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3,472,769

LIQUID SYSTEMS HAVING IMPROVED FRICTION CHARACTERISTICS

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5 Claims

ABSTRACT OF THE DISCLOSURE

The use of various polymeric thickening agents in conjunction with friction reducers selected from acrylic acid-acrylamide copolymers and dextran for reducing hydraulic friction characteristics of aqueous liquids such as employed as drilling fluids and fracturing fluids.

This application is a continuation-in-part of copending application Ser. No. 412,324, entitled "Liquid Systems Having Improved Friction Characteristics," filed Nov. 19, 1964, now abandoned, James L. Lummus and Billy V. Randall, inventors.

The present invention relates to liquids having improved hydraulic friction characteristics suitable for use in the drilling of wells, for fracturing or otherwise treating formations penetrated by such wells, and for other applications where liquids must be pumped at high rates. More particularly, it contemplates such liquids, including improved well treating and low solids drilling fluids, having minimum power requirements for circulation through the well system.

One of the main factors in the cost of drilling a well in which a hydraulic system is used for removing bit cuttings from the hole, is the power required to circulate the fluid through the drill pipe and out of the hole. Even with relatively light-weight fluids, such as clear-water and low solids drilling fluids, the power costs are a substantial portion of the over-all drilling expense.

In using drilling fluids of the above type, one of their functions is to transmit energy, or to do work at a remote point or points through the use of pumps and connecting conduits. The efficiency with which such work is performed by these fluids, however, is hampered by the loss of energy in the system and is commonly referred to as hydraulic friction loss. Such losses may vary from a fraction of a horsepower to hundreds of horsepower. For example, mud pumps of from 500 to 1500 horsepower are used to circulate fluids in deep drilling for oil. In many cases, more than 90 percent of this horsepower is dissipated as the result of hydraulic friction losses inside the drill pipe with only a minor amount performing useful work at the bit and carrying cuttings to the surface.

In procedures for treating oil-bearing formations such as—for example—in acidizing and hydraulic fracturing, relatively high pressures are employed. In some instances the pressures required to accomplish the desired result are less than the safe working pressure of the casing and, accordingly, treatment of the formation through the casing via perforations, etc., can be effected without compli-

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cations. On numerous occasions, however, the pressure required far exceeds the operating pressure of the casing and, therefore, it has been the practice to inject the treating fluid through tubing with the packer set in the casing while still permitting adequate pressures to be applied. Although this procedure avoids possible damage to the casing while still permitting adequate pressures to be applied to the formation face being treated, the power requirements for accomplishing the desired results are often excessive. Stated in another way, after initial formation break-down in the case of fracturing operations, for example, the bottom hole injection pressure decreases sharply so that the working pressure of the casing is then adequate for subsequent injection of fluids. However, the packer which was necessary in the first phase of the fracturing operation, now prevents the simultaneous injection of fluids down the tubing and annulus. This condition results in a limited injection rate and a large percentage of available horsepower is required to overcome the friction loss of the fracturing fluid traveling through the relatively small diameter tubing. The matter of additional horsepower to deliver a fracturing fluid at the proper pressure to a formation where the operation is to be performed can become not only a substantial item of expense but points up the inefficiency of present methods of carrying out jobs of this sort. For example, in a well having casing perforations at 3,185 feet, it was found that 58 percent of the total horsepower needed for a fracturing job at that level was expended in friction loss to pump the fluid through two-inch tubing in accordance with current practice.

In the past it has been recognized that by the addition of certain natural gums or synthetic polymers to a liquid, the hydraulic friction characteristics of such a liquid were very materially improved. Many of these "friction reducers," however, are relatively expensive and, hence, their use for this purpose many times is limited because of economic considerations.

Accordingly, it is an object of our invention to provide an improved drilling or well treating fluid which can be delivered to its intended area of use in a well with a minimum loss of horsepower. It is another object of our invention to provide such a fluid by the combination of two or more substances, one of which is a known friction reducer while the other, or others, by themselves do not have this property. It is still another object of our invention to provide an aqueous liquid suitable for use in any circumstance requiring transport or delivery of said liquid through a conduit.

Systems which exhibit reduced hydraulic friction or drag reduction characteristics are generally referred to as "viscoelastic." As the term implies, such liquids possess both elastic and viscous properties. These liquids have a characteristic viscosity function, which function may or may not be dependent on the rate of shear or stress. They also exhibit elasticity of shape and a retarded elastic recovery in deformation. A viscoelastic liquid may be a solution comprising one or more solvents containing one or more solutes. The phenomenon of viscoelasticity exhibited by certain liquid systems is discussed in "Corelation of Drag Reduction With Modified Deborah Number for Dilute Polymer Solutions," by J. M. Rodriguez et al.,

SPE Paper No. 1678, prepared for the Society of Petroleum Engineers Symposium on Mechanics of Rheologically Complex Fluids, held in Houston, Tex., Dec. 15-16, 1966.

We have now found that the friction characteristics of aqueous liquids not only can be reduced more effectively than in the past for a given amount of friction reducing agent added, but that this unexpected effect is brought about by the combination of said agent with a substance which by itself has little or no effect on the friction characteristics of such liquids. We have further observed that friction reducers which exhibit their best friction reducing characteristics at low concentrations are enhanced by the use of thickening agents in accordance with our invention.

In preparing these aqueous systems having reduced hydraulic friction properties in accordance with our invention, we provide, for example, an aqueous solution of a known friction reducer such as an acrylate-acrylamide copolymer, prepared by the partial hydrolysis of a polyacrylamide, and a thickening agent. The resulting solution, which may be in concentrated form, is then added to the liquid to be used in amounts such that the concentration of thickening and friction reducing agents each ranges from about 1 to not more than about 12 lbs./1000 gals. of said liquid.

The essence of our invention resides in the surprising discovery that there is obtained an unexplained additional reduction in hydraulic friction of an aqueous liquid when we add a combination of known friction reducer and a thickening agent to said liquid. For example, 0.1 lb./bbl. of the aforesaid copolymer plus 0.2 lb./bbl. of partially (approximately one-half) hydrolyzed sodium polyacrylamide—which exhibits no tendency by itself to reduce hydraulic friction—not only gives a greater reduction in hydraulic friction than 0.1 lb./bbl. of said copolymer alone, but a concentration of said copolymer, alone, corresponding to 0.25 lb./bbl. must be used to obtain a similar degree of friction reduction; a truly synergistic effect. We have observed that for a given concentration, with the combination of friction reducer and thickening agent employed in our invention, the percentage improvement in friction reduction in large diameter, typically oil field tubular goods ranging in diameters from about 2 to 8 inches, is greater than that obtained with smaller diameter pipe.

It should be pointed out that while certain thickening agents and friction reducing materials generically belong to the class of partially hydrolyzed polyacrylamides, the factor determining whether they function as thickeners or as friction reducers depends on their relaxation time. The term "relaxation time" may be defined as a measure of the relative amounts of viscous and elastic response. Mathematically, relaxation time is expressed as follows:

$$\theta_{f1} = \frac{1}{2\Gamma} \left(\frac{\tau_{11} - \tau_{22}}{\tau_{12}} \right)$$

where

θ_{f1} is relaxation time,

Γ is shear rate (sec.⁻¹),

$\tau_{11} - \tau_{22}$ is first normal stress difference (lb. F*/ft.²), and

τ_{12} is shearing stress (lb. F*/ft.²).

*Force.

For further discussion of this phenomenon, reference is made to "Flow of Viscoelastic Fluids Through Porous Media," SPE Paper No. 1687, prepared for the Society of Petroleum Engineers Symposium on Mechanics of Rheologically Complex Fluids, held in Houston, Tex., Dec. 15-16, 1966.

Both of the above mentioned types of partially hydrolyzed polyacrylamides can be prepared in accordance with the procedure described in Morgan, U.S. Patent 2,775,557. The materials used as thickeners in accordance with our invention are prepared by reacting acrylic acid with acrylamide in the presence of an oxidizing catalyst to produce a highly branched cross-linked polymer that has the property of thickening water. The partially hydrolyzed poly-

acrylamides that function as friction reducers are considered to be linear in structure and have the ability to coil somewhat like a spring. These are prepared by the partial hydrolysis of a previously prepared polyacrylamide. Chemically, both types of polymers are thought to be essentially the same but differ in their physical structure which is responsible for their distinct difference in physical properties—such as for example—their relaxation times.

In our work we have found that partially hydrolyzed acrylamide polymers having relaxation times of from about 0.1 to about 0.5 millisecond—and preferably less than about 0.3 millisecond—act as thickeners. Those having relaxation times ranging from about 0.75 to about 1.4 milliseconds—and preferably more than 1 millisecond—function as friction reducers. This is illustrated in Table I below, listing different acrylate-acrylamide copolymers (designated by proprietary names) which have been subjected to varying degrees of hydrolysis.

TABLE I

Material	Conc. in water, percent	Shear rate, sec. ⁻¹	Relaxation time, milliseconds
25 Water Thickeners:			
Cypan ¹	2	8,000	.22
Carbopol 934 ²	1.5	13,000	.13
Calcium salt of polymer prepared from equal amounts of vinyl acetate and maleic anhydride.....	1	10,000	.43
30 (Viscoelastic Materials) Friction Reducers:			
Cyanamer P250.....	1.4	7,800	1.15
Separan AP-30.....	1	13,000	1.08
Nalco RV-13.....	.14	11,000	1.14
Nalco RV-9.....	.33	9,000	.75
Nalco RV-50.....	.14	6,000	1.00
J-100.....	.14	10,000	1.14
FR-8.....	.25	8,500	1.09
	.25	13,000	1.17
	.25	8,000	1.18
	.14	18,000	1.01
	.14	8,000	1.30

¹ Partially (approximately one-half) hydrolyzed.

² Completely hydrolyzed polyacrylamide.

Another friction reducer we have found suitable for use in the process of our invention are dextran type polysaccharides, prepared by fermentation of glucose or other carbohydrates. The most useful of these fermentation derived polysaccharides typically have molecular weights of the order of 20 to 25 million.

As examples of suitable thickening agents for use in accordance with our invention there may be mentioned guar, completely hydrolyzed polyacrylamide, the copolymer of methyl vinyl ether and maleic anhydride, and methyl cellulose which in aqueous solutions in concentrations of about 2 percent exhibits a viscosity of about 4000 cps. at 68° F. Still another material suitable for use as a thickening agent is the copolymer of vinyl acetate and maleic anhydride which may be used in un-neutralized form or as a salt, preferably the calcium salt as described in detail in Baer, U.S. Patent 2,476,474. It is to be understood that further reference to this copolymer in the present description and claims is intended to include the salt as well as the un-neutralized polymer.

In determining the friction characteristics of fresh water solutions containing one of the above-mentioned friction reducers and a thickening agent, said solution is pumped from a 20 gal. stainless steel tank through a hard brass tube 57.25 feet long and having an internal diameter of 0.432 inch. In general, the tube length should be from about 1500 diameters or greater in order to minimize the end effect corrections due to the so-called "velocity heads" of the fluid being tested. The brass tube is equipped with a 0-5 g.p.m. and 0-25 g.p.m. range precision magnetic flow recorder and a set of laboratory test gages together with a water-to-air-to-mercury monometer for the determination of pressures. A variable speed Moyno pump is employed having a maximum displacement of 25 gal./min. and a maximum output pressure of 450 p.s.i. The test

liquid is pumped through the tube at velocities of from about 5 to 55 feet per second. Similar tests were also made using tubing of .375 and .25 inch diameter. The results obtained are shown in the table below.

TABLE II

Thickening Agent	Concentration, lb./bbl.	Friction Reducing Agent	Concentration, lb./bbl.	Reduction in Friction, percent		
				Tube diameter, inch		
				.452	.375	.25
Sodium polyacrylamide ¹	0.1	None		0	0	0
Do.	0.3	do		0	0	0
Do.	0.15	Acrylic acid-acrylamide copolymer	0.15	70	71	68
Do.	0.1	do	0.1	66	66	64
Do.	0.2	do	0.2	60	58	60
Do.	0.05	do	0.05	46	44	40
None			0.2	48	51	53
Do.		Dextran	0.2	35	33	24
Sodium polyacrylamide ¹	0.2	do	0.2	52	51	53
Guar	0.1	Acrylic acid-acrylamide copolymer	0.1	69	65	62
Do.	0.1	None		18	16	15
Do.	0.05	Acrylic acid-acrylamide copolymer	0.1	66	62	60
Methyl cellulose ²	0.3	None		0		
Do.	0.1	Acrylic acid-acrylamide copolymer	0.1	65		
Do.	0.2	do	0.1	67		
Methyl vinyl ethermaleic anhydride copolymer	0.1	Acrylic acid-acrylamide copolymer	0.1	66	61	54
Do.	0.3	None		0		
Sodium polyacrylate ³	0.3	None		0		
Do.	0.1	Acrylic acid-acrylamide copolymer	0.1	67		

¹ Partially (approximately one-half) hydrolyzed.

² A 2% aqueous solution having a viscosity of 4,000 cps. at 68° F.

³ Completely hydrolyzed polyacrylamide.

From the above data it will be seen that in all instances the hydraulic friction of the test liquid was less—under otherwise identical conditions—when the combination of thickening agent plus friction reducer was used than when only the friction reducer or thickening agent was employed. Also, it will be observed that the reduction in friction generally decreases with tubing of decreasing diameter.

The improvement in hydraulic friction characteristics of a liquid, as taught by our invention, is applicable to salt or sea water systems as well as fresh water. However, the concentrations of the thickening and friction reducing agents required to produce the desired effect in such systems generally are higher than those used for fresh water.

In addition to the effect that we have discovered, a synergistic effect in reduction of hydraulic friction through the use of the combinations taught herein, our invention affords outstanding economies both in material and operating costs. Thus, the friction reducing materials mentioned herein cost about \$3.00 per pound while the thickening agents cost approximately 50¢ to 70¢ per pound. In the above table it is indicated that to obtain a 60 to 70 percent reduction in friction, 0.1 lb./bbl. and 0.25 lb./bbl., respectively, of copolymer must be used, with a corresponding cost of 40¢ and 75¢ per barrel. By the use of partially (approximately one-half) hydrolyzed sodium polyacrylamide (70¢ per pound) in concentrations of 0.2 lb./bbl., together with 0.1 lb./bbl. of copolymer, a friction reduction of 70 percent is obtained at a cost of 44¢ per barrel. In 1,000 to 2,000 barrel mud systems and fracturing jobs requiring the use of 100,000 to 500,000 gallons of fracturing liquid, it will be realized that the use of our invention affords substantial savings.

With regard to power consumption, hydraulic power costs are approximately \$1.00 per horsepower under current economic conditions. If one is limited to injection of fluids through the tubing, power cost becomes uneconomical at pumping rates much above 5 barrels per

minute which rates are frequently insufficient for many acidizing and fracturing jobs. By the use of our invention it is possible to employ pump rates substantially in excess of 5 lbs./min., at no increase in horsepower.

While we have stressed the application of our invention in hydraulic fracturing and drilling fluids, it likewise can be used to advantage in fire-fighting and other instances where liquids must be pumped at high rates.

We claim:

1. An aqueous liquid having improved hydraulic friction characteristics and having as its essential ingredients a thickening agent and dextran each in a concentration of from about 1 to about 12 lbs./1000 gals., said thickening agent being present in at least about the same concentration as the dextran, and said thickening agent being selected from a class consisting of methyl cellulose, guar, completely hydrolyzed polyacrylamide, a copolymer of methyl vinyl ether and maleic anhydride, and a copolymer prepared from substantially equal molecular amounts of vinyl acetate and maleic anhydride.

2. The liquid of claim 1 in which the thickening and friction reducing agents are present in a weight ratio of from about 1:1 to 2:1.

3. The liquid of claim 1 in which the thickening agent is methyl cellulose.

4. The liquid of claim 1 in which the thickening agent is guar.

5. The liquid of claim 1 in which the thickening agent is methyl vinyl ether-maleic anhydride copolymer.

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