LIGHTWEIGHT PROPPANT, A NEW INNOVATION IN HYDRAULIC FRACTURING

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ABSTRACT

The well stimulation process of hydraulic fracturing has existed in the oil & gas industry for over 50 years. During this time, many innovations and technologies have been employed that have substantially enhanced the process. In recent history, the industry has focused on the creation of cleaner fracturing fluids, while propping agents have remained relatively unchanged.

Recently, water frac treatments have found success in some niche areas. The widespread use of slick water fracturing has lead to the research of improved proppant transport and the subsequent development of lightweight proppants. This paper will discuss lightweight proppants, their development, what they are, and why they work. The paper will also examine the settling velocity of proppant in a hydraulic fracture and the positive effects of reducing this velocity. Additionally, improvements in overall proppant transport will be documented. Case histories will also be provided which will support the claims made by the authors.

INTRODUCTION

Hydraulic fracturing has experienced an amazing array of innovation and technical advancement since it's inception in the late 1940's. The oil and gas industry continues to rely upon this process to develop resources in mature basins and areas where economics are marginal. The Permian Basin located in west Texas is an excellent example of both of these criteria, and therefore has experienced a long and successful history with regard to fracture stimulation.

In it's purest form, hydraulic fracturing is a means of parting a formation with fluid pressure to create highly conductive flow paths laterally away from the wellbore in an effort to increase the productivity of the completion. Typically, a propping agent (or proppant) is placed in the fracture to ensure that the flow path remains open once the hydraulic pressure is released.

Hydraulic fracturing continues to play a major role in enhancing petroleum reserves and daily production and is arguably the key process in the exploitation of low permeability reservoirs. While the process of hydraulic fracturing enhances the ability of low permeability reservoirs to produce at economical rates, the cost associated with massive hydraulic fractures can place the economics of these same marginal plays at risk. Mayerhofer, et.al.[1] documented the success of water frac technology and the ability to reduce completion costs by pumping large volumes of slick water with relatively low volumes and concentrations of proppant. As is the case with many successful processes, slick water fracturing has been attempted in many different reservoirs, some of which have proven very successful relative to conventional fracture designs incorporating high viscosity crosslinked or foamed fluid systems and proppant concentrations greater than 3 lbm/gallon. However, even when applied in an applicable reservoir there exists certain fundamental and physical disadvantages associated with the process of slick water fracturing.

The industry has directed substantial resources towards the understanding of fluid rheology and effective proppant transport. One concept that remains unchallenged and is widely accepted in conventional fracture theory is the belief that fracture extension is the key design parameter in tight (low perm) reservoirs[1]. In recent history, it has also been accepted within the industry that propped fracture conductivity in the fracture is the key to productivity and that in some cases more is better. In most fracture designs, the practice has been to achieve concentrations of at least 1 lbm/ft^2. This design concept of high sand concentrations to achieve more conductivity certainly applies in high permeability reservoirs (> 1 md). However, in fracture literature from the 1960's Darin and Huitt[2] studied factors affecting fracture conductivity. In this study, of fracture flow capacity, methods of calculating the permeabilities of fractures containing various amounts of proppants were presented. This study points out the conductivity and differences between the extreme of an open fissure and one of a packed fracture. A packed fracture is one in which the space between the fracture faces is completely filled with a single or multiple layers of propping agent. A partial mono-layer is a fracture in which there exist some space between proppant agent particles which lie between the two fracture faces. In vertical fractures, where proppants can fall to lower parts of the fracture, it may be extremely difficult (or impossible) to design a treatment guaranteed to achieve a partial monolayer[3]. Figure 1 contrasts a full and partial mon-layer. A partial mono-layer would exhibit the same geometry, but would maintain some distance between proppant particles, thereby increasing the relative conductivity of the propped fracture.

In most all cases, engineers today will design a packed propped fracture regardless of the permeability of the reservoir or extent (length) of the created propped fracture. Early SPE fracturing monograph (Volume II) Howard and Fast[4] share methods utilized to obtain a partial mono-layer and examine the conductivity differences associated with a 25 percent mono-layer (0.06 lb/ft^2) relative to a mono-layer consisting of 50 percent or greater (0.33 lb/ft^2) mono-layer. It should be pointed out that when considering these differences, several factors affect the resulting conductivity. This may include the size and type of proppant particle utilized the formation and well depth (closure).

While proppant conductivity is paramount, the method of its creation and amount of conductivity required has been challenged with the advent and early success of lightweight proppants. This early success has provided evidence that the current application of lightweight proppants in slick water fracturing has resulted in longer effective propped fractures where the partial monolayer technique was employed.

LIGHT WEIGHT PROPPANT DEVELOPMENT

It has long been recognized that one of the cleanest and most economic fluids available for fracturing is un-gelled water. In areas where formation compatibility issues and fluid leak-off are minimal, there has been a substantial amount of recent interest in utilizing un-viscosified water as a primary fracturing fluid. These treatments are commonly referred to as a water-frac, slicked water frac, or occasionally as dendritic fracs. Typically, this type of job involves pumping very large amounts of water with friction reducer and relatively small amounts of proppant at very high rates. Where they are applicable, this type of treatment has produced adequate results at a reduced total cost when compared to traditional gelled fluids; making them more economically viable than previous fluid systems.

Like all forms of stimulation techniques; however, water fracs have their advantages and disadvantages. The key to this particular stimulation technique is applying it to an area where it's unique advantages suit the application. The following is a list of possible water frac advantages:

Water Frac Advantages:

- Operationally and chemically straight forward
- Very long hydraulic frac lengths can be generated
- IP rates can be comparable to conventional treatments
- Less cost than conventional treatments
- Little or no polymer in the formation

As might be expected, water fracs also have several disadvantages associated with them:

Water Frac Disadvantages:

- Limited to low sand concentrations
- Rapid screen-out potential
- Short effective frac half-lengths
- Resulting production declines can be steeper than similarly sized conventional jobs
- Water zones below are dis-proportionally propped open

The interesting aspect of the second list is that all of the negatives associated with water fracturing are symptoms of poor proppant transport. If proppant could be placed effectively by water, almost all of the negatives would be greatly diminished or eliminated entirely. This fact was the underlying goal behind the development of the extreme low-density proppants.

In it's simplest terms, the ability of a fluid to transport a particle is proportional to the settling velocity of the particle relative to the surrounding fluid. Since the fluid in question is water (Newtonian), the terminal settling velocity of the particle (proppant) can be estimated by using Stokes law (Equation 1)

Equation 1

$$V_t = \frac{(\rho_p - \rho_f)\, g_c d_p^2}{18\mu_f}$$

Given that water fracturing has proven to be a popular and cost effective method to stimulate many marginal reservoirs with the major drawback being poor proppant transport, the question was asked: “Is there any way to improve the proppant transport characteristics of water?” Starting with this hypothesis, Stokes law was examined on a variable, by variable basis to look for a way to decrease the terminal settling velocity of proppant.

The most common method of reducing settling velocities in water is by decreasing the diameter d_p (mesh size) of the proppant. This approach is particularly effective given that the diameter term is squared in stokes law, thus if the diameter is cut in half, the settling velocity is cut by a factor of four. However, this technique has its limits due to the fact that proppant conductivity is also proportional to the diameter, with an exponent that is unfortunately greater than two. This means that very rapidly, the benefit that is achieved by reducing the settling velocity is offset by the reduction in conductivity achieved. This places an insurmountable lower constraint on lowering the particle diameter to lessen the settling velocity.

Similarly, the other variables in Stokes Law were examined. It stands to reason that the Viscosity μ_f of the fluid could be increased to reduce the terminal velocity; however the very act of gelling the fluid would negate the previously mentioned benefits of water fracturing. Altering the frac fluid density ρ_f was not deemed practical because to achieve parity with the proppant density (sand) one would need to find an economic source of 22.1 ppg non-damaging fluid.

By the process of elimination, it was determined that the most practical way of improving proppant transport in water would be to decrease the proppant density until it approached that of the carrier fluid. Obviously, since the fluid in question is water, it would require that a prospective proppant have a specific gravity that was as close to one as possible. The prospective material would also have to provide adequate conductivity for as wide a closure and temperature range as could be practically achieved.

Many different substrates were investigated in search of a material that exhibited low specific gravity and a useful conductivity range. After extensive laboratory screening, the material that best met the previously mentioned design constraints was a porous cellulose substrate impregnated with and encapsulated in a pre-cured resin coating. The organic nature of the proppant substrate provided a substantial amount of porosity that could be filled with a low density resin to achieve both strength and a low specific gravity. The entire particle was then coated with an external film and cured to protect the substrate from degradation and to add additional closure resistance (See figure 2). The final product proved to be a proppant that not only exhibits a specific gravity which makes it almost neutrally buoyant, but also enables the proppant to be placed in reservoirs with closure pressures up to 6000 psi for the 1.25 specific gravity proppant (Figure 3). Relative results of the settling velocity of several well recognized propping agents used within our industry can be seen in Figure 4. The settling velocities of these various propping agents were calculated using the modified Stokes Law equation described.

PROPPANT TRANSPORT DESIGN

Fracture fluid selection for a given treatment has a significant influence on the resulting effectively propped fracture length and fracture conductivity, as well as treatment cost. Fluid properties strongly govern fracture-propagation behavior and the distribution and placement of propping agents[3]. However, in low permeability or naturally fractured reservoirs where long effective fracture lengths are desirable, it may not be necessary to utilize high viscosity fracture fluids for proppant placement. It is in these reservoirs where the use of linear gels or non-gelled water have seen their biggest usage. While low viscosity fluids are desirable to create longer fracture lengths and less vertical fracture height growth in some instances, their inability to transport proppant effectively has deemed them banking fluids[5]. This name comes from the process by which proppants tend to collect or bank in the near wellbore region of the hydraulic fracture where a differential in fluid velocity exists. This banking phenomenon is the primary reason water fracturing has been somewhat overlooked in the past. Modeling of these banking systems provides a fracture that may yield a long hydraulic fracture length while the effective (or propped) length may be limited. Figure 5 shows a relative comparison of the same reservoir modeled with first a banking fluid system (fresh water) transporting a conventional sand with a specific gravity of 2.65 and then 10# brine water transporting light weight proppant with a specific gravity of 1.25. Upon examination of the Figures 5 and Figure 6, one may note the perforated interval represented by the horizontal lines above and below 4700’. In the case of the fresh water and sand (Figure 5), note the amount of proppant outside the zone of interest relative to the lightweight proppant model in Figure 6.

CASE HISTORIES

Initial success with lightweight proppant has been documented in the San Andres formation located in the central basin platform of the Permian Basin. The central basin platform finds its eastern border along a line dissecting the middle of Gaines and Andrews Counties, Texas. The San Andres formation in these two counties has been well developed and produces from approximately 7 major fields.

The San Andres formation is categorized broadly as shallow-platform and marginal carbonates[4]. There exist several facies from which permeability and porosity occur. However, the reservoir quality varies considerably within each. In some fields, deposits of dolomite, anhydrite, mudstone and sandstone can appear thinly bedded and generally make poor reservoirs because of their marked heterogeneity in thickness and lateral extent. It is these same deposits and the aformentioned heterogeneity that can make fracture stimulation of these reservoirs a challenge as vertical fracture height growth can be dramatic in areas where anhydrites are not present to create some form of vertical growth barrier.

In Andrews County, Texas an independent operator had embarked on a refrac program in an aging San Andres field which is currently under water flood. The original re-frac program included the use of slick water fluids and conventional sand as a propping agent. Original treatments incorporating sand, as proppant would include approximately 120,000 gallons fresh water containing 22,000 lbs. brown sand. Nineteen wells were completed in this manner followed by four wells that were completed using fresh water and approximately 7000 lb. of lightweight proppant. Average injection rates for all 23 treatments ranged from 10-25 bpm with average surface treating pressures at 2,700 psi for 5 ½" casing completions and 4,400 psi for 2 7/8" tubing completions. The depth of the San Andres interval in the treated wells ranges from 4280 feet to 4700 feet.

The thirty-day post frac results of the 19 conventional water fracs and the results of the 4 water fracs containing light weight proppant are displayed in Table 1. Note the folds of increase of the wells fracture stimulated with lightweight proppant relative to the conventional water fractured wells.

Additional treatments were performed for a second operator in Gaines County, Texas. This time the fracture treatments included 10-lb. brine water with a specific gravity of 1.20 as the carrying fluid. The small difference in specific gravity between the lightweight proppant at 1.25, relative to the brine water at 1.20 makes the proppant almost neutrally buoyant. Once again these wells were re-fracture treatments of producing San Andres wells and incorporated treatments of 100,000 gallons 10 lb. brine water carrying 10,000 lbs. of lightweight proppant. The initial production created an approximate 7 fold of increase over conventional fracture treatments in the area (see Figure 7). It has been documented more conventional fracture treatments using standard crosslinked fluids and brown sands as a propping agent will yield a post fracture increase of approximately 4 fold over the pre-frac production. Re-frac production response of this magnitude had not been realized in this area by the operator before and resulted in a re-fracture program that may not have been economically feasible without the results obtained with use of extreme light weight proppants.

While early success with lightweight proppant has been documented in the San Andres formation, similar treatments have been performed in other Permian Basin formations. Treatments utilizing lightweight proppants have been performed in the Canyon Sand, Bonespring, Grayburg, Delaware, Strawn, Wolfcamp and Queen formations. Over 60 fracture treatments have been performed with lightweight proppants in the Permian basin to date. While initial production reports are encouraging, long term production will eventually prove the practical employment of lightweight proppants and define their most advantageous application.

CONCLUSIONS

1. Early production reports from treatments in the San Andres formation have proven that higher initial production response can be achieved with the use of lightweight proppants relative to like volumes of standard water fracture treatments utilizing conventional sands.
2. Fracture treatments have been performed with lightweight proppants which have proven to outperform conventional crosslinked fracture treatments and post fracture incremental production has been realized that is much as 3 times higher than that achieved without lightweight proppant application.
3. It has believed that longer effective (propped) fractures can be obtained with the use of lightweight proppants and the ability to create a partial mono-layer in a low closure stress reservoir without the use of soluble proppant spacers may have been achieved.
4. The application range of lower cost slick water fracturing may have been expanded due to advent and recent application of lightweight proppants.

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Table 1

	Before Workover		**After Workover**		**Folds of**
	BOPD	**BWPD**	**BOPD**	**BWPD**	**Increase**
Ottawa (19)	17	11	27	53	2.9
LiteProp (4)	22	11	49	115	5.0

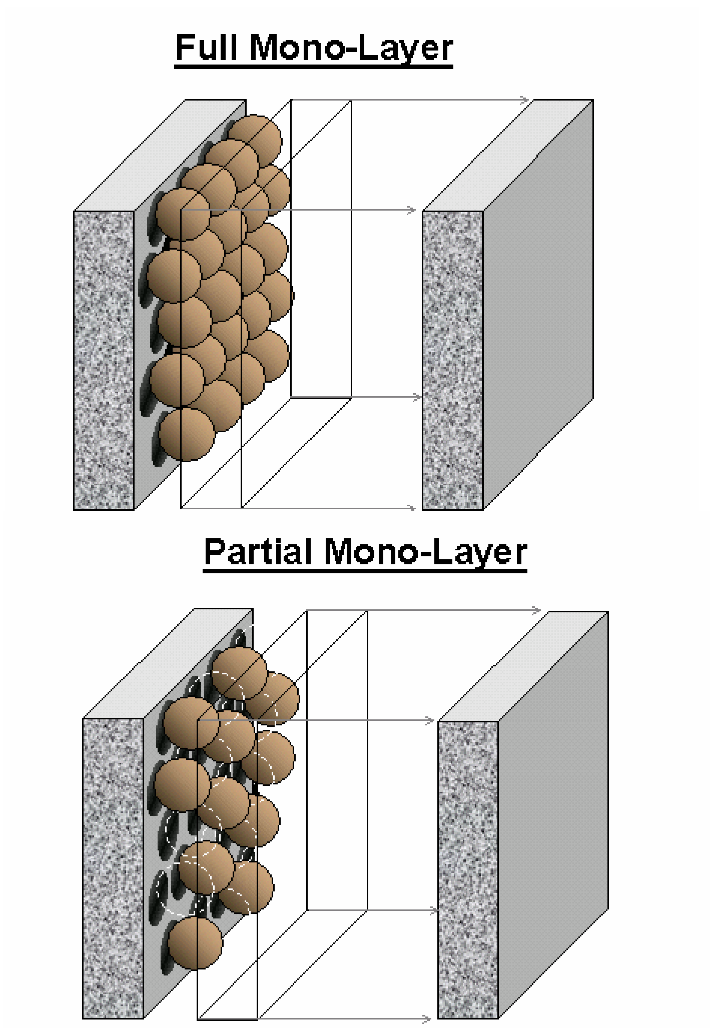

Figure 1 is a representation of a fracture containing a full mono-layer (top) and a partial mono-layer (bottom)

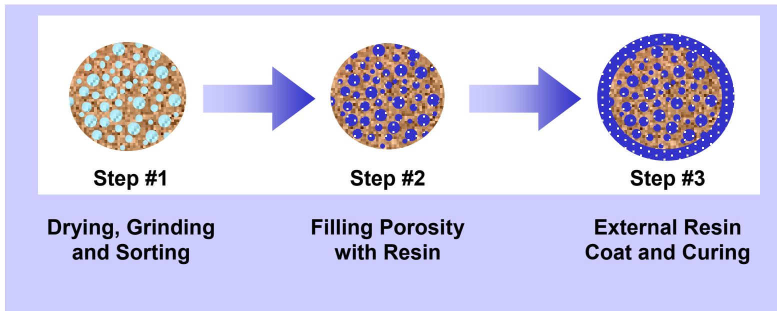

Figure 2

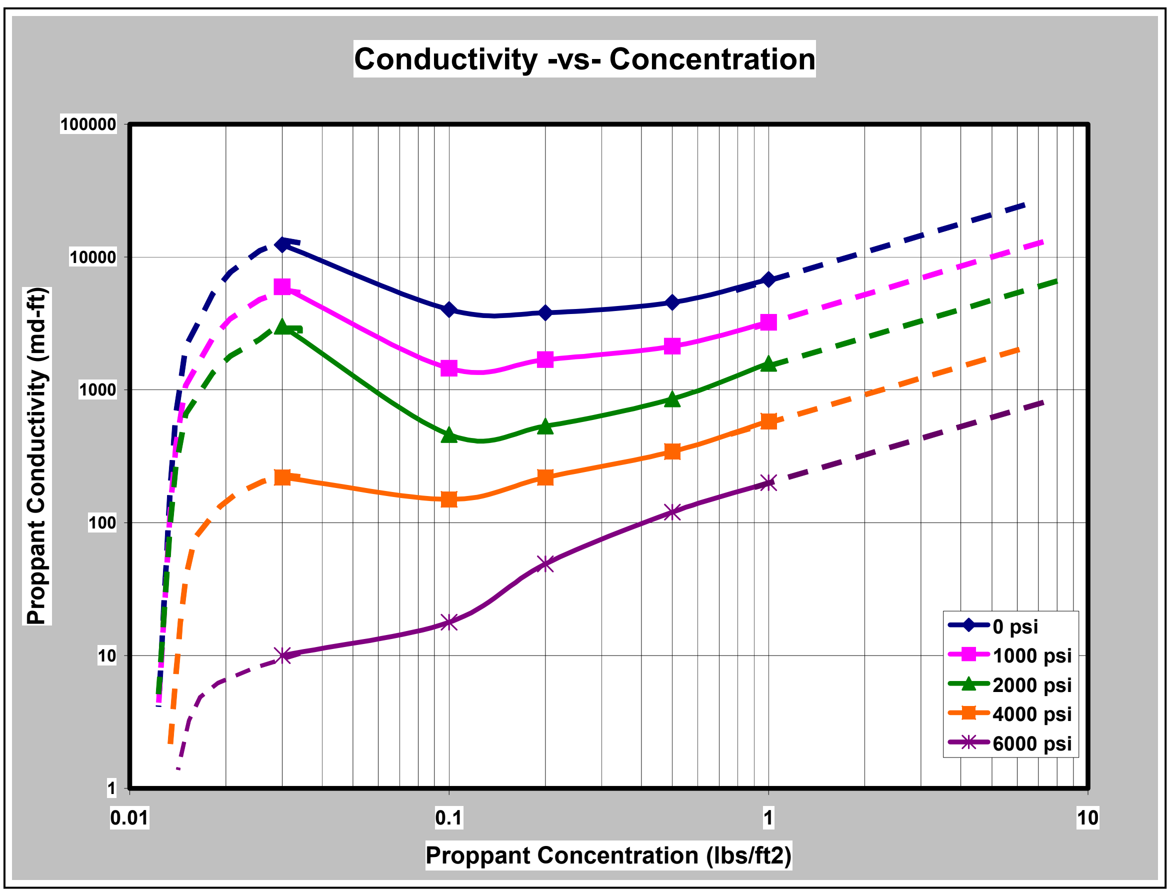

Figure 3 - Represents the Conductivity of the Lightweight Proppant Verses Closure Stress at an Ambient Temperature of 150°F.

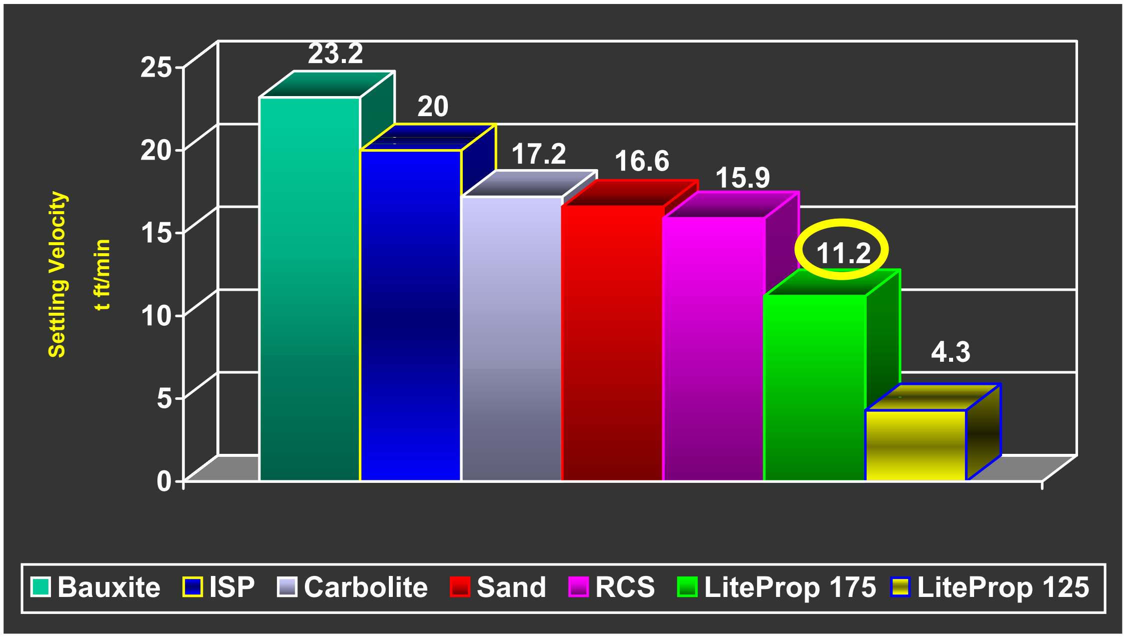

Figure 4

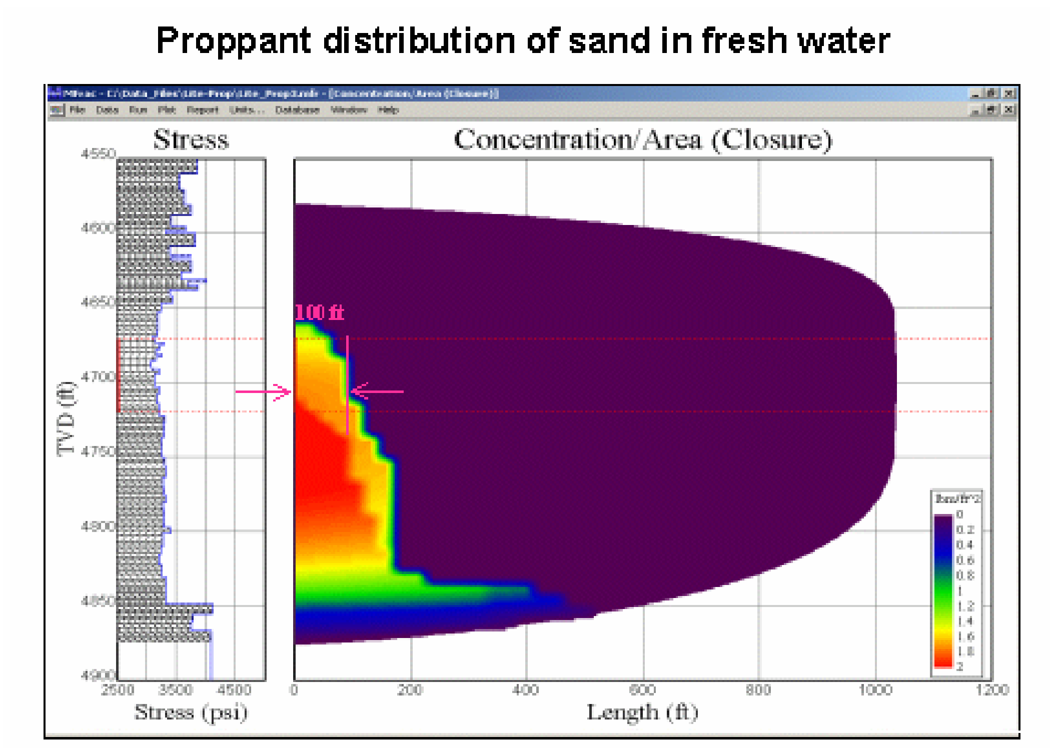

Figure 5

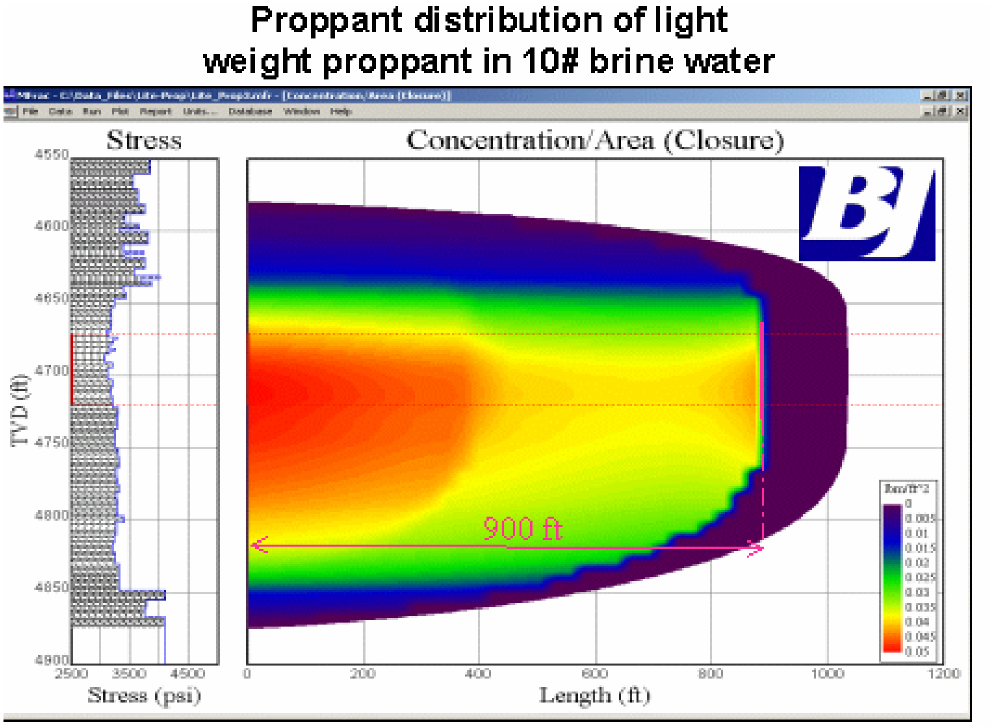

Figure 6

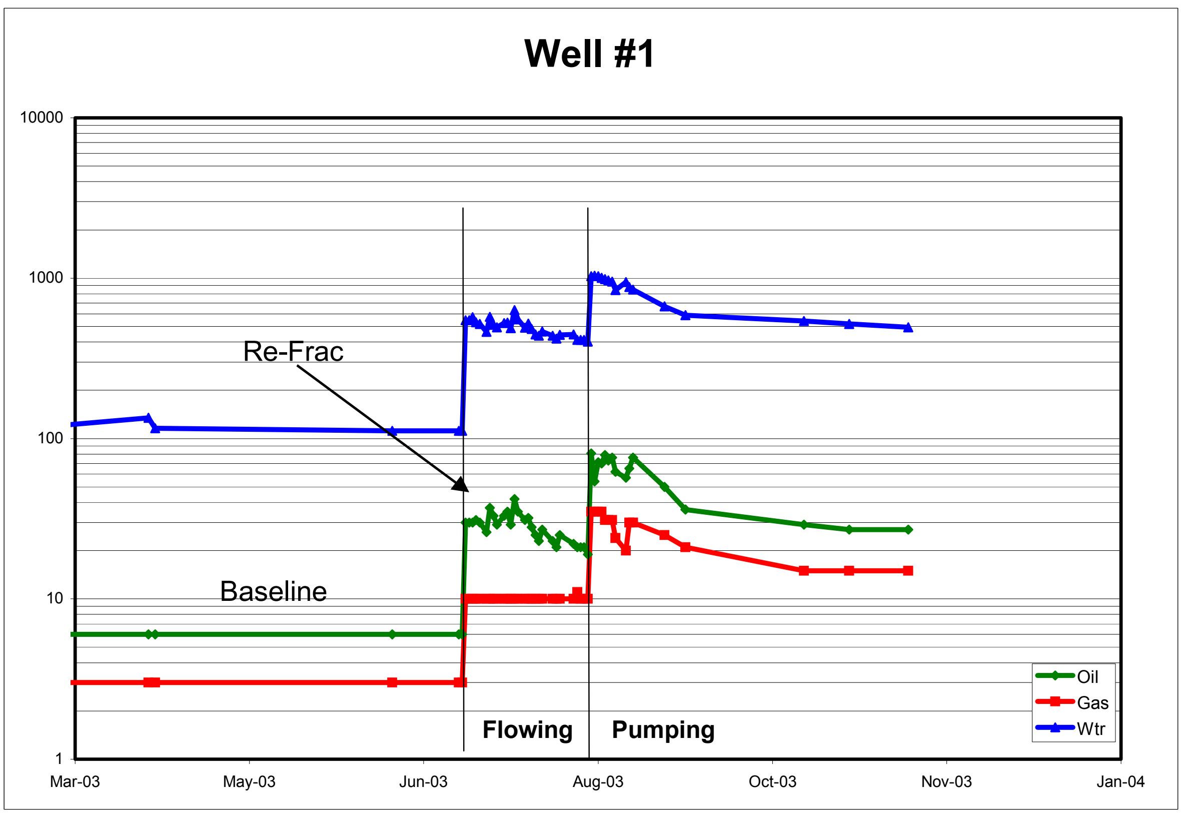

Figure 7