# AN ANALYSIS OF CONTINUOUSLY-MIXED HYDRAULIC FRACTURING TREATMENTS

Stephen A. Baumgartner
Charles Clark
BJ-HUGHES, Inc.

## ABSTRACT

As hydraulic fracturing treatments continue to increase in fluid volume and in expense, emphasis is now being placed on more efficient treatment techniques. The traditional method of batch mixing a fracturing fluid has several disadvantages. Once the chemicals are added to the mixing water, they must be pumped within a specific length of time in order to retain their effectiveness. A delay due to well, weather or equipment problems can cause the premixed chemicals to degrade. Chemicals used to mix fracturing fluids constitute a substantial part of the treatment cost. Finally, any fluid left from the treatment usually cannot be reused unless it is transported to another location within a certain time limit. A continuous-mixing technique has been recently developed to more efficiently mix fracturing fluids. The technique eliminates pretreatment mixing of the fracturing fluid by proportionally combining the fracturing fluid chemicals with the mixing water in the blender tub at the time of the job. Sand is then added to the fluid, and the resulting fracturing slurry is pumped to the high pressure pumps for injection into the wellbore. In this paper, field and laboratory studies are cited in the attempt to describe the continuous-mix methodology. A cost comparison of continuous mixing and of traditional batch mixing based on job analysis is also presented.

## INTRODUCTION

Highly viscous fracturing fluids are widely used in hydraulic fracturing treatments. The effectiveness of such fluids has been reported by various authors.[1,2,3] Highly viscous fluids create wide and deeply penetrating fractures and will carry high concentrations of proppant. The traditional method of batch mixing these fluids involves mixing a prehydrated polymer solution with a crosslinking agent during the treatment. The main desadvantage of this method is that the polymer must be dispersed and hydrated prior to the job. For a massive hydraulic fracturing treatment, premixing the polymer can take days. In addition, if the treatment is prematurely ended, the remaining volume of polymer solution must be discarded. Chemical waste can also occur when there are job delays due to problems with equipment, well conditions or the weather. In contrast, the relatively new continuous-mix method can reduce the chemical waste which so often occurs when fracturing fluids are batch mixed.

## BATCH-MIXING METHOD

Commonly used to mix fracturing fluids, the batch-mixing technique involves circulating the mixing water in the fracturing tanks while clay control chemicals, buffers, surfactants and polymers are added. Once mixed, this solution must be used within a certain time span. Water and air temperatures play a critical role in the life of the resulting polymer solution. The main problem in extending the life of the solution is bacteria which will attack the polymer. To combat this problem, bacteriacides are used to help prevent viscosity loss and to extend the life of the solution. Of course, bacteriacides also add to the treatment cost.

In the event of job delays, the premixed gels must be constantly monitored to maintain suitable viscosity. Monitoring is done with a Fann 35 VG meter. Additional polymer must be added if the viscosity falls below minimum levels. Sometimes the frac tanks must be dumped, cleaned and refilled with water which will double the cost of the fracturing fluid.

Pregelling frac tanks for a massive hydraulic fracturing treatment can require a long lead time. It usually takes an hour to gel a 500-barrel frac tank. If a job requires 20 tanks, at least 20 hours would be needed. Unless two blenders are used, pregelling would take two days.

Equipment hookup for batch mixing is relatively simple (Fig. 1). A manifold enables the blender to be connected to all the fracturing tanks simultaneously. When the polymer is mixed, the blender draws the solution into the blender tub. Then, such additives as diesel, condensate or methanol can be blended into this mixture. Proppant is also added at this time, and finally, the cross-linker is injected into the blender discharge manifold.

## CONTINUOUS-MIXING METHOD

The continuous-mixing technique is used to totally mix a fracturing fluid while it is being pumped downhole, thus eliminating the need to pregel frac tanks. Mixing water, additives, polymer, proppant and finally cross-linker are combined at various stages during the job. Since the frac tanks are not pregelled, no polymer is wasted when a treatment is terminated prematurely. Thus, one important advantage to continuously-mixed treatments is that chemical waste is virtually eliminated.

Fracturing fluid comprises a large part of the total treatment cost. In massive hydraulic fracturing treatments, the expense of the fluid can approach 40 percent to 50 percent of the treatment cost. With the continuously-mixed technique, the polymer is not mixed until the job is pumped. By eliminating the premixing of polymer, the lead time and the chance of chemical spoilage are reduced.

Prejob planning is critical in a continuously-mixed treatment. First, the projected pump rates should be determined. With this information, the service company can then calibrate pumps and metering systems. Equipment operators should also have charts which assist them in adjusting additive rates when the pump rate varies. Measures such as these help insure proper blending of the fluid. The success of the continuous-mixing method is well documented.[4]

In a continuously-mixed job, the polymer will generally have less than one minute to swell or hydrate. Most cross-linking agents cross-link a hydrated polymer solution rapidly. Usually when these cross-linkers are added to a polymer solution, no additional polymer will hydrate. Therefore, it is imperative to fully hydrate the polymer before the cross-linker is added.

An effective dispersing system can add polymer so that it will hydrate rapidly. The hydration time of a polymer is measured from the moment it is dispersed in water until it swells. This reaction can occur in less than 30 seconds. The temperature and pH of the water, in addition to the chemicals used to buffer the system, will affect the hydration time. Accurate prejob planning can assure proper hydration time.

For a continuously-mixed job, the blender is hooked up to a common manifold from the frac tanks or water source (Fig. 2). The only prejob mixing required is to make an additive stream usually comprised of 10 percent of downhole volume. This stream includes buffering chemicals, clay control chemicals, surfactants, breaker and defoamer. When pumping is initiated, the blender mixes the water and additive stream in the blender suction manifold. Next, polymer is added to the blender tub through the disperser, and proppant is added to the blender tub by a conveyor system. Finally, the cross-linker is added downstream of the blender tub to make a viscous fracturing fluid.

## SEMI-CONTINUOUS-MIXING METHOD

The semi-continuous-mixing method is identical to a continuously-mixed system except that a buffer or holding tank is needed (Fig. 3). The holding tank increases the time the polymer can hydrate before cross-linking. The increased hydration time varies according to the size of the holding tank and the pump rate. The residence time or time in the holding tank can be calculated by dividing the tank size in barrels by the flow rate in barrels per minute. The residence time is then calculated in minutes.

The system also requires an additional blender or polymer mixer. The two streams of fresh water and additives are mixed in the gelling blender. There the polymer is also added and then pumped to the holding tank. Next, the job blender pumps the polymer solution to the blender tub where proppant is added. Cross-linker is then added downstream of the blender tub to make viscous fracturing gel.

The advantages of semi-continuously-mixed fracturing fluids are the same as those of continuously-mixed treatments. In fact, due to the addition of holding tanks, more control over polymer concentration is possible with the semi-continuously-mixed system. Historically, one polymer concentration is pumped throughout a job. However, as the treating fluid gradually cools down the formation during a massive hydraulic fracturing job, the bottomhole temperature can be drastically reduced near the end of the job. For example, a 50-pound cross-linked system may be required at 275$^{o}$F in order to maintain desired fluid properties. But as the formation cools down, the polymer concentration can be decreased accordingly to maintain the desired fluid properties.

Today, massive hydraulic fracturing treatments are designed with three or four polymer concentrations to help control viscosity. The accuracy of the semi-continuously-mixed method allows a change in polymer concentration to be performed easily. Thus, the operator can save on job expense by gradually decreasing the amount of polymer used.

Polymer is the most expensive part of a fracturing fluid. In most cases it will represent 75 percent of the fluid cost. Continuously- and semi-continuously-mixed treatments require premixing of the buffering system and the breaker, but this cost is small compared to the amount of polymer saved. One drawback of semi-continuously-mixed fluids is that savings are not as great for small treatments as they are for large ones. The greatest savings are realized in massive hydraulic fracturing treatments of over 100,000 gallons.

## LABORATORY STUDIES

To study the hydration of polymers, laboratory tests were run under different conditions. The results indicate that polymer hydration is dependent on water characteristics and shear circumstances. The higher the shear rate, the faster the polymer disperses and swells. The pH, temperature and mineral content of the water also affect polymer hydration time.

Also studied was the effect of short hydration times on the viscosity of cross-linked fluids as is encountered in continuous and semi-continuous mixing. A cross-linked, hydroxypropyl guar system was chosen for testing. Samples of 30-, 40-, and 50-pound polymer per 1,000 gallons of water were used. In the first tests, the polymer was hydrated for one minute in a Waring Blendor, then placed on a Fann 50C high temperature, high pressure viscometer. In these tests, the fluids were subjected to temperatures within their effective working ranges. Fig. 4 shows the test results. A second series of tests run on the Fann 50C viscometer allowed only 30 seconds of polymer hydration. Good stability was also shown by the continuously-mixed fluids in these tests.

## FIELD RESULTS

While both continuously-mixed and semi-continuously-mixed treatments have been successfully field proven, more semi-continuous jobs have been performed (Table I). In these cases, any premature job terminations that occurred have not been traced back to fluid performance. On this type of job, samples of the fluid are taken regularly to insure proper fluid viscosity. The cross-linked fluid can be tested after the cross-linker is added. To acquire a sample of the cross-linked fluid, a valve can be placed in the line just before the fluid enters the suction of the high pressure pumps. Because the blender normally has about 60 PSI of discharge pressure, caution is imperative when taking a sample.

The equipment hookup of a semi-continuously-mixed treatment usually divides the frac tanks into two lines. The front row is for flush tanks and holding tanks while the back row of tanks holds the remainder of the water needed for the treatment.

The back row of tanks are manifolded into the gelling blender or polymer mixer. The discharge lines of the blender are routed to the holding tanks. The additive stream is normally mixed in a tank close to the gelling blender, and a separate hookup is made to the gelling blender to allow for accurate suction of the additive stream. The job blender is positioned in front of the holding tanks and flush tanks to allow room for bulk proppant equipment. The job blender pumps fluid out of the holding tanks and into the blender tub. At this point, proppant is added, and finally the cross-linker is added downstream of the blender. If desired, diesel, condensate or methanol can be blended into the fluid at the job blender.

## ECONOMIC ANALYSIS

Shown in Table II are the economic advantages of continuously-mixed treatments. For instance, a semi-continuous mixing job was designed for 166,000 gallons of fluid to be cross-linked with hydroxypropyl guar and for 667,000 pounds of 20/40 sand. The day before the job, two holding tanks were pregelled. About halfway through the treatment, the surface treating pressure exceeded the maximum pressure for the tubing, and the job was terminated.

If the treatment had gone to completion, 6,640 pounds of polymer would have been used. At a price of $3.50 per pound of polymer, the cost for polymer totaled $23,240. Thus, if the polymer had been pregelled as is required when batch mixing, the total amount of money for polymer would have been committed. In actuality, only 77,000 gallons of the treatment were pumped. Therefore, only 3,080 pounds or $10,780 of polymer were pumped downhole. By using a semi-continuous mix technique, the operator was able to save over $12,000. Obviously, this technique will allow the operator to save the expense of polymer if the job is prematurely terminated.

## CONCLUSIONS

Highly viscous fracturing fluids will create wide fractures and carry high concentrations of proppant. When mixed continuously or semi-continuously, such fluids have proven highly successful in many areas. In addition, the continuous-mixing technique eliminates the waste of fracturing fluid chemicals if problems are encountered before or during a treatment.

## REFERENCES


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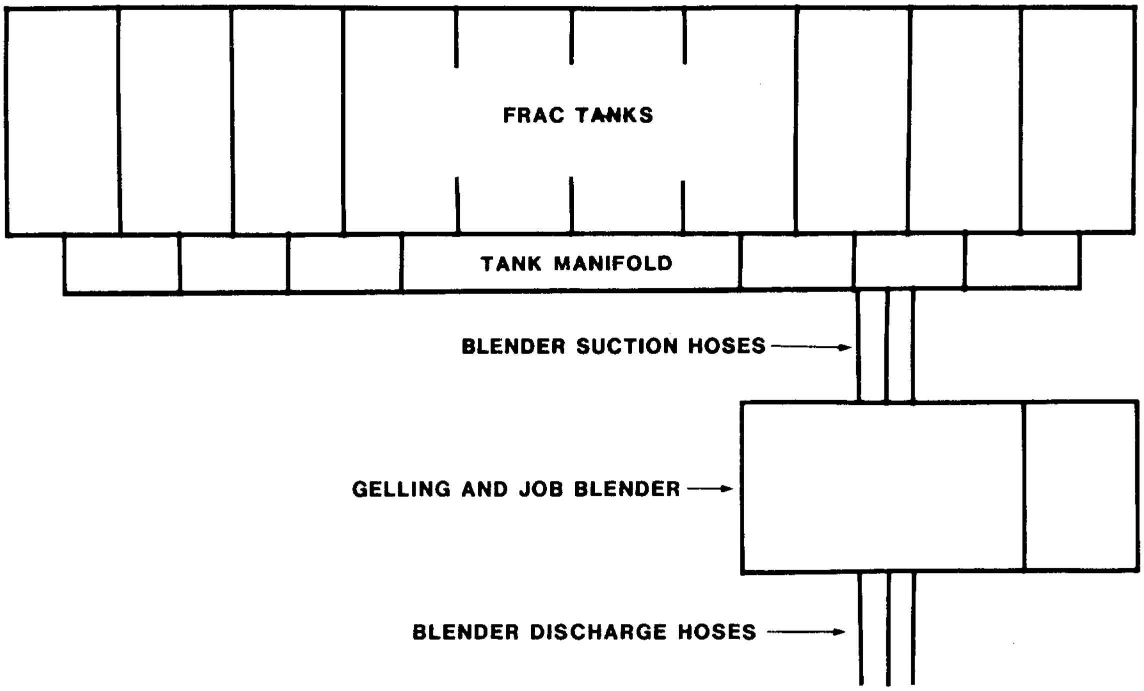



FIGURE 1—BATCH-MIXED FLUIDS

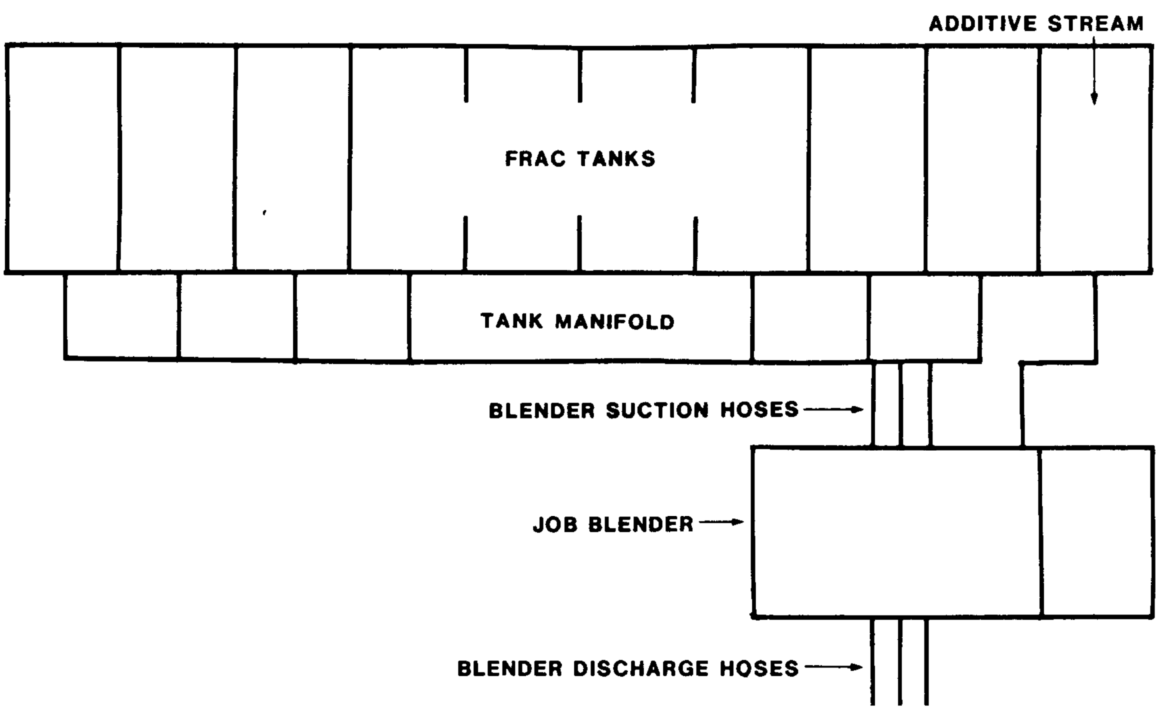



FIGURE 2—CONTINUOUSLY-MIXED FLUIDS

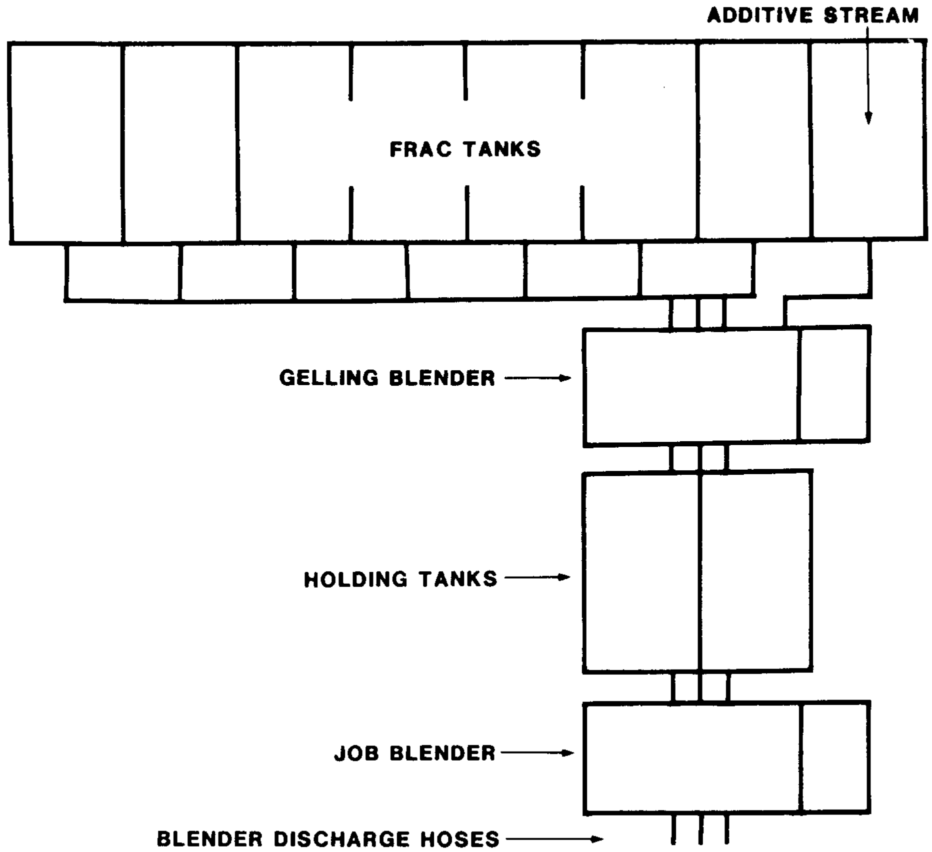
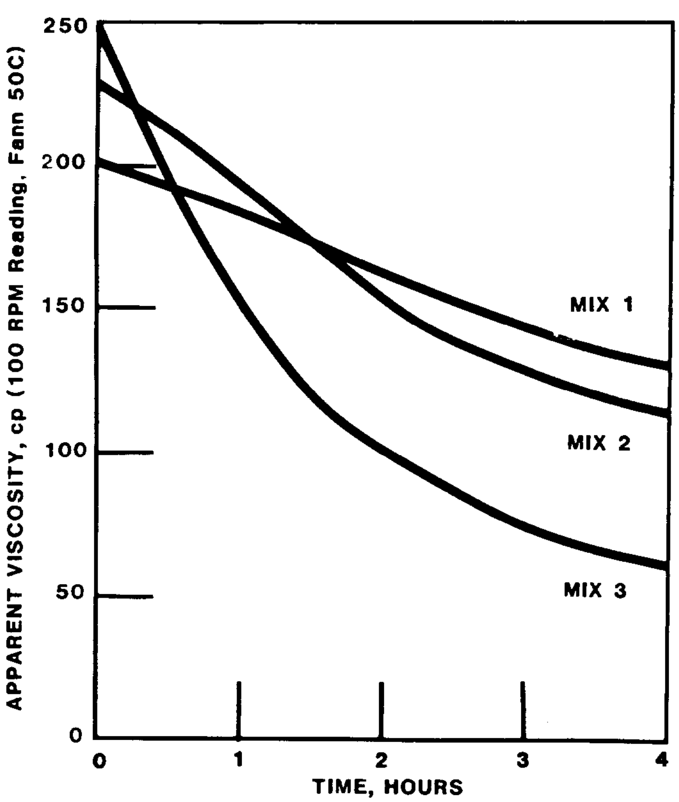



FIGURE 3—SEMI-CONTINUOUSLY-MIXED FLUIDS




MIX 1 = 30-pound HP guar cross-linked at 125°F.

MIX 2 = 40-pound HP guar cross-linked at 200°F.

MIX 3 = 50-pound HP guar cross-linked at 250°F.

FIGURE 4—VISCOSITY VS. TIME

TABLE 1—CASE HISTORIES OF SEMI-CONTINUOUSLY-MIXED TREATMENTS

| Job Location | Fluid Components | Amount Of Proppant |
|---|---|---|
| Wyoming | 211,000 gals. of fluid cross-linked with HP guar; 5% hydrocarbon. | 435,000 lbs. of sand |
| Wyoming | 150,000 gals. of fluid cross-linked with HP guar; 5% hydrocarbon. | 615,000 lbs. of sand |
| Wyoming | 125,000 gals. of fluid cross-linked with HP guar; 5% hydrocarbon. | 270,000 lbs. of sand |

TABLE 2—ECONOMIC ANALYSIS OF SEMI-CONTINUOUSLY-MIXED TREATMENT

| Recommended Treatment Amounts | Treatment Amounts Actually Used | Economic Analysis Of Semi-Continuously-Mixed Treatment |
|---|---|---|
| •166,000 gals. of fluid cross-linked with HP guar.<br>•6,640 lbs. of polymer at a concentration of 40 lbs./1,000 gals. of water. | •77,000 gals. of fluid cross-linked with HP guar.<br>•3,080 lbs. of polymer at a concentration of 40 lbs./1,000 gals. of water. | By employing a semi-continuously-mixed treatment, the operator realized a savings of 3,560 lbs. of polymer when the job did not run to completion. At $3.50/ lb., the polymer saved totaled $12,460. In a conventional job, the polymer would have been wasted if the job had not been completed. |