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ACCOMPLISHMENTS

1. What are the major goals of the project?

The goal for this product development program is the validation of the swellable, structural proppant concept for fracture stimulation and enhanced energy resource recovery. This is achieved by developing and validating structural swellable material candidates, developing scalable manufacturing processes for manufacture of expandable proppants, and validated enhanced oil recovery through geomechanical simulation using swellable structural proppants. The core innovation of this transformative technology, expandable structural proppants, provides a mechanism for adding and manipulating force in the far field fracture network, enhancing and maintaining drained area and fracture conductivity, thereby increasing oil and gas recovery, and enhancing the ability to develop and control geothermal fracture network flow conductivity and connectivity. Two Major product platforms are expected from the program - a family of structural swellable materials that are stable in geothermal and oil and gas reservoir environments, and a family of low density, fine and easily transported proppants made from that materials. Additionally, as the program has developed in identifying the value proposition expandable proppants has on well stimulation, modeling and experimental methods are being developed for the evaluation of far-field fracture propping.

The first year of this program advanced Terves' material development and evaluation for expandable composition design and completed preliminary computational simulations of fracture geomechanical response (oil recovery) for demonstration of the end use value proposition and to guide the expandable proppant design as well as defining a method of use. Enhanced testing capabilities for proppant testing were developed, with higher fidelity/stability and full API conformance compared to Phase I initial feasibility tests. Two significant developments Terves would like to highlight include:

- The concept validation of expandable proppant in increasing recovery yields
- The development of a controllable bead forming process in proppant development
- (NEW) Development progress towards an elastic-plastic fracture and proppant model for simulating far field fracture conditions for evaluating proppant embedment into soft rock fractures.
- (NEW) Ongoing process development for fracture conductivity experiments evaluating submono-layer proppant packs between soft-rock (carbonate shales).

The program is laid out with the following objectives:

- The optimization of performance and understanding compositions, microstructure, and performance interactions for expandable proppant's maximum performance.
- The design, development, and understanding of field application protocols, including pumping profiles to control proppant placement. Understanding/validating long term performance/degradation mechanisms in simulated well conditions.
- The development of scalable manufacturing processes to produce desired sizes and shapes at acceptable cost, including processing and shape effects on microstructure and performance of product.
- The demonstration of well production enhancement by simulation (FracGeo), and (outside of scope) field trial.

These goal objectives are designed around the development of an expandable proppant that meets the following product specification goals:

1. Ability to be readily transported into fine cracks at high angles from main flow path (density < 2g/cc, size 150-450µm)
2. Compression (crush) strength after expansion of >7,000 psi, goal of >10,000 psi, as measured in API crush test
3. Unreactive in ambient conditions - can be readily pumped in slick-water; or swelling can be delayed to allow placement of proppants
4. Expand to >20V%, with >7% fracture width increase (>50%, >10% goals);
5. Ability to apply high forces to crack faces, force application greater than 5000 psig, with goal of 12000 psig.
6. Retain high permeability (greater than 200 mdarcies) after swelling with closure forces of 2000-7000 psi

under ISO13503-5 conductivity testing. (Program simulation work has identified a material modulus goal of 4.0GPa for >600md-ft conductivity)

These specification goals are being challenged and may be adapted to better suit the value addition method of use, as these goals were designed around a hard shale multi-proppant pack usage design. As the modeling and evaluation of soft-rock far-field fracture unfold these value goals are subject to change.

2. What was accomplished under these goals?

During the first year of this program Terves and simulation partner FracGeo have accomplished these set objectives towards its goal:

1. Completed development matrix of expandable filler type, loading content, and strengthening agent addition for epoxy expandable structural composite designs, and down-selected to compositions with 20vol.% CaO loadings and addition of carbon nanotube reinforcing filler as meeting proppant performance minimum requirements for 70-130C well temperatures.
2. Developed a non-aqueous spherical bead forming process for water sensitive polymer based composites.
3. Measured material properties and developed expandable proppant micromechanical model, which was integrated and incorporated into FracGeo's geomechanical fracture forming simulation package.
4. Completed initial simulations based on wolfcamp 80% carbonate 20% shale formation. Oil Production Simulations showed expandable proppants offset fracture closure stress and maintain crack width and conductivity, generating a 23% increase in total oil production by delaying the hyperbolic decline curve
5. Terves set-up facilities capable of API RP 19C standard proppant property testings, and updated its fracture conductivity test equipment to API RP 19D standards, and qualified the procedures using known proppants, to allow us to providing reportable expandable proppant performance data.

During this past reporting period Terves has used a number of elementary proppant stress-strain calculations to determine performance of Terves' XOProp design against silica proppants within hard and soft shale fracture environments. These results, while simple, provide reason that XOProp plastic proppant design with its plastic strain response does not perform better than silica proppants under any full proppant packs with more than a mono-layer of proppant. The harder silica proppant maintains permeability better than the expanding proppant. Where there is perceived added value is at submono layer proppant packing at the far-field of the fracture (at the skirt of the fracture zone) where the fractures are smaller and proppant is more challenging to deliver out to. These modeling efforts foresee Terves' plastic expandable proppants (XOProp) as having a significant value towards maintaining these far-field fractures where had silica proppants fail by being engulfed and embed into the softer rock.

These accomplishments has lead Terves to pursue development of a more accurate model system that includes the plastic-elastic responses from both the proppant and fracture rock. The incorporation of these properties are necessary when try to accurately model a submono-layer of proppant in soft rock. Along with this Terves seeks to validate the model with a modification to its ISO standard proppant conductivity test for submono-layer and soft-rock samples. Current to date accomplishments in this pursuit include:

1. Terves has begun working with Idaho National Laboratories in developing their discrete elemental "particle" model towards modeling far-field fractures with submono-layer proppant packings.
2. Terves has been developing, and problem shooting, the modification of its equipment and testing method towards being able to testing submono-layer proppant packs and incorporating soft carbonate rock core samples (such as those seen in parts of the Wolfcamp basin).

Additional work has been continued towards developing large scale production methods and opportunities for quick scale up of Terves' XOProp proppant. Terves has been working with large scale proppant coating manufactures for pilot tests in coating Terves' XOProp material onto proppant cores. This is believed to be a realistic first step in scale up production.

3. What opportunities for training and professional development has the project provided?

The project supported a summer intern from Purdue University who aided Dr. Werry in material processing and

mechanical property testing. The opportunity provided the student an experience in laboratory setting experimental work.
No training or professional development opportunities occurred during this past reporting period.

4. How have the results been disseminated to communities of interest?

Terves has prepared brochures for XOProp(TM) expandable proppants, and now Exalon(TM) structural expandable composites, and exhibited at the SPE unconventionals conference in Austin, the SPE annual technical conference and exhibition in Dubai, and the SPE hydraulic fracturing conference in the Woodlands, TX. A press release was jointly issue by FracGeo and Terves prior to the unconventionals conference event. Interested parties in expandable proppants, such as those involved and those engaged at conferences, have been shown the measured available. Terves does not yet have a fully viable product, so that we have not commenced with taking orders for field test materials.
Terves is currently in the process of raising capital, and has been conducting a road show with venture capital, private equity, and NOC venture arms, and prepared and presented technical briefings including XOProp structural swellable, and derivative Exalon structural swellable materials/devices to a wide variety of operators, including Chevron (partner), Newfield Energy, Southwest Energy, CNCP/CNOC, volumetric expansion of Terves' material, and the simulated work validating the achievable recovery in using an expandable proppant. This has led to three operators willing to move forward to field trials by purchasing pilot scale materials once they become BP, Apache, ADNOC, and Aramco.

5. What do you plan to do during the next reporting period to accomplish the goals?

The primary goal of the second program year is to develop the expandable material and manufacturing process to sufficient maturity that it is ready for the further investment (order funded) to proceed to field trials by accepting trial orders. While year 1 established the epoxy based proppants and developed a bead-forming technique sufficient for laboratory demonstration, further development is ongoing to investigate lower cost and more easily scaled processing technologies. Considerations in our evaluation include the impact expansion has on the proppant's mechanical properties, and the manufacturing ease/economics of producing either spherical epoxy beads or extruded proppant pellets with thermoplastic binders. Initial attempts to "crash" the program (speed/leap-ahead into manufacturing scale-up) based on early success with the epoxy formulations was great as a pathfinder, but not yet successful in meeting cost and production volume goals needed, such that parallel efforts on composition development (including lower density, lower cost, easier processed thermoplastic binders). Terves directive for the program's second year is to create a "minimal viable product" suitable to move forward in supporting field trials.
During the next period of this program development is broken into three high-level objectives.

1. The optimization and refinement of structural expandable proppant compositions for far-field fracture propping through modeling development and experimental conductivity testing validation.
   - 1.1. This includes the development of a more complex model using a dynamic elemental modeling design. Work is with INL.
   - 1.2. This includes the development of Terves' proppant conductivity testing system for submono-layer proppant packs and soft-rock cores.
2. The development of a scaleable production process for the expandable composite to produce proppant, and qualification of the processing steps and conditions through proppant production and testing.
3. Both prior tasks leading to completion and generation of sufficient test data, including proppant transport conditions, to support transition into initial field trials.