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Dry Powder Deliver of Friction Reducers: A Step Change in Slickwater Fracturing

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Abstract

Since the early development of unconventional resource plays, slickwater fracturing fluids have expanded rapidly and are now the most common type of fluid system used in the industry. Slickwater and viscosifying friction reducer (VFR) fluids consist of polyacrylamide (PAM) polymers and are typically delivered to location in a liquid form such as a suspension or emulsion in a hydrocarbon-based carrier fluid. Recently, advances in dry powder delivery operations have provided unique advantages over the liquid versions of FRs including cost savings and improved health, safety and environmental (HSE) aspects. This paper describes the dry powder delivery process and describes the advantages that this new technology has brought to field operations.

The method involves delivering polyacrylamide powder for slickwater fracturing treatments directly into the source water on location, thereby eliminating the use of liquid polymer slurries or emulsions. Liquid friction reducers typically contain 20-30% active polymer loading, with the remaining volume being the carrier fluid to keep the polymer in suspension. By delivering 100% powder, several benefits are gained including elimination of truck deliveries of FR liquids to location, reduction of total chemical volumes by 70-80%, reduction of spill hazards, and lower overall chemical costs. Different powders are available for various applications including the use of fresh or produced water, and viscosifying or non-viscosifying polymers.

The key technology for "dry on the fly" (DOTF) operations is the powder delivery equipment. Due to the different molecular structures between polyacrylamide and guar polymers, delivering PAM is more technically challenging than guar and requires much higher mixing energy to achieve proper dispersion and hydration. The delivery system described in this paper uses a unique technology which creates the necessary conditions for powder mixing and has been successfully applied on over 350 wells since early 2019, with over 7,000 tons of polymer delivered.

Current Friction Reducer Delivery Methods

Currently, the most common method for delivery of friction reducers to a fracturing location are in the form of liquids such as emulsions and suspensions. **Oil-based emulsions** are manufactured using a reactor and heat to bond a dry polyacrylamide polymer with water and oil into an emulsion. Emulsions are very stable and offer excellent storage properties whereby the product can sit for months or longer with very little settling. Emulsions also exhibit very rapid inversion and hydration properties when mixed with the source water during a fracturing treatment. Usually, the polymer's friction reduction and viscosity development properties are observed within less than a minute.

Liquid suspensions are another form of delivery of PAM polymers to location. Unlike oil-based emulsions, suspensions do not require a reactor process, but do require several chemical components in the formulation to prevent the polymer from settling. These additives commonly include suspension agents, surfactants and dispersants. The additional chemicals involved to develop suspensions can result in higher product costs and high suspension viscosity, sometimes making the thick mixture difficult to pump. Additionally, suspensions generally do not remain stable for long periods of storage and polymer settling can occur within the tank or storage tote. One final disadvantage of polymer suspensions is that polymer hydration times, after being added to a fracturing water source, are typically longer than those for emulsions. Figures 1 and 2 below shows results from two laboratory tests in which a VFR emulsion was compared to a slurried FR for viscosity development (Figure 1) and friction reduction (Figure 2). In order to obtain an apples to apples comparison in these tests, the dosage (in gallon/thousand gallons GPT) was adjusted so that the same active polymer loading was being evaluated. One can observe from Figure 1 that the viscosity development of the emulsion (run at 3 gpt) was much quicker than that of the slurry. This extended time for viscosity development with the slurry could present problems for the efficient transport of proppant during the fracturing operation.

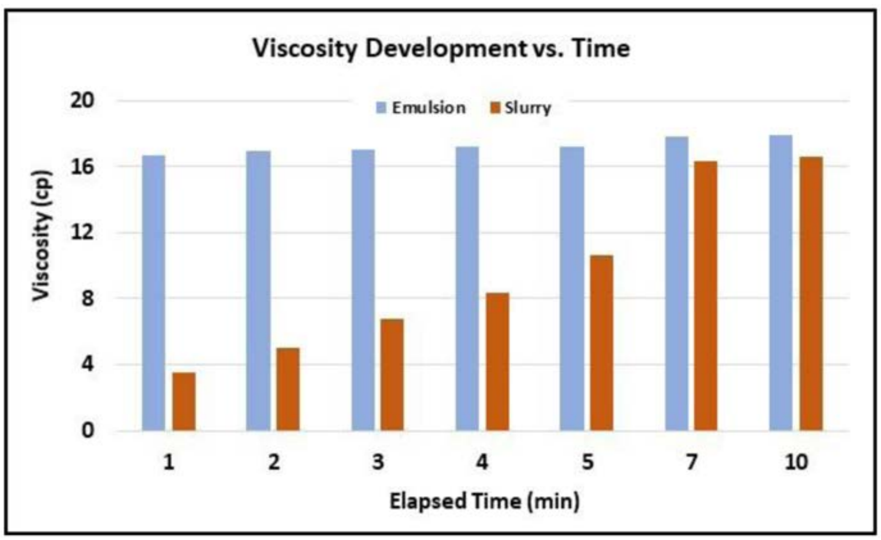

Figure 1—*Viscosity development of emulsion vs. slurry based friction reducers showing longer hydration times for the slurry*

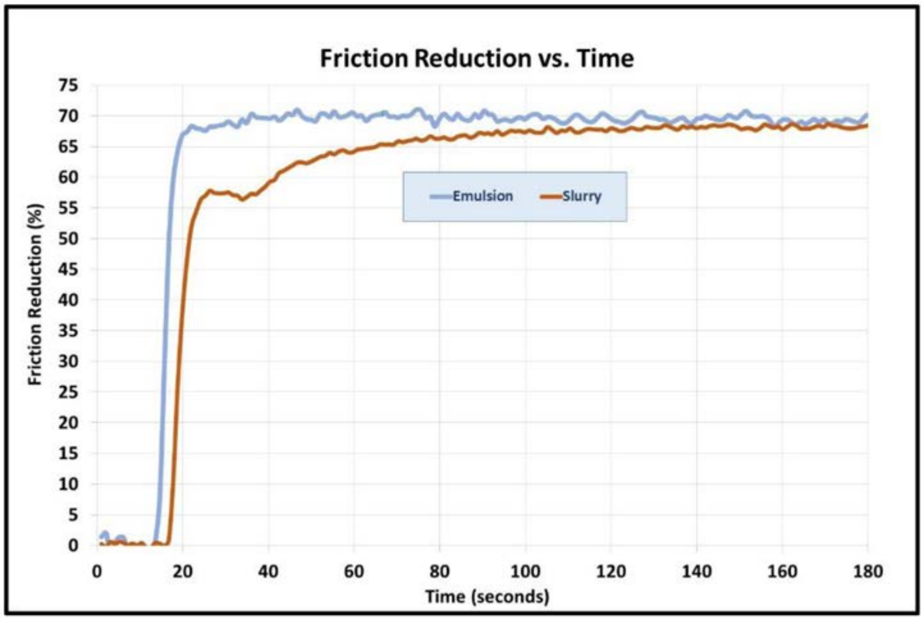

Figure 2—*Friction reduction of emulsion vs. slurry based friction reducer*

In Figure 2, the time required to achieve the desired friction reduction properties is also delayed with the slurry compared to the emulsion due to slower polymer hydration. Although not as significant as the delay in viscosity development, the delay in friction reducing properties by the slurry could result in higher pipe friction and therefore higher treating pressures.

A third method of PAM polymer delivery, and focus of this paper, is **dry powder** which is mixed directly into the frac source water during the fracturing operation. This delivery technique is relatively new to the oil and gas industry, due mainly to the fact that PAMs are not easily dispersed in water and tend to form lumps upon contact with water. The system described in this paper overcomes the dispersion and lumping problems using a high energy mixing technology. Delivering dry powder to location provides unique operational advantages which will be described in more detail in the sections below.

The system described in this paper has now been in operation since early 2019. Starting with a single unit for field testing, there are now 16 of the units operating in various basins within the USA. Figure 3 shows the growth of the DOTF operations since 2019, including the number of units and total amount of powder delivered on fracturing operations.

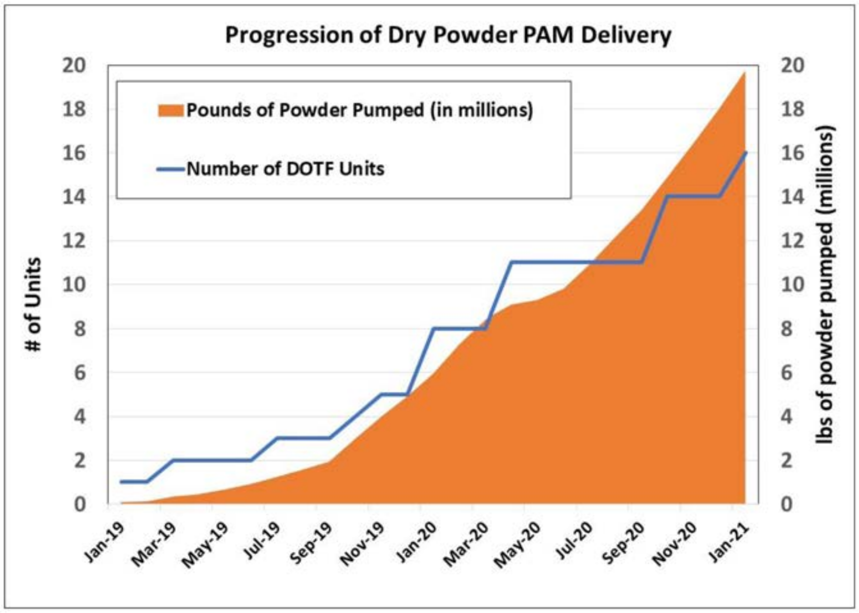

Figure 3—*Rapid growth of dry powder delivery systems since early 2019*

Dry Powder Delivery System

The dry on the fly (DOTF) powder delivery system consists of two main components that are brought to location: 1) a pneumatic trailer for the delivery of the PAM powder, and 2) a trailer-mounted mixing and control system. The system pulls water from the frac water tanks and treats a portion of the total downhole pump rate with the correct amount of FR powder, delivering it to the service company fracturing equipment. A summary of the key components is provided in the next section.

Water System

The DOTF water system is simple and utilizes the venturi effect to mix powder with water. Referring to Figures 4, 5 and 6 below, a suction pump (3) pulls water from the frac tanks on location through the suction manifold (1), then through a filter (2). Water is discharged from the suction pump into the DOTF mixing system (4). The force generated by the unique mixing system creates a vacuum that acts as the force for pulling powder from the pneumatic trailer. The mixed product exits the mixer system and is discharged into a 10 barrel buffer tank (5) where the mixed product resides prior to discharge. The discharge pump (6) pulls water from the buffer tank and discharges first through a check valve (7), an auto valve (8), a discharge flow meter (9), and then out to the frac equipment through the discharge manifold (10).

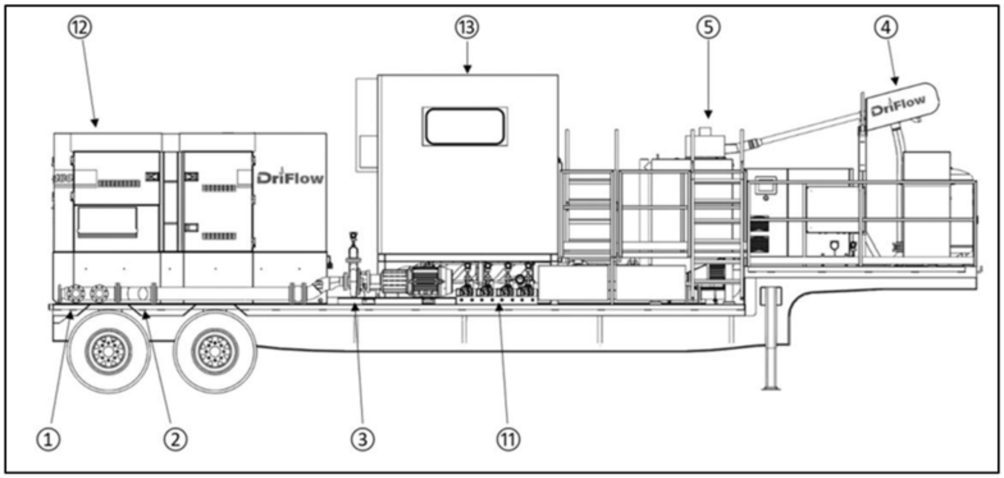

Figure 4—*Right side view of DOTF delivery system*

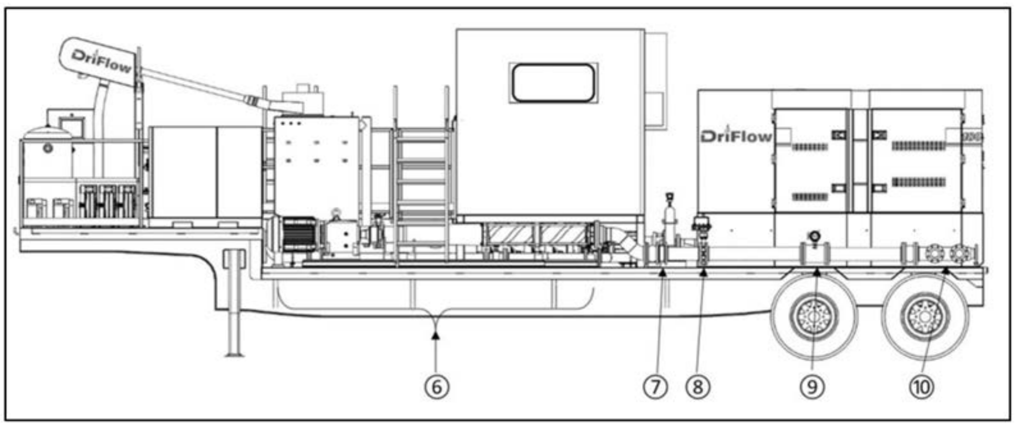

Figure 5—*Left side view of DOTF delivery system*

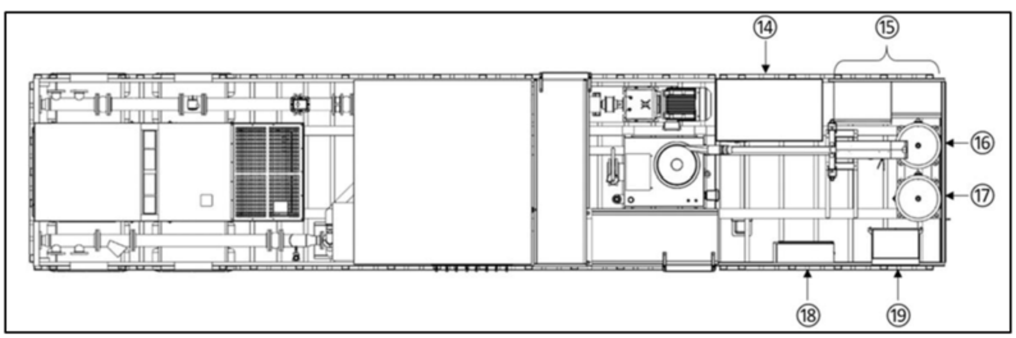

Figure 6—*Top view of DOTF delivery system*

In addition to the Dry FR mixing and delivery system, the DOTF unit has an onboard chemical additive system (11) for pumping ancillary chemicals. Operation of the chem-ad system is fully independent of the DOTF system, though it operates off similar setpoints.

Power, Electrical and Control

A generator (12) acts as the primary power source for the DOTF unit. The generator is tied into a breaker inside the control room (13) that allows for the ability to disconnect power from the generator to the rest of the DOTF system. Downstream of the main breaker, power is distributed to the other major components, which are mounted inside the control room on a control console. Data is gathered from all end devices, transmitted to cloud-based databases via cellular and satellite integration devices, and monitored in real-time. The DOTF technology package also allows for full remote control of all devices and systems on the units through any of the system interfaces.

Powder and Air System

The air system on the DOTF unit has 2 main objectives: 1) ensure that powder in the pneumatic trailer remains fluidized, and 2) maintain a dry environment for all onboard powder. Air is generated by an air compressor (14), then stored in a wet air tank (16). Air then flows through a dryer (18) and enters the dry air tank (17) where it is stored until needed. The dry air tank is tied into the pneumatic panel (19), where air is handled and distributed to all components requiring air in the system, primarily on the pneumatic trailer.

The DOTF unit works alongside a dedicated pneumatic trailer. The pneumatic trailer both transports powder to location, as well as serves as the metering mechanism. The pneumatic trailers have two independent powder hoppers, each with a volumetric feeder mounted to the bottom. There are two power reels and three hose reels (15) that allow the pneumatic trailer to be integrated with the DOTF unit. The power reels serve to control the motor speed, provide tachometer feedback from the feeder, and monitor powder level in the downspout. The hose reels are used to condition the powder being metered by vibrating the hoppers, fluidizing the powder inside, and maintaining a dry atmosphere for the powder.

Realtime Water Analysis

The DOTF unit is also capable of monitoring incoming water quality using onboard liquid analyzer technology. The system monitors pH, oxidation reduction potential (ORP), conductivity and total dissolved solids (TDS) of the water during real time using sensors that transmit the data to the DOTF system. Figure 7 shows an example of the display screen for the water quality measurements. Realtime water quality monitoring is particularly useful for fracturing operations in which produced water, or mixtures of produced and fresh water, are being used. For example, if any significant changes in water composition are detected, fracturing chemicals such as the FR concentration can be adjusted to account for the change in source water quality. The system can transmit the measured and calculated data over the web to any location, such as a completion engineer's office, in order to monitor water quality throughout the completion operation.

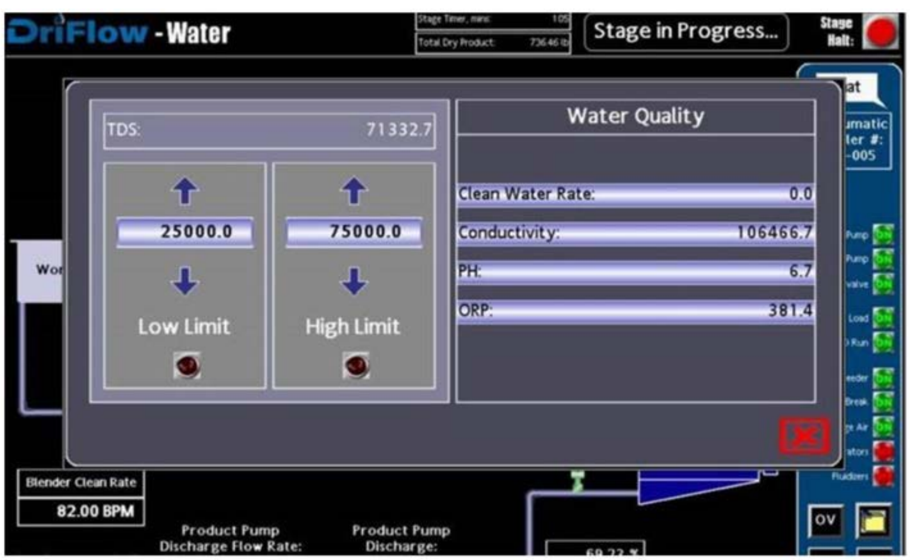

Figure 7—*Example display screen for realtime water quality measurements*

DOTF Advantages and Features

Delivering friction reducers in the dry powder form during fracturing operations provides unique advantages, primarily resulting from the elimination of liquid additives required to build emulsion and slurry based FRs. As described previously, emulsified and slurried FRs require a suspension agent (usually an oil-based carrier fluid), surfactants and dispersants which typically comprise about 70% of the volume of material required on location. Eliminating the need for the liquids provides advantages including:

- Reductions in material costs
- Elimination of mineral oils used in liquid FRs
- Reduced HSE (spill and safety) risks by removing liquid FR tanks on location
- On the fly adjustments in FR concentration
- Realtime water quality measurement

Minimizing cost is at the forefront of every operator's well completion objectives. The final invoiced cost for friction reducers depends upon several factors, however specific cost savings when using powders have been reported by multiple operators. Figure 8 below shows an example of cost reduction obtained by a Permian Basin operator using the dry polymer deliver system on two wells. On both wells, a liquid friction reducer was run for the first several frac stages shown with the blue bars on the charts below, followed by dry powder FR in the latter stages shown with the dark brown bars on the charts. Prior to the switch from liquid to dry FR, a few "transition" stages were pumped (stages 16 and 17 on Well 1, and stage 15 on Well 2) in which both liquid and dry FR were run on the same stage. The charts show the FR cost per stage for each of the two wells. In this case, the operator achieved a 30% cost reduction on Well 1, and a 37% cost reduction on Well 2. It should be noted that Well 2 was landed in a different target interval with more challenging frac conditions, which resulted in higher overall FR requirements.

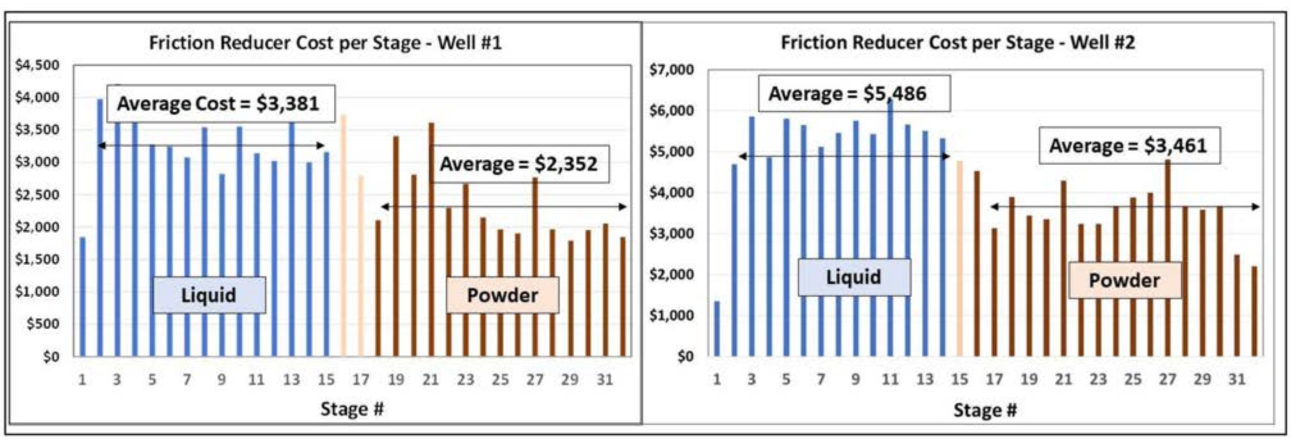

Figure 8—*Example of cost reduction obtained using dry powder delivery for a Permian Basin operator. Cost reduction was 30% for Well 1 and 37% for Well 2.*

Regarding health, safety and environmental issues, the use of dry powder eliminates the need for transport trucks to deliver liquid FR to location. On any given fracturing operation, multiple transport truck deliveries are required to refill ISO tanks containing liquid FR. This process involves transfer pumps and hoses and can potentially result in chemical spills and/or injury to personnel on location. Additionally, liquid FRs commonly use oil-based carrier fluids, adding to the environmental risk.

A final potential benefit that must be noted with the use of DOTF operations is the potential for significant cost savings for fracturing operations outside of the United States. With shipping costs being a significant portion of the total sourcing cost for friction reducers (and chemicals in general) internationally, the reduced volume requirements by shipping powder rather than liquid FRs will result in lower overall total cost of materials.

Dry FR Powders and Rheological Properties

The polyacrylamide FR powders delivered by the system can handle most design requirements, including a wide range of source water qualities, from relatively fresh water to high TDS produced water, and ionic charge type (anionic or cationic). The powders can be run at low concentrations to minimize pipe friction pressures or higher concentrations to build viscosity and improve proppant transport characteristics. Laboratory and field testing have been performed on the powders to evaluate key fluid properties such as friction reduction percentage (FR%) and viscosity as a function of shear rate. Testing data is shown below in this section.

One of the common learning curves when transitioning from liquid to dry powder FRs is the conversion from liquid FR concentrations to the equivalent dry powder concentrations. For example, a common question is "what dry powder loading do we need to run to be equivalent to one gallon per thousand (gpt) of our normal liquid FR?" The correct conversion depends upon a few factors including the density of the polymer and the activity of the liquid FR, which can vary from product to product typically over a range of 20% - 30% by weight. For a typical dry powder with 30% activity, the conversion rate is about 2.6 pounds per thousand gallons (ppt) equaling 1 gpt of liquid FR. Figure 9 below shows a series of curves with the conversion from liquid (gpt) to powder (ppt) concentrations.

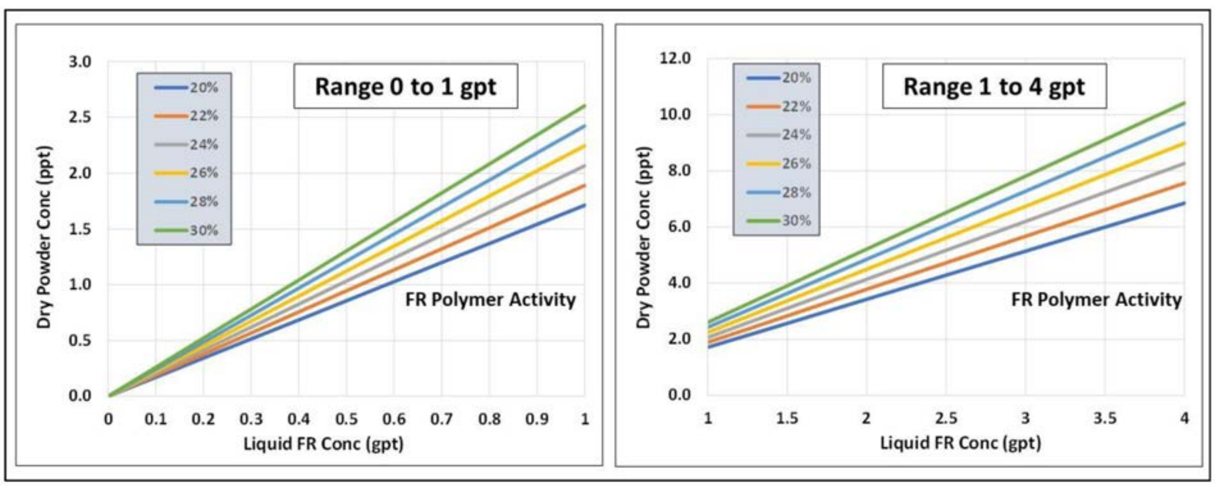

Figure 9—*Conversion charts from dry FR concentration (in ppt) to the equivalent liquid FR concentration (in gpt). The chart on the left shows conversions for 0 to 1 gpt equivalent, while the chart on the right shows conversions from 1 to 4 gpt equivalent*

Given the type of polymers used with the DOTF system, combined with the enhanced dispersion and hydration provided by the mixing unit, friction reduction properties for the dry FR powder are generally excellent and the polymer can often times be run at very lower concentrations. Figure 10 below provides data from a flow loop in the lab showing the friction reduction percentage vs. time for the dry powder run at a very low concentration of 0.54 ppt, or an equivalent liquid FR concentration of 0.2 gpt. Two different source waters were used in this test: a clean tap water as well as an API brine containing 93,000 ppm TDS and 21,000 ppm total hardness. Even in the higher TDS brine water, the polymer controlled friction pressure effectively at the low dosage.

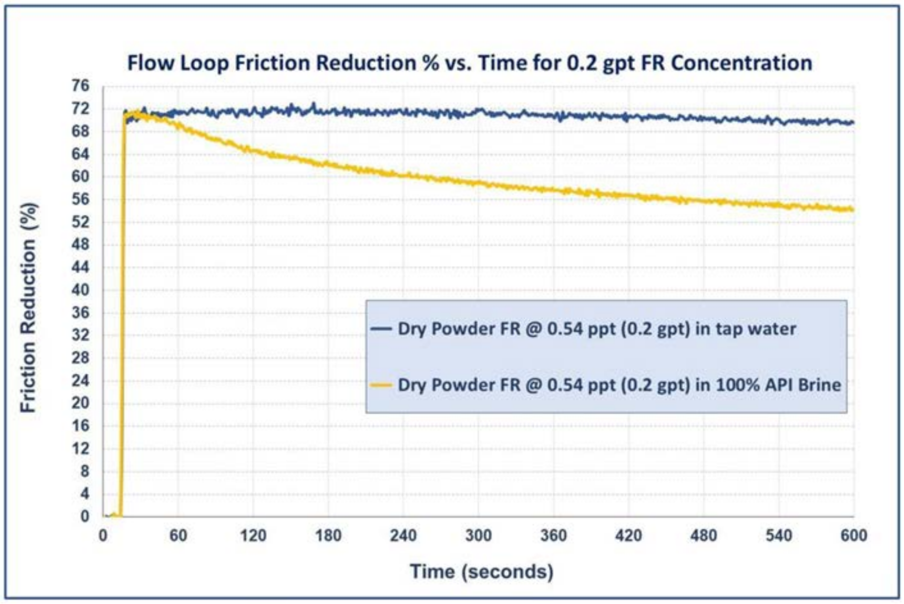

Figure 10—*Flow loop friction reduction for dry FR polymer at low concentration of 0.2 gpt equivalent*

Figure 11 shows the viscosity profile for the dry powder FR in both fresh and high TDS water sources. Similar to viscosity development profiles commonly seen with liquid emulsion VFRs, the dry polymer begins to build noticeable viscosity when the concentration reaches about 5.4 ppt, or an equivalent liquid emulsion FR concentration of 2 gpt. If higher viscosities are desired on the frac operation, the polymer concentration can simply be increased.

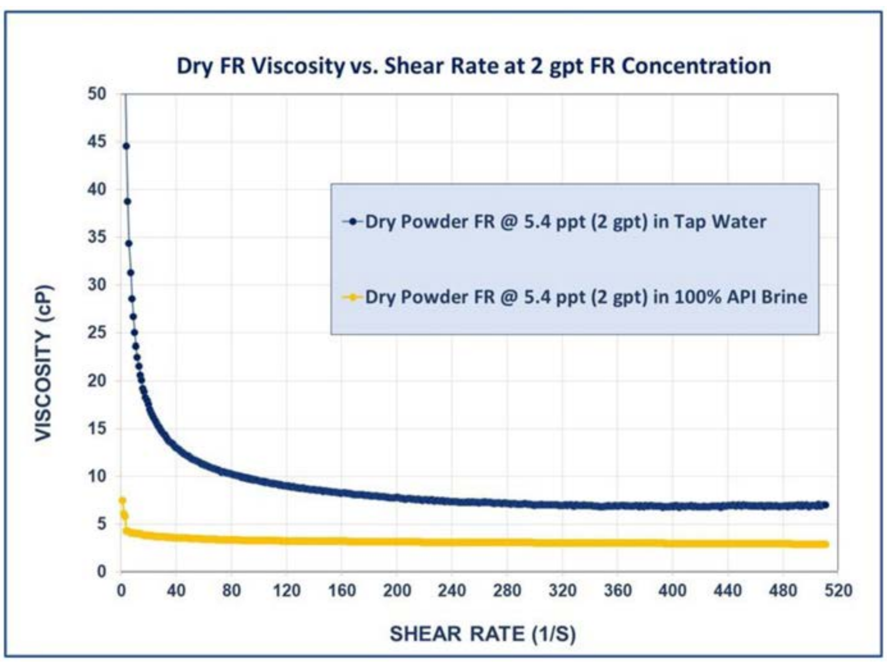

Figure 11—*Viscosity vs. shear rate for dry FR polymer at 2 gpt equivalent*

Case Study - Hibernia Resources

Hibernia Resources operates in two West Texas counties, Upton and Reagan. Figure 12 shows an acreage map of the areas in which Hibernia operates their wells. Hibernia's objectives for moving to DOTF operations were to simplify their fracturing operations, reduce cost, and eliminate the interaction between oil-based FR emulsions/slurries with their produced water. Beginning in March of 2019, Hibernia has used the DOTF delivery system on 17 wells, pumping over 850,000 lbs of FR powder.

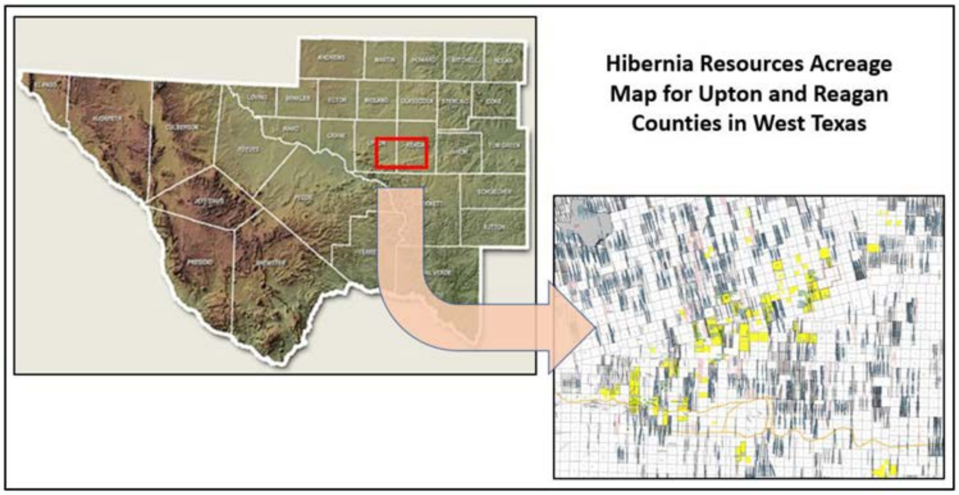

Figure 12—*Acreage map of Hibernia properties in Upton and Reagan counties, West Texas*

The DOTF delivery system has worked well thus far, meeting the expectations that were anticipated from the system described above, as well as providing good friction reduction properties. Figure 13 shows an example job chart from one of the well stages, showing smooth pressure and rate conditions, with 470,000 lbs of 100 mesh proppant placed at a maximum concentration of 2.5 ppg. Figure 14 shows the surfactant and FR concentration pumped during the stage. The black curve near the bottom of figure 14 shows the dry powder concentration ranging from 0.3 to 0.4 gpt (equivalent liquid FR concentration), or 0.78 to 1.3 ppt of powder. The relatively low FR concentrations show the ability of the dry friction reducer to perform effectively during the frac operations.

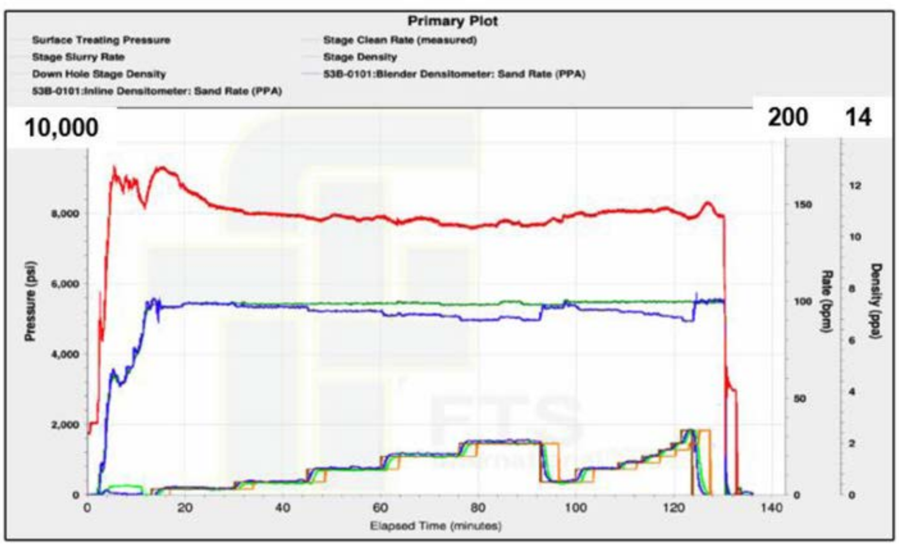

Figure 13—*Example job chart for a frac stage using DOTF system*

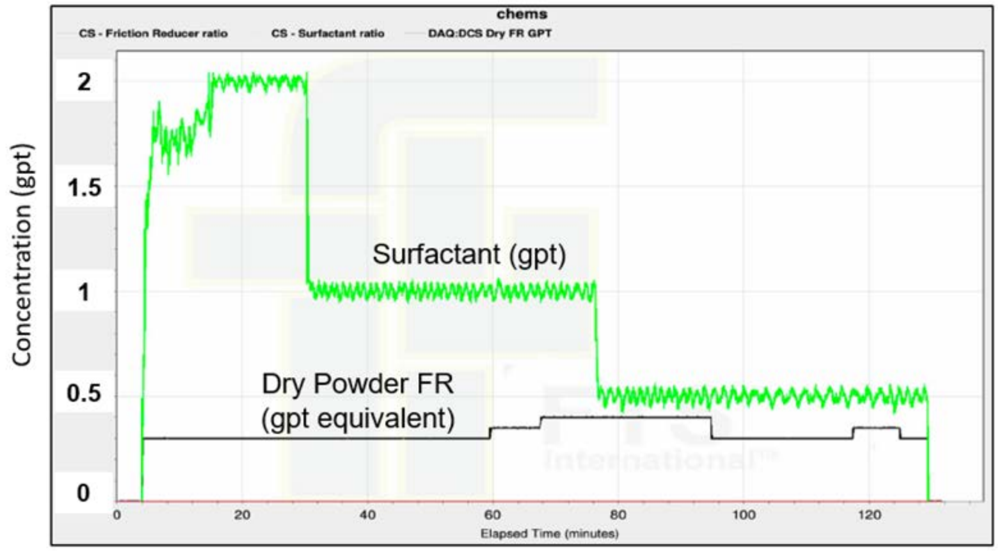

Figure 14—*Additive concentrations for frac stage showing FR run at 0.3 to 0.4 gpt equivalent*

Injection Point for Dry Friction Reducer

One of the optimization efforts from this project involved determining the optimum location for delivery of the FR into the fracturing equipment surface manifolding. Through past experience, it is known that delivering the FR into the suction side of the blender is not the best solution due to the fact that excessive shear placed on the FR going through the frac blender can lead to a reduction in the effectiveness of the FR powder. The initial injection strategy on this project was to split the 8 bpm flow from the DOTF unit to approximately 4 bpm to each side of the high pressure manifold. Using real time fluid quality measurements (described in the next paragraph), the determination was made that the rheological properties of the fluid were not uniform on both sides of the HP manifold using this approach. The FR injection point was subsequently moved to the blender manifold, resulting in a much smoother distribution of FR to the high pressure pumps.

Figure 14 below shows an example of the real time fluid quality measurements which were used to help determine the effectiveness of the FR injection point location. The top half of Figure 15 shows the normal treating pressure parameters measured over seven frac stages, with the bottom half of the chart showing friction reduction measurements for the fluid near the two FR injection points (represented by the blue and red curves). Ideally, the two curves should match if the FR is being evenly distributed. For the first two frac stages, an uneven distribution is noted, however beginning with the third frac stage, the fluid samples from both locations become uniform. The real time fluid rheology measurements were a useful tool in assisting with the proper FR injection point determination.

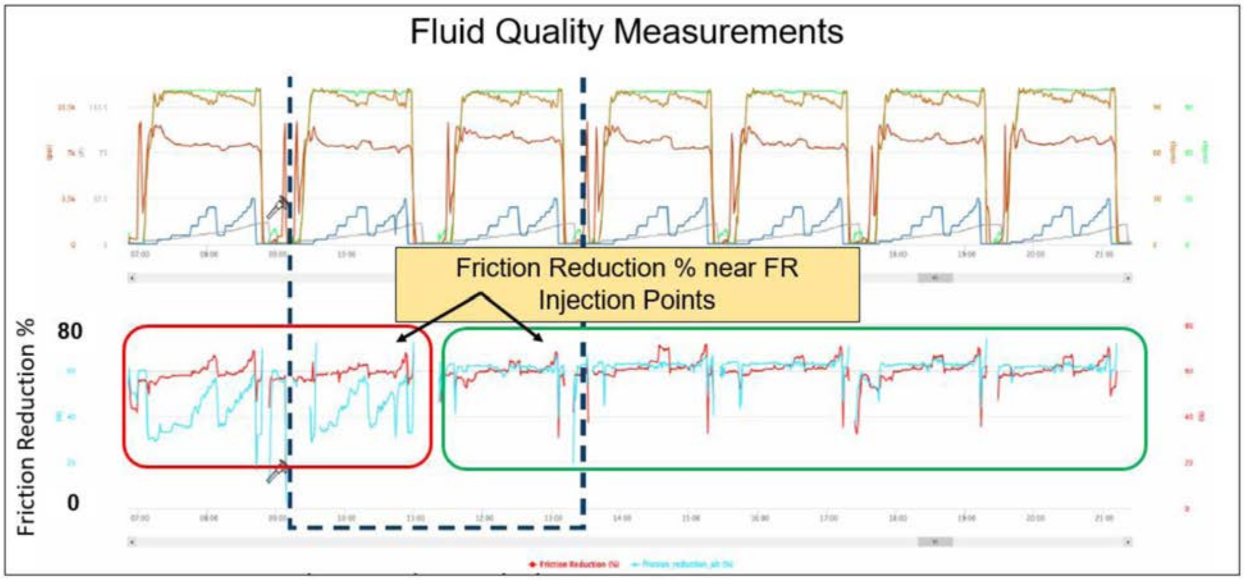

Figure 15—*Example of real time fluid quality monitoring before (stages 1 and 2) and after (stages 3 thru 7) modification of FR injection point*

From a cost savings perspective, Hibernia observed cost savings with the DOTF technology over both FR fluid system types (emulsions and slurries). When the DOTF delivery system was compared to emulsion based FRs, product cost reduction was the primary mechanism for improved economics. When the DOTF system was compared to a slurry-based FR system, the primary mechanism for improved economics was related to operational efficiency. On several occasions when pumping the slurry-based FR system, excessive viscosity of the slurry caused issues and downtime with the additive pumps used to deliver the slurry to the frac blending equipment. This downtime resulted in NPT and reduced the average number of stages that were completed on a per day basis.

Conclusions

This paper describes a new type of delivery system for polyacrylamide-based friction reducers using dry powder and mixed on-the-fly with fracturing source water. The DOTF system consists of two units which are brought to location; a mixing/control unit and a pneumatic transport which carries the dry powder. The key component with the DOTF system is the mixing unit which uses a unique vacuum technology to create sufficient mixing energy for proper dispersion and hydration of the polyacrylamide polymer.

Hibernia Resources began using the DOTF system in March 2020 and have completed 17 wells to date. Based on the results of the well completion operations in 2020, the DOTF system has met the project objectives which were to reduce cost, simplify operations, and eliminate oil-based friction reducer emulsions or slurries for Hibernia.

By eliminating the use of liquid FR emulsions or slurries, the DOTF delivery system provides a step-change in slickwater fracturing chemical delivery and offers unique opportunities for reducing cost and HSE risks, and simplifying operations. For international operations, the transportation of powder should be significantly less expensive than shipping liquid FRs, making this technology an attractive option for unconventional developments outside of the United States.

Acknowledgements

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