RECENT MECHANICAL AND CHEMICAL IMPROVEMENTS IN FOAM FRACTURING

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INTRODUCTION

Since the first foam fracturing treatment in approximately November of 1974, great strides have been made in both the technology of foam per se and the equipment to handle same. Countless numbers of papers, presentations and patents have been presented. A sampling of these is listed in the bibliography of this paper. The early foam fracturing treatments were conducted using water, foamer, and nitrogen injection trucks. The treatments were small and sand concentrations quite normally did not exceed two to three pounds per gallon downhole. It was always a very frightening experience for a company man, who had not been on a foam frac, to attend his first treatment. A company man who was used to visual read-out of both flow rate and pressure of all materials going down hole was in for quite a surprise on the early foam fracturing treatments.

Nitrogen rate, which in many cases is produced by anywhere from 5 to 50 trucks, was measured by counting pump strokes on the units. A nitrogen treater would stand in the frac van and indicate to the company man what the rate was at all times. One could monitor with flowmeters, clean and dirty fluid rate of the base fluid to be pumped. But unless one was very trusting, one never really knew what was being pumped downhole. Without the benefit of both low-pressure and in-line high-pressure densiometers, one really never knew what the sand concentration was and because of the complexity of the density of the foam fluid there was very little in the way of checking same.

In spite of all the aforementioned problems, many successful foam fracturing treatments, in fact hundreds, were conducted in just this manner. This says a great deal for the dilligence of nitrogen treaters and fracturing operators. Quite thankfully, today foam fracturing is not such a black art. We in today's industry have quite functional in-line flowmeters for measuring the exact rate of nitrogen as it is pumped downhole.

Most foam fracturing treatments should be conducted utilizing both in-line low-pressure densiometers for measurement of sand concentration in the concentrate as well as high-pressure in-line densiometers for measuring the final concentration of sand in the foam. Both of these measuring techniques, in addition to much improved sand handling capabilities from the service companies, utilizing either specialized valving in their pumps or sand concentrators, allow sand concentrations up to and including 8 pounds per gallon.

Foam fracturing treatments have been conducted approaching two million pounds of sand with pump times well over 10 hours. Foam fracturing pump rates have varied anywhere from 5 barrels per minute up to 150 barrels per minute. Foam fracturing has indeed become another very useful tool for oil companies in the enhancement of production of oil and gas. Recently, a new development in this area has been the utilization of the emulsion foam/CO_2 technique which has given new emphasis to energized gaseous foam fracturing.

IMPROVEMENTS IN FOAMERS

Most of the oil service companies in the early 1970's utilized standard foamers from various suppliers. Many of these foamers were simply sulfonates or sulfates which had been used as detergents or soaps in the industry for many years. Research conducted by the service companies yielded improved ionically charged sulfonates, amine cationics, amphoterics and other products which have allowed us both high temperature stability as well as compatibility with various contaminants and foam stability beyond our wildest dreams. Foam fracturing treatments have been conducted where, due to mechanical problems, the treatment had to be shut down for periods of up to 1 hour and restarted with no settling of sand, which indicated foam half-life well in excess of 60 minutes.

Foam stabilizers which have been developed through a great deal of work by various service companies have created a fluid comparable in carrying power and proppant suspension to the crosslinked fracturing fluids presently in use today. The most common foam fracturing treatment today consists of sulfonates as foamers, cationic amines or zwiterion foamers. Some service companies prefer one or the other depending upon the application involved. Most of these foam fracs also will contain hydroxypropyl guar or xanthan gum as a foam stabilizer. The typical nitrogen foam frac treatment will consist of sand concentrations sometimes up to as high as 8 pounds per gallon downhole, and with a combination of valving and concentrators, these concentrations can even exceed these levels.

Variations on this theme today are the crosslinked foam, which includes the aforementioned foamers as well as the delayed crosslinkers compatible with foamers. The crosslinked foam allows more viscosity in the fracture as well as enhanced half-life stability and an expansion of the typical foam quality range.

In addition to the new developments in foamers for aqueous base fluids, foamers have been developed for use in water-alcohol and pure alcohol solution as well as foamers for hydrocarbons and hydrocarbon-based fluids. The typical hydrocarbon foamers consist of fluorocarbon-based products. Many of the service companies have proprietary blends with various special properties. The fluorocarbons also find their way into the alcohol-based foamers. Quite stable foams can be prepared utilizing methanol-soluble foam stabilizers which allow us to place high concentrations of sand in both water-methanol, methanol and hydrocarbon-based foams. Typically, the stabilizers for oil-based foams are the organic phosphate ester gel systems which are used so successfully at higher concentrations for gelled oil fracturing fluids.

A new type of treatment that has been utilized over the last 2 to 3 years has been the development of CO_2 emulsion/foam system. This system uses CO_2 emulsified with water and when allowed to reach critical temperature in the fracture, creates a foam system. This technique has found wide success, particularly in low-pressure oil reservoirs where the obvious advantage of CO_2 comes to bear. Typical foamers for this system are sulfonates, cationic amines or combination emulsifier-foamers which are for the most part in the zwiterion or sulfonate category.

Virtually all service companies have the capability to do both nitrogen and CO_2 foam fracturing treatments for extended periods of time at high temperatures and carry large concentrations of proppant in high temperature reservoirs. One treatment conducted two years ago allowed the placement of some 6 pounds per gallon of sintered bauxite in a 320°F well in South Texas. Quite commonly a normal treatment in the Vernal, Utah area is a treatment where sand concentrations reach or exceed 8 pounds per gallon downhole.

These new generation foamers, stabilizers, etc. have allowed foam fracturing to become a useful and versatile tool in the attempt to obtain enhanced productivity from tight oil and gas reservoirs.

IMPROVED TESTING PROCEDURES

In the early days, cursory studies on foams, foam half-life, and foam stability were made utilizing Waring blenders or something defined as a foam generator. A foam generator generally was a venturi device where you pumped nitrogen through a tube and sucked water and foamer into the same tube, creating a frothy foam downstream. The Waring blender test, although a fairly good one for a cursory look in the study of foams, certainly tells us very little or nothing at all about the stability of foam at temperature and pressure conditions. The foam generator test was found to be an even poorer quality test for evaluating foam under virtually any conditions.

Most of the service companies in the industry today have high temperature, high-pressure loops for studying foams using flowing conditions under pressure and temperature. Under these conditions, the service company is able to evaluate the fluids under similar conditions to what they will see downhole. They can also introduce contaminates and evaluate absorption problems with the surfactants by flowing them through a bed of simulated formation. Most of the service companies also have see-through cells for a visual observation of effects on quality of the foam.

A great deal has been written about these studies in SPE papers and presentations evaluating structure of foam, bubble size, etc. The improved test procedures have allowed us to be able to utilize foam in much harsher conditions and environment than heretofore thought possible. Prior to this research, it was felt that foam had very little application in the deeper, higher-pressure wells. Thanks to rheological investigations on foam, we have been able to apply foam under conditions with which no other fluids would have been found applicable.

IMPROVEMENTS IN EQUIPMENT

The improvements which have allowed foam to become more successful and have been even more important than the improvements in the chemicals were the development of blending and pumping systems for handling very high sand concentrations. Due to the unique nature of foam fracturing with CO_2 or nitrogen, one must achieve very high sand concentrations at the blender tub or downstream through concentrators to be able to achieve high sand concentrations downhole. For instance, in a 75 quality foam fracturing treatment, one must have 20 pounds per gallon on the surface to have 5 pounds per gallon downhole.

Special velocity enhancement devices such as paddles, screws, etc. or recirculation of fluid have been added to the blenders to allow suspension of sand concentrations as high as 22 pounds per gallon in the blender tub. Two service companies utilize special downstream valving in their pumps which allow them to pump these high sand concentrations through standard pumps. Other service companies, although not using the special valving, do use venturi sand concentrators which allows them to concentrate the sand while feeding clean fluid back to the frac tanks. Either technique is functional if handled properly, allowing very high sand concentrations downhole. There is, of course, a limit to the amount of sand which can be handled in a slurry condition. Something in excess of 22 pounds per gallon with any viscosity on the base fluid is approaching that limit.

The new generation densiometers also have been very beneficial in monitoring and controlling sand concentrations. Typically, two are used to measure the concentrate slurry and the downstream diluted sand concentrations. It is imperative that they be present on a treatment for adequate quality control and for a successful treatment to be accomplished. Additionally, one must monitor closely clean side and slurry side flow rates to be assured of proper foam quality downhole.

New developments in nitrogen flowmeters also have been a tremendous development. One service company uses turbine meters with temperature and pressure compensation. Other service companies use mass flow meters with full opening Coriolis type devices for giving very accurate read-out of the gaseous fluids going downhole. Of course, CO_2 can be monitored also with Coriolis devices or turbine meters as the CO_2 quite typically is pumped in a liquid phase. These improvements in equipment have allowed foam fracturing to be utilized where high sand concentrations are required due to imbedment and/or crushing. Before these developments, very low sand concentrations and low volumes limited the applicability of foam fracturing greatly.

IMPROVEMENT IN FOAM FRAC DESIGN

Improvements in foam frac design have come about for many and sundry reasons. One of the reasons is the ability to use on-site computers for calculation of downhole foam quality when variations in pump rate occur on the surface. Additionally, by being able to monitor exactly what is being pumped, one can give accurate estimates of downhole viscosities under temperature and pressure conditions.

There are basically two philosophies followed by service companies and some consultants in designing foam fracs. One of these philosophies relates to the use of a constant downhole pump rate. The other philosophy relates to a constant nitrogen or CO_2 rate and a constant clean fluid rate. I personally prefer the latter philosophy, as it greatly simplifies the treatment.

If one will look at Figures I and II, you can see comparative designs with a constant slurry rate, and an increasing slurry rate treatment. If one uses a constant slurry rate or constant downhole pump rate, one has to constantly vary the clean fluid and nitrogen or CO_2 rate during the treatment. With treatments of short duration, it is almost impossible to do so accurately. With an increasing slurry rate treatment, one simply has to maintain a constant rate on his nitrogen and a constant rate on the clean fluid. One simply increases his slurry rate to compensate for the volume of sand added to the clean fluid. One will obviously end up at a higher pump rate during the latter stages of the treatment than one had during the early stages.

These treatments can now be conducted either by constant rate or increasing slurry rate with the use of computers and more sophisticated control equipment. If at all possible, if one does not get into friction pressure problems by the increasing rate and adequate fracture growth barriers exist, I feel quite strongly that the constant clean side and constant gas rate is a much more viable and an easier conducted foam fracturing treatment.

Another reason that foam fracturing design has shown a great deal of improvement is we now have accurate and adequate data with which to design treatments, which we did not have prior to the development of data using loop rheometers under downhole pressure and temperature conditions. Prior to the development of these devices, we simply had to extrapolate ambient pressure and temperature conditions to downhole conditions. This put a great deal of unnecessary guessing into design work.

Another area which I feel has improved foam fracturing design has been the realization that foam fluids, although having good fluid loss control are not adequate for control of leak-off in fractured formations or high permeability, and one must incorporate standard oilfield type fluid-loss additives if one is going to place high concentrations of proppant downhole. We feel quite strongly that in the past too much emphasis has been placed on the use of foam singularly as a total fluid loss control medium. I think the basic criteria relates to the fact that C_v is not the controlling function in fluid loss. Although the viscosity and the bubble character of foam is a good fluid loss medium, one must have the bridging and wall-building properties if one is going to have an adequate and efficient fracturing fluid, particularly in some of the fractured formations in the Rocky Mountains.

FUTURE IMPROVEMENTS

Future improvements in foam fracturing will relate to future developments in new-generation CO_2, nitrogen or perhaps other gaseous foam fracturing fluids. We are only beginning to study and evaluate these types of fluids. I see the future being extremely bright for CO_2 fluids. With the advent of EOR use of CO_2, the price of CO_2 will greatly decrease and we in research will be able to find new and unique properties of foamed and viscosified CO_2 fluids.

I also see a great deal of development in microprocessor-controlled blending and pumping equipment, allowing us to tailor downhole viscosity by varying foam quality on the surface. I see us through modifications of concentrator and valving equipment achieving higher sand concentrations where required. I see us utilizing controlled foam degradation through encapsulation techniques or other systems. I see enhanced foam stability through new generation type stabilizers for use at higher temperatures and for longer periods of time. And I see foam fracturing becoming much more useful with real time downhole bottom hole treating pressure measurement devices.

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FOAM VOL. GALS.	LIQ. VOL. GALS.	PROPPANT			SLURRY VOL.		RATE				TIME MIN:SEC
		FOAM PPG.	LIQ. PPG.	TOT. LBS.	FOAM GALS.	BLEND. GALS.	N_2 SCFM	LIQ. BPM	SAND* BPM	TOT. BPM	
35,000	10,500	0	0	0	35,000	10,500	13,820	4.5	0	15	55:33
25,000	7,500	1	3.3	25,000	26,130	8,630	13,225	4.3	.6	15	41:28
30,000	9,000	2	6.7	60,000	37,712	11,712	12,700	4.1	1.25	15	51:55
12,500	3,750	3	10	37,500	14,195	5,445	12,200	3.96	1.8	15	22:32
10,000	3,000	4	13.3	40,000	11,808	4,808	11,700	3.81	2.3	15	13:44
7,500	2,250	5	16.7	37,500	9,195	3,945	11,223	3.67	2.8	15	14:35
7,500	2,250	6	20	45,000	9,534	4,284	10,860	3.55	3.2	15	15:08
1,800	540	0	0	0	1,800	540	13,820	4.5	0	15	2:51

FOAM QUALITY: 0.70
TOTAL N_2 REQUIRED:

*RATE OF SAND (BPM) = LB/GAL. X BPM X .0452

Figure 1 - Foam frac pump schedule (constant slurry rate)

FOAM VOL. GALS.	LIQ. VOL. GALS.	PROPPANT			SLURRY VOL.		RATE				TIME MIN:SEC
		FOAM PPG.	LIQ. PPG.	TOT. LBS.	FOAM GALS.	BLEND GALS.	N2 SCFM	LIQ. BPM	SAND* BPM	TOT. BPM	
35,000	10,500	0.0	0.0	0	35,000	10,500	13,820	4.5	0.0	15.0	55:33
25,000	7,500	1.0	3.3	25,000	26,130	8,630	13,820	4.5	0.7	15.7	39:37
30,000	9,000	2.0	6.7	60,000	32,712	11,712	13,820	4.5	1.4	16.4	47:29
12,500	3,750	3.0	10.0	37,500	14,195	5,445	13,820	4.5	2.0	17.0	19:53
10,000	3,000	4.0	13.3	40,000	11,808	4,808	13,820	4.5	2.7	17.7	15:53
7,500	2,250	5.0	16.7	37,500	9,195	3,945	13,820	4.5	3.4	18.4	11:54
1,800	540	0.0	0.0	0	1,800	540	13,820	4.5	0.0	15.0	2:51
121,800	36,540			200,000	130,840	45,570					193:10

FOAM QUALITY: 0.70

TOTAL N_2 REQUIRED: 2,669,563 scf (calculated as "scf/min" x "total time")
2,671,480 scf (calculated as "total bbls N_2" x "scf/bbl space")

*RATE OF SAND (BPM) = LB/GAL. X BPM X .0452

Figure 2 - Foam frac pump schedule (increasing slurry rate)