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(54) Homogenizer/high shear mixing process for on-the-fly hydration of fracturing fluids and on-the-fly mixing of cement slurries

(57) A method and apparatus for rapidly hydrating a hydratable gel comprising the steps of introducing a predetermined amount of the gel into a stream of hy-

drating fluid, pumping the stream into a high shear rate mixer having a shear rate of at least 25,000 s⁻¹, and directing the hydrated fluid away from the mixer means for treatment of a subterranean formation.

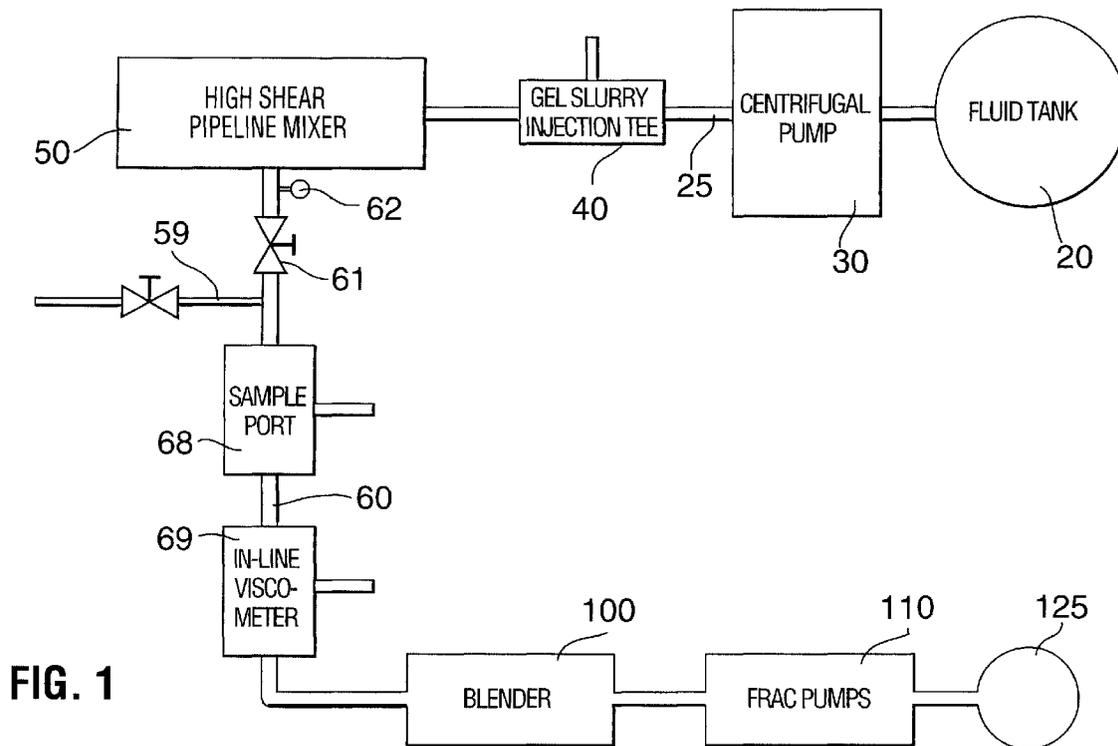


FIG. 1

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Description

FIELD OF THE INVENTION

The present invention relates to the mixing of chemical agents and base fluids to form well treatment fluids and more particularly to a method and apparatus for continuously mixing such fluids including, but not limited to, fracturing and acidizing gels, polyemulsions, foams and cement slurries, on a real time on-the-fly basis.

BACKGROUND OF THE INVENTION

High viscosity aqueous fluids, such as fracturing gels, acidizing gels, cement slurries and high density completion fluids, are commonly used in the oil industry for the treatment of subterranean wells. The gels for example are normally made using dry polymer additives or agents which are mixed with water or other aqueous fluids at the job site. Mixing procedures used in the past have resulted in a number of problems. For example, early "batch" mixing procedures involved mixing bags of powdered polymer in tanks at the job site. This resulted in uneven and inaccurate mixing, lumping of the powder into insoluble balls or globules which obstructed the flow of the gel, chemical dust hazards, and required the transport and use of huge tanks adding greatly to costs.

A known method of solving the lumping, gel ball problem is to delay hydration long enough for the individual polymer particles to disperse and become surrounded by water so that no dry particles are trapped inside a gelled coating to form a gel ball. This delay is achieved by coating the polymer with material such as borate salts, glyoxal, non-lumping HEC, sulfosuccinate, metallic soaps, surfactants, or other materials of opposite surface charge to the polymer.

Another known way to improve the efficiency of polymer addition to water and derive the maximum yield from the polymer is to prepare a stabilized polymer slurry, also referred to as a liquid gel concentrate. The liquid gel concentrate is premixed prior to transport and then later added to the water at the well site. In Briscoe U.S. Patent No. 4,336,145, a liquid gel concentrate is disclosed comprising water, the polymer or polymers, and an inhibitor having a property of reversibly reacting with the hydratable polymer in a manner wherein the rate of hydration of the polymer is retarded. Upon a change in the pH condition of the concentrate such as by dilution and/or the addition of a buffering agent (pH changing chemical) to the concentrate, upon increasing the temperature of the concentrate, or upon a change to other selected conditions of the concentrate, the inhibition reaction is reversed, and the polymer or polymers hydrate to yield the desired viscosified fluid. This reversal of the inhibition of the hydration of the gelling agent in the concentrate may be carried out directly in the concentrate or later when the concentrate is combined with additional water. The aqueous-based liquid gel concentrate of

Briscoe has worked well at eliminating gel balls and is still in routine use in the industry. However, aqueous concentrates can suspend only a limited quantity of polymer due to the physical swelling and viscosification that occurs in a water-based medium. Typically, about 0.8 pounds of polymer can be suspended per gallon of the concentrate.

By using a hydrocarbon carrier fluid for the slurry, rather than water, higher quantities of solids can be suspended. For example, up to about five pounds of polymer can be suspended in a gallon of diesel fuel carrier. Such a liquid gel concentrate is disclosed in Harms and Norman U.S. Patent No. 4,722,646. The hydrocarbon-based liquid gel concentrate is later mixed with water at the well site in a manner similar to that for aqueous-based liquid gel concentrates to yield a hydrated viscosified fluid, but hydrocarbon-based concentrates have the advantage of holding more polymer. Proppants can be added to the hydrated gel prior to injection of the fluid down the well bore. Elevated viscosities in the treatment fluid are required to maximize its proppant carrying capacity and to minimize leak off into the treated formation during the high pressure fracturing phase of the operation.

An additional problem with prior methods using liquid gel concentrates is the time required for the polymer material in the concentrate to fully hydrate, i.e., absorb water. Without complete or near complete hydration, fluid viscosities will be inadequate to maximize proppant concentrations and to minimize leak-off. As well, without complete hydration, the addition of buffer or pH adjusters for cross-linking will actually prevent full hydration. Without agitation of the gel/water mixture, full hydration requires at least 15 minutes of residence time, necessitating the use of huge and difficult-to-transport storage vessels capable of holding a "batch" of sufficient quantity to complete the job at hand. Batching is expensive because of wasted time and unused fluid resulting from treatment delays, termination of the treatment before pumping all fluids, and fluid residues remaining at the bottom of the storage tanks that cannot be pumped out. The disposal of unused gelled fluid has also become an expensive process due to stricter laws on the disposal of chemical wastes.

More recently, it has been proposed to effect real time or on-the-fly hydration of a gellable fluid for well treatment operations by increasing the residence time of the gellable flow in a flow-through operation through a series of vertical flow tanks. The hydratable gel material is mixed with water at the beginning of the series of tanks and, in theory, the mixture passes through the tanks in a "plug flow" which allows the gellable material sufficient time to hydrate in the aqueous mixture. Such a system is described in U.S. Patent No. 4,828,034 (Constien) for achieving substantially complete hydration of the hydratable gel. Systems like that of Constien however, as actually used in the field, still typically require a blender tub operating volume on the order of 200

barrels to obtain sufficient residence time for full hydration. A 200 barrel blender tub moreover makes an extremely large unit difficult to transport to the field.

Yet more recent approaches are described in U.S. Patents 5,046,856 and 5,195,824. McIntire in '856 proposes hydration of a hydratable gel by achieving near absolute theoretical plug flow through a plurality of tanks in series fluid communication. The plug flow is accompanied by high shear of the hydratable gel along its flow path through the series of tanks using a radial flow impeller positioned within at least one of the tanks. In practice, some or even all of the tanks are provided with mixing impellers.

Stromberg in '824 proposes to reduce the size of the apparatus required by the McIntire process by subjecting the hydratable/gel water mixture to "high shear rotary mixing". High shear rotary mixing means are disposed in a blender tub divided into first and second zones with first and second mixers disposed in the first and second zones. The plurality of rotary mixers provides a total circulation flow rate at least an order of magnitude greater than the mixture flow rate through the tub so that an average fluid particle of the mixture passes through the mixers a total of at least 10 times while passing through the blender tub.

A slightly modified approach is taught by Wilson in U.S. Patent No. 5,052,486. Wilson initially applies a relatively low level of mixing energy to the hydratable gel/water mixture and then allows this mixture to flow through a first compartment of a residence tank for approximately 45 seconds, after which the mixture enters via plug flow into a second recycle compartment. The product in the recycle compartment is withdrawn in portions. The withdrawn portion is subjected to high shear and is then returned to the recycle compartment. This reoccurs until fully hydrated product is introduced into an exit compartment. Wilson claims a reduction of residence time to three minutes or less.

It will be appreciated that all of these on-the-fly methods still require residence times measured on the order of minutes. Residence times of this magnitude remain sufficiently large that storage containers or high volume manifolds are required. Stromberg requires a blender tub, McIntire teaches the use of a "plurality of tanks" arranged in series for plug flow, Wilson requires a multi-compartmented mixing chamber, and Constien requires plug flow holding tanks. Whatever the nature of these reservoirs, they are all prohibitively expensive, difficult to clean, and all require specialized and expensive mounting for transport to the field. For systems designed to deliver 4 m³ to 10 m³ of hydrated gel per minute, a residence volume of 12 to 30 m³ to 16 to 40 m³ is required. Even though these volumes represent a substantial reduction in holding capacity compared to "batch" systems, this remains a substantial volume of fluid for disposal if a job screens out. Moreover, for flow rates of 40 bbls/min. (approximately 6 m³/minute) and water at 80°F, even with a 70 barrel hydration volume

for approximately 2 minutes of residency, 218 horsepower of agitation is required. (Society of Petroleum Engineers Paper No. SPE 21857, "Modeling the Effects of Time, Temperature and Shear on the Hydration of Natural Guar Gels", Stromberg, J.J., et al.) Lower agitation reduces horsepower requirements, but residency times then go up and so must residence volumes.

There remains therefore a need for a true on-the-fly high shear mixing technology that achieves complete or near-complete hydration of a hydratable gel in the residence time available during normal fracturing operations in a system having no residence volumes in the form of large tanks or manifolds and which requires significantly fewer horsepower (E.g. 40 to 100 H.P.)

SUMMARY OF THE INVENTION

The applicant has discovered that in-line high shear rotor/stator mixers (sometimes also referred to as homogenizers or emulsifiers) can be used to hydrate gel slurries on the fly without the need for hydration units having or requiring large residence volumes.

In a preferred embodiment, a base fluid, normally water, is pumped directly into a high shear in-line mixer with gel concentrate added to the water supply line by means such as an injection Tee or venturi. Back pressure is maintained in the pipeline mixer either by means of an elongated hose from the mixer to the blender where proppants are added to the hydrated gel or by means of a restriction or gate valve downstream of the mixer or a combination of the two.

Accordingly, it is an object of the present invention to provide a method and apparatus for the mixing of chemical agents with base fluids that obviate and mitigate from the disadvantages of the prior art.

It is a further object of the present invention to provide a method and apparatus for the complete or near-complete on-the-fly hydration of a hydratable gel concentrate or cement slurry without the need for residence volumes in the form of tanks or reservoirs.

According to the present invention, then, there is provided a method of rapidly hydrating a liquid polymer concentrate to form a fluid for treating a subterranean formation, comprising the steps of combining an effective amount of said concentrate with a hydrating fluid to ultimately yield a treatment fluid having a viscosity within a predetermined range; supplying said concentrate and hydrating fluid into high shear rate mixing means for mixing thereof at a predetermined shear rate to rapidly hydrate said concentrate; and directing the flow of hydrated fluid away from said mixing means for eventual use treating said formation.

According to another aspect of the present invention, there is provided a method of hydrating a hydratable gel to form a hydrated fluid comprising the steps of dispersing a predetermined quantity of said hydratable gel into a stream of hydrating fluid to form a mixture; supplying said mixture to high shear rate mixing means

for shear mixing said mixture at a shear rate of at least 25,000 s⁻¹ to hydrate said hydratable gel; and directing the hydrated fluid away from the mixing means at a controlled rate to maintain back pressure in said mixing means.

According to yet another aspect of the present invention, there is also provided apparatus for hydrating a hydratable fluid to form a hydrated fluid comprising high shear rate mixing means for shear mixing therein of said hydratable fluid and a hydrating fluid to form said hydrated fluid, said mixing means having an inlet and an outlet; supply means for introducing a mixture of said hydratable fluid dispersed in a stream of said hydrating fluid to said inlet; means for regulating the flow of said mixture through said mixing means; and conduit means from said outlet for directing said hydrated fluid away from said mixing means.

According to yet another aspect of the present invention, there is also provided apparatus for hydrating a polymer gel slurry to form a hydrated and viscosified fracturing fluid for the treatment of a subterranean formation, comprising high shear rate mixing means for the mixing therein of said gel slurry and a fluid for hydrating said gel slurry to form said hydrated fluid, said mixing means having an inlet and an outlet; pump means for supplying a mixture of said gel slurry and said hydrating fluid to said inlet; and means in fluid communication with said outlet for directing said hydrated fluid away from said mixing means at a controlled rate for subsequent use treating said formation.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention will now be described in greater detail and will be better understood when read in conjunction with the appended drawing which is a schematical block diagram illustrating the present method and apparatus.

DETAILED DESCRIPTION

With reference to Figure 1, there is shown schematically the present system for the mixing of a stabilized polymer slurry or concentrate with a base fluid which normally will be water. Although the following description is limited by way of example to the formation of fracturing fluids for the treatment of underground stratigraphic formations from the mixture of a polymer concentrate and a base fluid, it will be understood that this same system can be used to mix together other fluids, including fluids having particulate suspensions therein. Examples include the mixing of polyemulsions, foams, cement slurries, drilling fluid and so forth. The use of the present system for the hydration of gelled fracturing fluids is particularly significant however in view of its ability to completely or nearly completely hydrate the fluids in a sufficiently short period of time to obviate the need for prior art residence volumes.

As can be seen from Figure 1, a base fluid, normally water, is pumped from a reservoir 20 by means of a centrifugal pump 30 through a supply line 25 into a high shear rotor/stator type pipeline mixer/homogenizer 50 at a pressure in the range of, but not restricted to, 250 to 300 psi. A polymer slurry is injected at a metered predetermined rate into supply line 25 via an injection Tee 40 for dispersal of the concentrate in the water stream. A venturi can be used for dispersal of the slurry into the water stream if preferred. Tee 40 can be located as shown in the drawing between pump 30 and mixer 50 but may also be located advantageously between reservoir 20 and pump 30 for better premixing of the water/slurry mixture. An exhaust line 60 from the mixer directs the viscosified hydrated fracturing fluid usually to a blender 100 for the introduction of proppants into the fluid prior to injection down the wellbore 125 for treatment of the subterranean formations using conventional high pressure frac pumps 110. Blenders and frac pumps are well known in the art and are not therefore described in detail herein.

The residence time of the hydrated gel/water mixture in pipeline mixer 50 can range from almost instantaneous flow through (i.e. near 0) to even a minute or more but will normally be in the range of 1 to 10 seconds and as a practical matter, the residence time is likely to be in the range of 1 to 2 seconds depending upon fluid throughput. In this context, mixer residence time refers to the amount of time a particular particle or sample of the gel/water mixture requires to travel from the mixer inlet, through the rotor/stator to the mixer outlet. Residence times can be controlled by regulating the mixer's outflow. In one prototypical system tested by the applicant, this is accomplished by subjecting the mixer's shear cavity to a back pressure in the range of 40 to 200 psi but preferably in the range of approximately 120 to 150 psi. Optimum back pressures, which could be inside or outside this range, may have to be determined on a job-by-job basis depending upon equipment used, ambient temperatures, fluid characteristics, desired throughputs, and possibly other factors as well. Pinching the flow of fluid from the mixer to create back pressure prevents or at least inhibits cavitation and maintains the system, at least upstream of the pinch point, full of fluid. It's felt this helps ensure that the water and gel are mixed immediately and that each particle of fluid is exposed to the high shear rates developed by the mixer. Back pressure can be developed by inserting a choke or gate valve 61 and back pressure meter 62 into exhaust line 60. In addition or in the alternative, the diameter and/or length of the exhaust line can be varied. For example, in tests conducted by the applicant, good results were obtained using a 4 inch diameter line 60 feet in length measured from the mixer to blender 100. Better results however seem to be available from longer lines on the order of 100 to 125 feet or at least a combination of line length and diameter that provides on the order of 20 seconds or more of residence time in the line for fluids

sheared at the rate of $56,000 \text{ s}^{-1}$ in mixer 50. In this context, line residence time refers to the amount of time a particle or sample of the gel/water mixture requires to travel from the mixer outlet to blender 100. This amount of residency appears to be appropriate not so much for hydration of the gel/water mixture, but rather to allow the mixture time to recover from the high rates of shear in mixer 50. It appears that if the sheared fluid is not allowed sufficient recovery time, the polymers will not fully crosslink when cross-linking agents are added usually at the proppant blending stage. A Fann™ 35 Sample Port 68 and an in-line viscometer 69 can be installed in line 60 for sampling and testing the fluid in line 60. The residency required for shear recovery can be obtained using a relatively small holding tank, but this would at least partially defeat one of the advantages of the present system which otherwise requires no such residence volumes of this sort.

It is not yet fully known whether back pressure directly affects gel viscosity and the speed of hydration (i.e. with back pressure, does the gel hydrate more quickly than without back pressure) or whether its effect is indirect resulting from the control or regulation of mixer residence times and avoidance of cavitation and fluid bypass of the mixer's rotor.

Mixer 50 is a commercially available product. In tests conducted by the applicant, good results have been obtained using either a Greerco Corp. 4" Tandem-Shear Pipeline Mixer or a Silverson Machines, Inc. 3" 600 LSH High Shear Mixer. Larger units are available from both companies. Two or more such mixers can be used connected together for example in series although to date this has not been found to result in significantly improved hydration times or viscosities.

In tests conducted by the applicant, a batch of polymer slurry was prepared using 590 liters of diesel fuel mixed with 5 kilograms of SA-1X mixed together and sheared for 10 to 15 minutes. One liter of methanol was then added and mixed in for 10 to 15 minutes. This was followed by the addition of 10 liters of S-11 mixed in for an additional 10 to 15 minutes. Guar gum (WG-15) was added in the amount of 550 kilograms mixed in for 25 minutes. The direction of rotation of the mixing auger was reversed for each bag of the powdered polymer. The resulting gel slurry achieves a viscosity of 14 to 16 cP at a shear rate of 511 s^{-1} when loaded to water in the ratio of 6 litres of slurry (equivalent to 3 kg of WG-15) per cubic meter of water. Based therefore on these tests, 100% hydration was considered to have been achieved at a viscosity of 14 cP @ 511 s^{-1} .

In testing, concentrate was introduced into supply line 25 at the rate of $1\frac{1}{2} \text{ l/min.}$ to 100 l/min. to be mixed with water introduced at the rate of $\frac{1}{4}$ to $10 \text{ m}^3/\text{min.}$ for a system throughput of $\frac{1}{4} \text{ m}^3/\text{min.}$ to $\approx 11 \text{ m}^3/\text{min.}$ At each of the lower and higher throughputs, full hydration to achieve initial viscosities at or about 14 cp at 511 s^{-1} were obtained in mixer residence times of near instantaneous to a few seconds.

In most of the tests performed by the applicant, 100% hydration (i.e. viscosities $\approx 14 \text{ cP}$) and fluid shear recovery were achieved with system residence times from the inlet of mixer 50 to blender 100 of approximately 20 seconds and thereabouts depending upon total throughput. This result was unexpected particularly having regard to Stromberg in '824 who indicates at column 5, line 5 that:

We have discovered, as further explained below, that for a specific energy input into a gelled fracturing fluid, the energy is much more efficiently used to increase hydration of the fluid if the energy is input at lower levels over a longer period of time rather than an intense burst over a very short period of time. Thus, large agitation tanks have been determined to be much more energy efficient viscosity producers than are small volume devices such as centrifugal pumps, static mixers and the like which are inefficient viscosity producers.

In contrast, the applicant has found the opposite to be true. More specifically, the applicant has found that the use of a low volume pipeline (inline) high shear mixer that applies an intense burst of shear over a short period of time measured in seconds provides the needed on-the-fly volumes of completely or near-completely hydrated gel for commercial fracturing operations in such a short period of time that residence tanks, blending tubs and the like are no longer required. No complete explanation of this phenomenon is as yet available but it's possible that the high shear pipeline mixers as used by the applicant which expose the particles of polymer in the concentrate gel to a specific shear rate of $25,000 \text{ s}^{-1}$ and preferably $50,000$ to $150,000 \text{ s}^{-1}$ and up to $1,000,000 \text{ s}^{-1}$, may actually be fragmenting the particles into even smaller pieces, exposing more surface area for faster and more complete hydration to provide higher yields and viscosities. Specific shear rates in excess of $400,000 \text{ s}^{-1}$ may necessitate the use of longer exhaust lines 60 to allow a greater time for shear recovery. For example, fluids subjected to a specific shear rate of $400,000 \text{ s}^{-1}$ appear to need as much as 40 to 50 seconds to recover for cross-linking purposes.

Shear rates can be varied in 3 ways or a combination thereof: change the rotor diameter; change the rotor speed; and adjust the gap between the rotor and stator. During operations, the shear rate will normally be adjusted by changing the rotor speed. For smaller (3"/4") mixer sizes, speeds of 3600 to 4800 rpm are typical. If using a 6" Greerco, for example, speeds of around 2500 rpm seem adequate. In tests performed by the applicant, a gap between the rotor and stator of 0.001" has produced good results.

In typical fracture operations, it is common to use a base or polymer gel concentration of 3 to 7 kg of polymer per cubic metre of water. At final system throughputs of 2 m^3 or less, the final concentration and rate required at the blender can be achieved by adding the slurry concentrate to the water and treating this mixture through high shear mixer 50. If higher throughputs are required,

there are several options. One is to use a larger mixer capable of treating the mixture at the desired shear and flowthrough rates. A second option is to add a higher concentration of slurry (polymer) than the finally desired concentration through the mixer and adding makeup water through a supply line 59 that taps into line 60 downstream of mixer 50 and prior to the sample port. This makeup water can be metered to dilute the polymer concentrations back to the desired final level. This second option may be the more practical as it does not require that a second higher volume mixer be on site.

The above-described embodiments of the present invention are meant to be illustrative of preferred embodiments of the present invention and are not intended to limit the scope of the present invention. Various modifications, which would be readily apparent to one skilled in the art, are intended to be within the scope of the present invention. The only limitations to the scope of the present invention are set out in the following appended claims.

Claims

1. A method of rapidly hydrating a hydratable fluid to form a hydrated fluid comprising the steps of:

dispersing a predetermined quantity of said hydratable fluid into a stream of hydrating fluid to form a mixture;
supplying said mixture to high shear rate mixing means for shear mixing of said mixture at a shear rate sufficient to rapidly hydrate said hydratable fluid; and
directing the hydrated fluid away from the mixing means at a controlled rate to maintain back pressure in said mixing means.

2. The method of claim 1 wherein said shear rate is in the range from about $25,000 \text{ s}^{-1}$ to $1,000,000 \text{ s}^{-1}$ and preferably in the range from about $50,000 \text{ s}^{-1}$ to $150,000 \text{ s}^{-1}$.
3. The method of claims 1 or 2 wherein said mixture is subjected to said shear for a sufficient time to fully hydrate said hydratable fluid, said time being in the range from about near instantaneous to 10 seconds and preferably in the range from about 0.1 sec. to 3 sec.
4. The method of any preceding claim wherein said back pressure is maintained in the range from about 40 psi to 200 psi and preferably in the range from about 120 psi to 150 psi.
5. The method of any preceding claim wherein said hydrated fluid, immediately following the mixing thereof, is contained for a predetermined length of

time determined at least partially in relation to the rate at which said hydratable fluid and hydrating fluid are sheared in said mixing means, said predetermined length of time being in the range of about 20 seconds for fluid sheared at the rate of $56,000 \text{ s}^{-1}$.

6. The method of claim 5 wherein said hydrated fluid is contained in at least one conduit having an end in fluid communication with said mixing means, said at least one conduit having a combination of length and diameter selected to contain said hydrated fluid for said predetermined amount of time.
7. The method of any preceding claim wherein additional hydrating fluid is added to said hydrated fluid downstream of said mixing means for maintaining the concentration of said hydratable fluid at a predetermined level.
8. The method according to any preceding claim wherein said hydratable fluid is a liquid polymer concentrate added to said hydrating fluid at a rate of from about $1\frac{1}{2} \text{ l/min.}$ to 100 l/min. , said hydrating fluid is water supplied to said mixing means at a rate of from about $\frac{1}{4} \text{ m}^3/\text{min.}$ to $10 \text{ m}^3/\text{min.}$, and said hydrated fluid is a viscosified fluid for treating a subterranean formation.
9. Apparatus for rapidly hydrating a hydratable fluid to form a hydrated fluid comprising:
- high shear rate mixing means for the mixing therein of said hydratable fluid and a hydrating fluid to form said hydrated fluid, said mixing means having an inlet and an outlet;
pump means for supplying a mixture of said hydratable fluid and said hydrating fluid to said inlet; and
means in fluid communication with said outlet for directing said hydrated fluid away from said mixing means at a controlled rate.
10. The apparatus of claim 9 wherein said mixing means comprise a low volume in-line high shear rotor/stator mixer for shear mixing of said hydratable fluid and said hydrating fluid at a rate of at least $25,000 \text{ s}^{-1}$ and preferably at least $50,000 \text{ s}^{-1}$ to $150,000 \text{ s}^{-1}$.
11. The apparatus of claims 9 or 10 wherein said means in fluid communication with said outlet creates back pressure at said outlet of said mixing means, said back pressure being in the range of from about 40 psi to 200 psi and preferably in the range from about 120 psi to 150 psi.
12. The apparatus of claims 10 or 11 wherein said rate of shear mixing in said mixing means is variable by

means of changing one or more of the diameter of said mixer's rotor, the rotational speed of said rotor and the annular gap between said rotor and said mixer's stator, said gap between said rotor and stator being adjustable in the range from about 0.0001" to .5" and preferably is maintained at or about 0.001".

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13. The apparatus of any preceding claim wherein said means in fluid communication with said outlet comprise one or both of conduit means and valve means in conduit means. 10
14. The apparatus of claim 13 wherein said conduit means are adapted to contain said hydrated fluid therein for a selected interval of time determined at least partially in relation to the rate at which said hydrating fluid and said hydratable fluid are shear mixed, said selected interval of time being approximately 20 seconds for hydrated fluid mixed at a shear rate at or about $56,000 \text{ s}^{-1}$. 15
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15. The apparatus of claims 13 or 14 wherein said conduit means are approximately 4" in diameter and in the range of from about 100 to 125' in length, 25
16. The apparatus of any preceding claim wherein said hydrating fluid is water and said hydratable fluid is a polymer gel slurry added to said water in an effective amount to ultimately yield a hydrated fluid having a viscosity within a predetermined range for use treating a subterranean formation. 30

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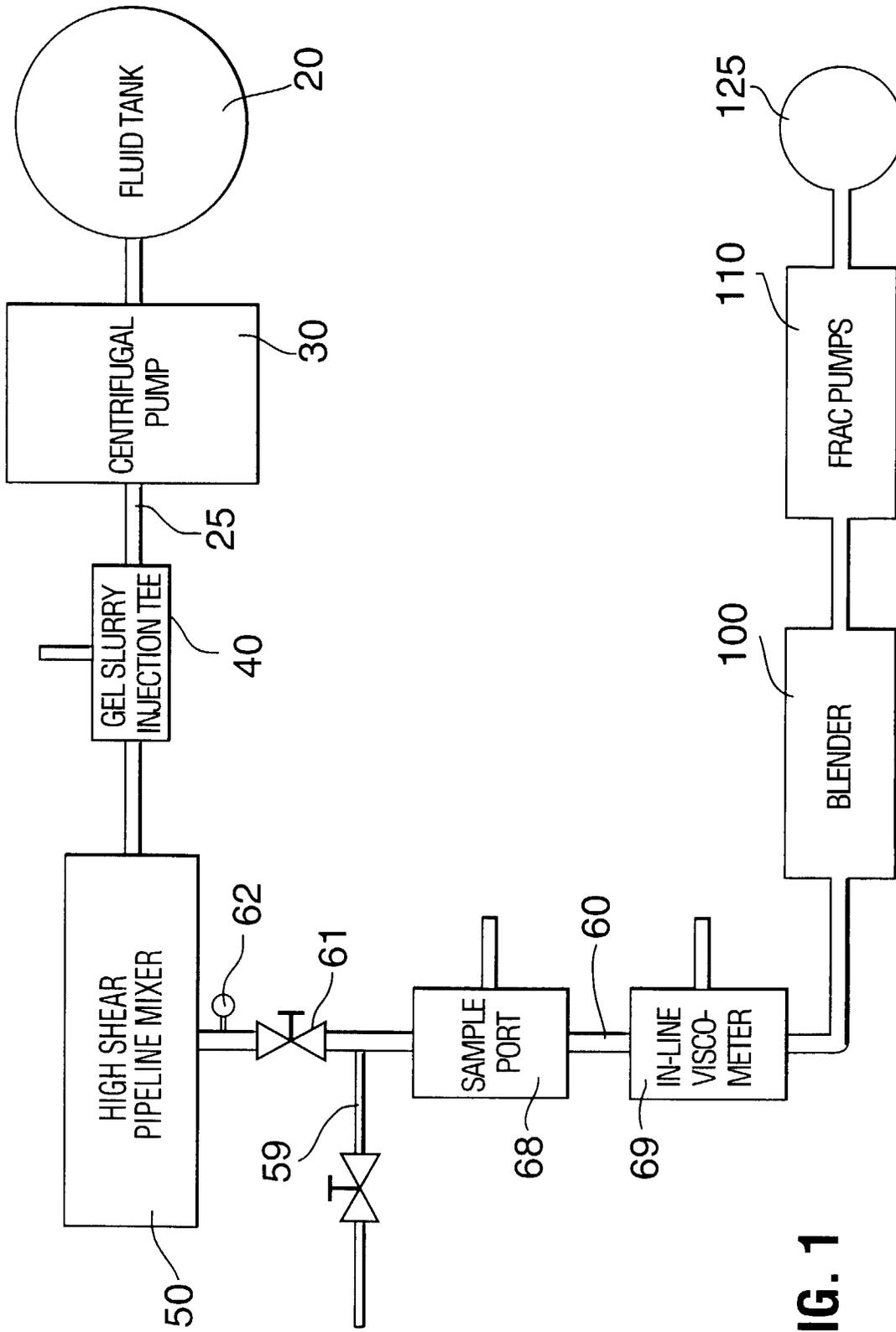


FIG. 1



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 9589

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	GB 1 500 901 A (CEMENTATION RES LTD) 15 February 1978 * the whole document *	1,2,7,9,10,12	B01F3/12 B01F13/10 B28C5/08 C08J3/075 B02C7/175 E21B43/26 B01F7/16
X	US 4 828 034 A (CONSTIEN VERNON G ET AL) 9 May 1989 * column 2, line 53 - column 3, line 51; figure 3 *	1,9	
X	US 5 046 856 A (MCINTIRE WILLIAM R) 10 September 1991 * column 4, line 14 - column 6, line 38; figures 1,2 *	1,9	
X	US 5 052 486 A (WILSON JAMES C) 1 October 1991 * column 2, line 53 - column 3, line 12 * * column 3, line 40-62 * * column 4, line 14-26 * * column 5, line 49-60 * * column 7, line 5-10; figure 1 *	1,9	
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A	EP 0 239 148 A (SCHLUMBERGER CIE DOWELL) 30 September 1987 * abstract *	1,9	
A	EP 0 186 552 A (ELF FRANCE) 2 July 1986 * abstract *	1,9	
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 24 March 1998	Examiner Hoffmann, A
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons</p> <p>& : member of the same patent family, corresponding document</p>			

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