the reservoir environment. An additional benefit of using facultative bacteria will be the scavenging of oxygen within the water phase of the reservoir. This scavenging of oxygen should help reduce corrosion.

Results of Task 1 Experimental Work. The cleanup of the wellbore environment was accomplished in four wells: Nos. 1, 5, 8 and 9 on the J. M. Finney lease in Rusk County, Texas

- The No. 1 well was producing at the rate of approximately 1.27 BOPD prior to the initial wellbore clean-up treatment. The treatment resulted in release of scale and debris that had two consequences: 1) there was too much material for the pump and it became clogged and eventually stuck, and 2) the biochemical material apparently removed scale and paraffin that was covering a hole in the tubing, and once removed, a tubing leak caused production to cease. When the pump was redressed and the failed tubing replaced, the production resumed at an slightly increased value of from 1.34 to 1.9 BOPD. Figure 1 is a photograph of the hole in the tubing that was revealed when the scale, corrosion and paraffin was removed by the biochemical treatment. This well is a candidate for a more substantial "squeeze" treatment in the future as discussed in Task 2.

Figure 1. Tubing leak that was discovered post-treatment in the Finney No. 1 well.

• Well No 5 was treated with chemical to open the perforation with no resultant change. Records for this well are sparse and a subsequent search of archived records at the Texas Railroad Commission revealed that this well was apparently never worked over by Hunt Oil Company; and as a result if the well was not deepened, then no liner was installed, and no sections perforated. It appears this well is still producing open hole; consequently a small cleanup treatment would not be sufficient to impact production from a large exposed open section of the Woodbine formation. No further work will be done on this well.

- The No. 8 well has always produced a small amount of total fluid and it was assumed that it has a substantial permeability block. Prior to treatment, the total volume produced was in the range of 10 to 25 barrels of fluid a day with oil production approximately 0.3 to 0.5 BOPD. Post-treatment production was essentially the same with no detectable difference and it was concluded that the permeability restrictions were not in the perforations, but formation damage. This well became a candidate for the more substantial treatment as discussed under Task 2.

- The No. 9 well was producing 0.3 BOPD and from 150 to 75 BWPD depending on the fluid level in the well, the lower values resulted from the well pumping off. Post treatment the production initially spiked, and the fluid contained debris and clumps of material released from the biochemical action. The sucker rods and pump were not able to adequately remove the material and the pump filled with debris and the sucker rods parted. Because it appeared that the treatment was successful, it was decided that this well would be a candidate for a more substantial treatment when the pump was cleaned and redressed and the rods replaced. This well is further discussed under Task 2.

Results of Task 2 Experimental Work. The objective of this task was to mobilize permeability blocking material such as scale, paraffin, tar, iron sulfide, etc. located both outside the wellbore and in the formation itself. To accomplish this the perforations were first opened with a small treatment as discussed in Task 1. Subsequently a large treatment was done consisting of 25 gallons of the biochemical mixture, 20 gallons of nutrient solution, 40 barrels of

2% KCl solution, 5 additional gallons of biochemical solution, and a carrier solution of 140 barrels of 2% KCl solution. The volume was predetermined to be sufficient to move the biochemical solution more than 10 feet into the reservoir sands to mobilize the target material in the reservoir near wellbore. The solutions were added without complication and allowed to acclimatize and react for at least a week before pumping of the well was resumed. Both well No. 8 and No. 9 were treated similarly, but the response was different from each well.

Well No. 9 was drilled in 1931 to a depth if 3709 feet below land surface then cased to the top of the Woodbine sand at 3605' depth; the Woodbine reservoir sands were produced as an open hole completion. In the 1970's Hunt Oil Company, who operated this lease, deepened the wells about 200' to install a liner and test the lower Woodbine stringers about 100 feet deeper than the top of the main Woodbine sand, as did most other operators in the East Texas Field. The recompleted wells could be logged with modern borehole geophysics which was not available when the wells were drilled in the 1930's, and by installing the liner through the Woodbine reservoir the zones with the most prospective sands could be perforated and tested. Figures 2 and 3 are photographs of the No. 8 and No. 9 location3, and Figures 4 and 5 are logs of the wells illustrating the intervals that were perforated for production in the 1970s.

Figure 2. Finney No. 8 location in the East Texas Field, Rusk County, Texas.

Figure 3. Finney No. 9 location in the East Texas Field, Rusk County, Texas.

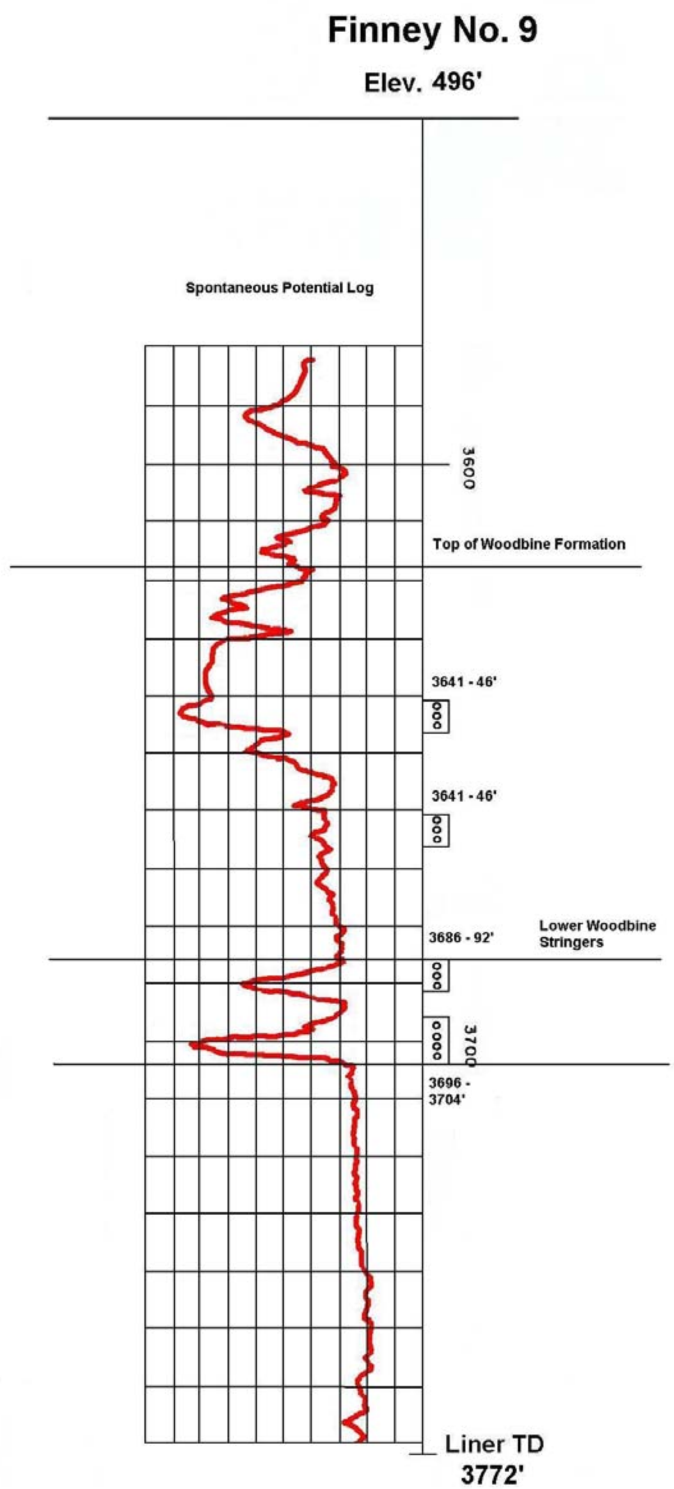

Figure 4. No. 9 well diagram with Spontaneous Potential log and well perforations indicated.

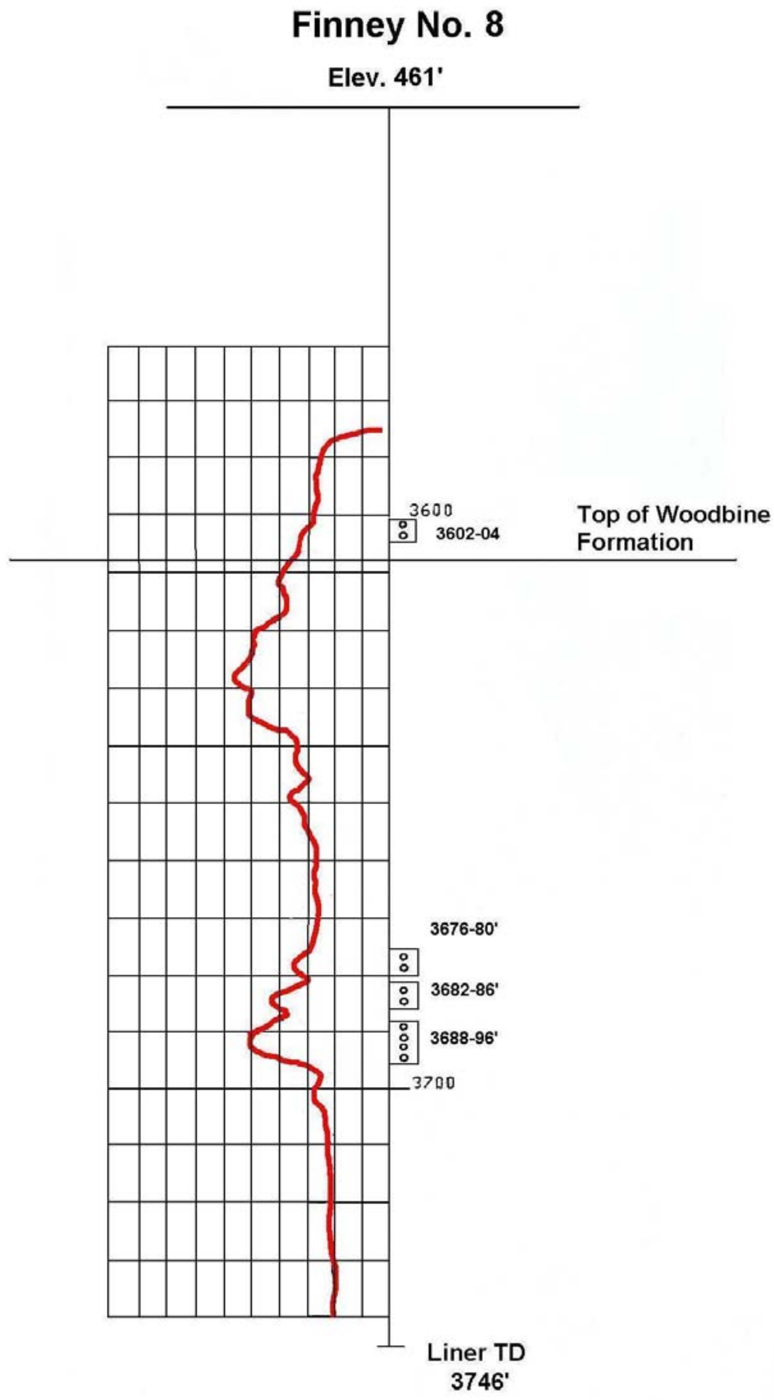

Figure 5. No. 8 well diagram with Spontaneous Potential log and well perforations indicated.

The No. 9 well was producing 0.3 BOPD prior to treatment as indicated in Figure 6. The initial cleanup treatment was performed in mid-September followed by a 3 day shut-in period. When the well as turned on it pumped fluid and debris immediately, indicating that the microbes had been successful in breaking down material that was affecting the perforations and allowing the material to be mobilized. Within 48 hours however the rods parted in this well and pumping ceased. It is our assessment based on observation of treated wells then and more recent treatments, that the biochemical treatment creates two circumstances that exacerbate the failure rate of sucker rods and tubing. First, the material creates a higher density solution, thus greater weight to lift and additional strain on sucker rods; secondly, the mobilized debris enters the pump and creates drag, restricts the valve action and restricts the movement of the traveling valves; and thirdly, the biochemical solution removes scale and paraffin that may be masking corrosion holes and rod cut gouges in the tubing thus creating tubing leaks not seen prior to treatment. The biochemical solution is effective in mobilizing the debris and the operator must be prepared to repair mechanical consequences to the production system.

The rods were repaired in the No. 9 well and the “squeeze” treatment of Task 2 as discussed above was done in October to place the active biochemical solutions into the formation. The solutions were allowed to acclimate and react for at least seven days, and when the well was repaired and turned on at the end of October, the produced fluid was again heavy with particles and debris released in the treatment. The total fluid produced was slightly greater than before the treatment, but the significant change was in the oil production (Figure 6). Production was increased from a pre-treatment rate of 0.3 BOPD to a range form 1.5 to 2.5 BOPD with a significant increase in the gas pressure in the well   Clearly the permeability to oil and gas was improved substantially, and permeability to water only slightly.

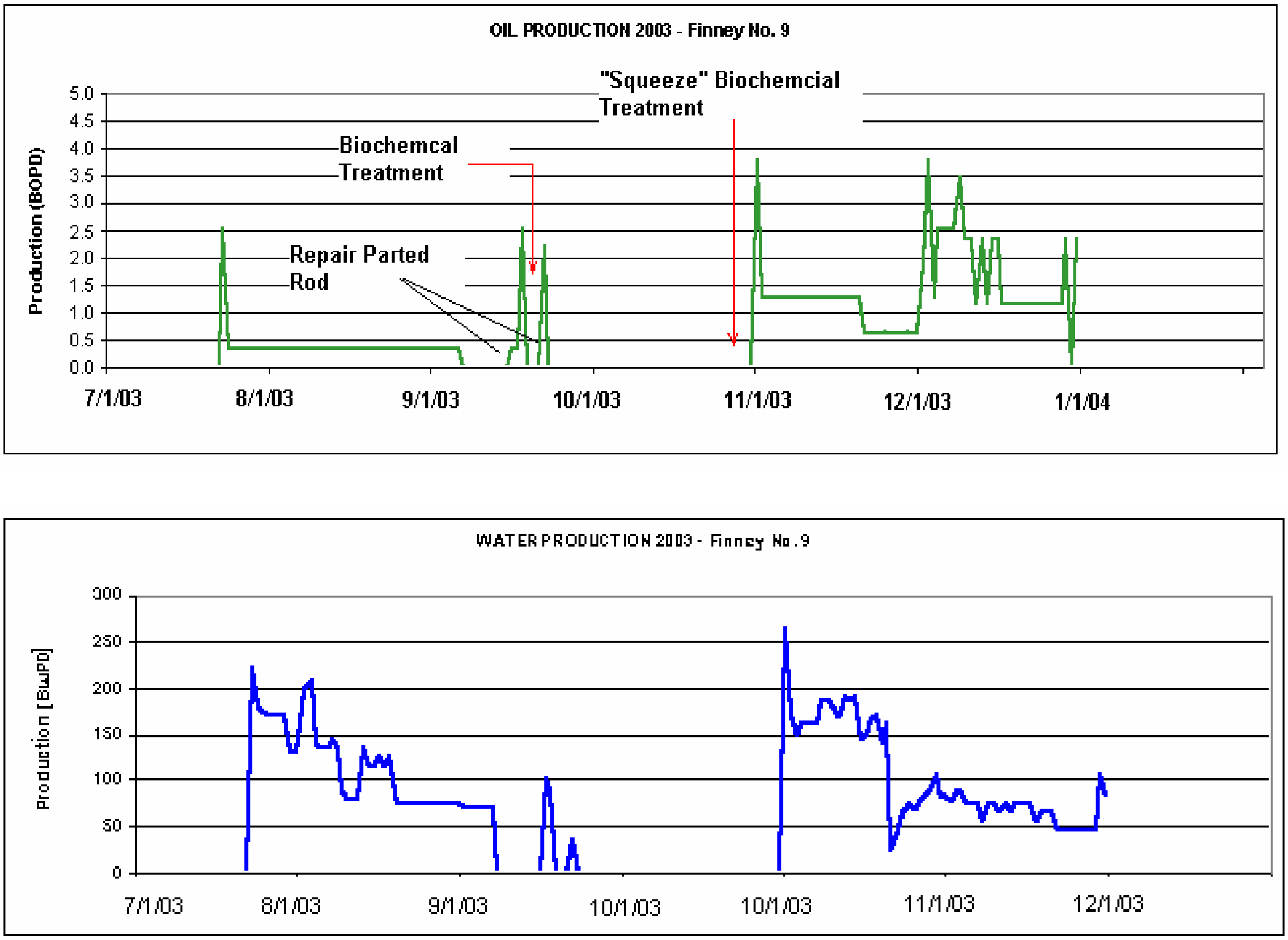

Figure 6. Production history for oil and water in No. 9 well before and after treatment.

The treatment for the No. 8 well has been only partially successful, but we are continuing the testing. The Spontaneous Potential log depicted in Figure 4 indicates that the lower Woodbine sand is not as well developed in the No. 8 well as it is in the No. 9 well. The squeeze treatment initially increased fluid flow, and the flush production was primarily oil and gas with significant clumps of debris released from the perforations. The gas pressure was significantly increased, for example most of the Woodbine wells have no measurable positive pressure, and after treatment the pressure is at least for a while between 10 to 35 psi and produced fluid is exceptionally gassy. It appears that this well does not produce sufficient total fluid to clean out all the released sand, scale and other debris so production for the well continues to be less than 35 barrels of gassy total fluid with an oil percent of about 1 to 2 percent. Additional treatments may be performed, but the immediate issue is the removal of released debris.

Secondary Effects. Valuable insight was gained during the testing periods that will be useful in this project and to other Operators in the future. The most difficult issue to cope with is the physical handling of the released well and formation debris. The objective is to mobilize this material and improve permeability but physical removal requires a strategy. Figures 7 and 8 are a photographs of the material produced from both the Finney No. 8 and No. 9 wells. The particles are primarily very fine sand what appears to be dense black hard iron sulfide and asphaltene grains, all of which tends to clump and coagulate once produced. Further analyses will be conducted on this and similar material in the future to better characterize the composition.

This debris was produced in such a large quantify that eventually the pumps were clogged, the flow lines were partially obstructed, and sediment could be seen coming out of the “stuffing box” at the well head. The 3-phase separator on this lease is a horizontal design with gas actuated dump valves for both the oil and water legs (Figure 9). The separator holds approximately 20 barrels of total fluid, and by December the separator was more than 50% full

Figure 7. Photograph of debris pumped from wells after treatment.

Figure 8. Photograph of pumped debris as closer view.

of sediment, the dump valves were stuck open and sediment was distributed throughout the flow lines. After many episodes of disassembling the separator and cleaning the valves, and `subsequently refilling the system with debris, it was determined that the use of a 3-phase separator was not the optimum method of separating oil. Not only is the maintenance required to clean the lines, pumps, and equipment expensive and time consuming, a further significant consequence is that when the values to the water leg become plugged the separator diverts water flow to the oil tanks, filling the oil tanks with produced water and sediment.

The lease was completely down for most of December and January as attempts were made to clean the production system. The remedy for the problematic maintenance of this debris is to produce into a gunbarrel separation system, which uses gravity feed, does not rely on any gas actuated valves, has 3 inch flow lines rather than 2 inch lines, and has a capacity five times a great as the three-phase separator. The current arrangement of the gunbarrel and oil tank are depicted in Figure 10. No additional problems have been encountered regarding the inability to handle the produced debris, and additional treatment and testing is continuing.

Figure 9. Photograph of 3-phase separator initially used in production.

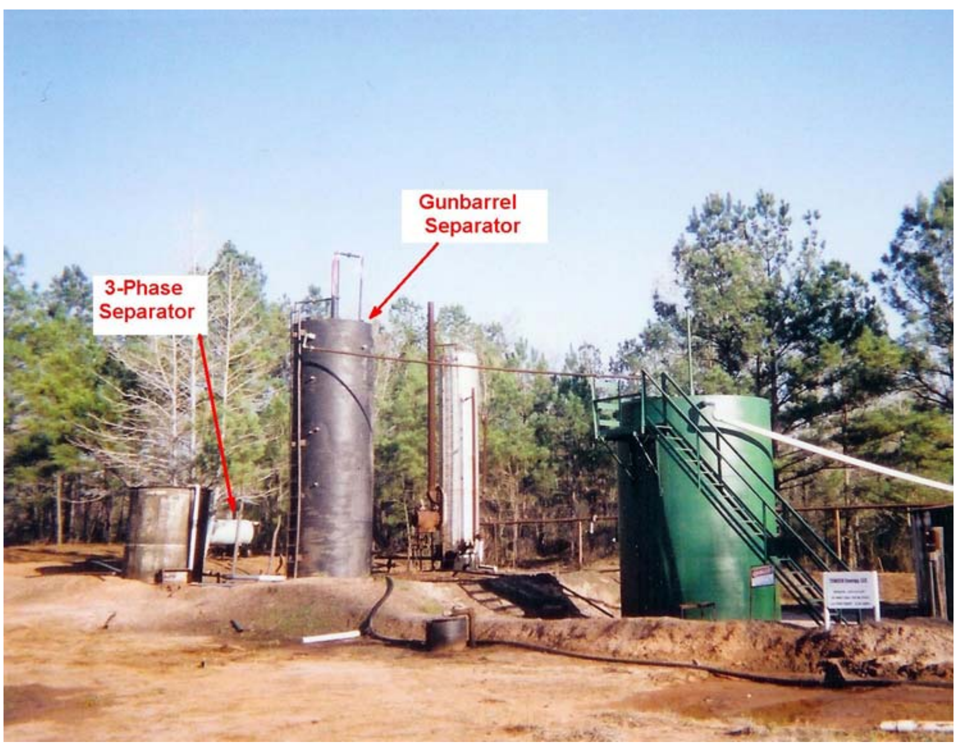

Figure 10. Photograph of Gunbarrel now used for separation to avoid debris removal issues.

5.0 CONCLUSIONS

Summary of Results from Task 1

- The addition of the engineered biochemical solution is easily added to the well by gravity feed down the annulus, and for the initial well clean-up phase, the solution can be mixed at the well site.
- Solutions are comprised of 5 gallons of the biochemical mixture, 5 gallons of nutrient solution, and 3 barrels of either lease water or 2% KCl solution. The solution should be allowed to acclimate and react for 24 to 72 hours, then the well is again placed on pump.
- Three wells with known well bore characteristics and perforation depths were treated and all three wells evidenced an improvement either by increased production volume or the pumping of sand, scale, and other debris with the produced water.
- Operations are affected at least two ways by the mobilized debris, 1) because it interferes with pump action and requires pump removal, and redressing or 2) the removal of scale and paraffin exposes corrosion holes that were protected by the coatings of scale and paraffin.
- The use of cup-type tubing tubing pumps significantly improves the capability of the pump to lift and discharge the mobilized debris with the produced fluid. The identification of weak or damaged tubing simply allows for proactive maintenance of tubulars.

Summary of Ongoing Activites from Task 2

- Two wells have been selected for the more substantial biochemical treatment in task 2. The treatment consists of at least 25 gallons of the biochemical solution and 25 gallons of nutrient solution, and approximately 140 barrels of carrier 2% KCl water.

- The biochemical solution is transported in drums and added directly to the annulus of the well, and the 2% KCl solution is brought in by truck to the well site. Addition of the solution is rapid and the only time constraint is the delivery time for trucking. Wells are left shut-in for 7 to 10 days for the microbes to acclimate and react. Wells are then placed back into production.
- Well No. 9 was successfully improved with oil production increased from about 0.3 BOPD to 1.5 to 2.5 BOPD. Water production increased only slightly indicating that the treatment may be impacting and improving the oil wet permeability more than the water wet permeability.
- Well No. 8 was also successfully treated evidenced by the increase in gas pressure and the increase in oil percent. This well does not produce a total fluid volume that is sufficient to remove the mobilized material and at present is still cleaning up.
- Significant lessons have been learned that will benefit other operators in the future. The quantity of material that is mobilized is significant. Flow lines, separators, and valves all become clogged with the debris and pressure actuated valves fail. A 3-phase separator is not recommended; rather a large gunbarrel works far more effectively in separation of oil and water in the presence of the mobilized sediment and debris. By using a cup type tubing pump and gunbarrel the movement of debris ceases to be a problem.

6.0 REFERENCES

No journal or technical references were cited in this report.