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METHOD OF DECREASING FRICTION LOSS IN
TURBULENT LIQUIDS

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This invention relates to a method of decreasing friction loss in liquids subjected to turbulent conditions. More particularly, the invention relates to an aqueous liquid having incorporated therein an additive system which will reduce the friction loss attending the turbulent conditions.

One of the most familiar operations in which a liquid is subjected to turbulent conditions is in flow through conduits. It is well known that in liquid flow, energy is expended in overcoming the friction encountered in the movement of the liquid. While the pressure drop obtained in pumping a small amount of liquid a short distance is small, the energy expended becomes considerable when large amounts of a liquid are moved through a conduit under turbulent flow conditions, such as in industrial plants and processes. Thus, an additive system which reduces the friction loss in flow of liquids will appreciably decrease pumping costs.

Various additives have been suggested for decreasing the friction loss in flowing liquids. For example, additives, such as the long chain aluminum soaps which convert hydrocarbon systems to thixotropic gels, have been suggested for decreasing the friction loss in flowing hydrocarbon liquids. As another example, long chain synthetic polymers have been suggested for decreasing the friction loss in flowing aqueous liquids. The additives which have been suggested, however, suffer from one or more disadvantages. Some of these additives lose their effectiveness in the presence of electrolytes. Some of the naturally derived and synthetic polymer additives are permanently degraded by the violent shearing characteristic of a turbulent flow field and hence lose their ability to reduce friction loss. More particularly, the links between structural groups of these additives are destroyed, and thus the degree of polymerization or molecular weight is reduced. Some others of the additives undergo thermal degradation and hence are not stable at elevated temperatures. Some additives also undergo bacterial and oxidative degradation. Others suffer a permanent loss of effectiveness in the presence of solids, particularly clay solids, since, as a result of their chemical nature, they are strongly adsorbed onto the surfaces of the solids, thus reducing their effective concentration in the fluid phase. Additionally, some form permanent gels which make the initiation of flow and flow in a laminar flow field difficult.

Accordingly, it is an object of the invention to provide an economical method of decreasing friction loss in an aqueous liquid being subjected to turbulent conditions which alleviates each and all of the foregoing disadvantages.

It is a particular object of the invention to provide an economical method of decreasing friction loss in an aqueous liquid being flowed through a conduit under turbulent flow conditions which alleviates each and all of the foregoing disadvantages.

It is also an object of the invention to provide a method of fighting fires which results in getting more water having improved wetting and oxygen-excluding capability to the burning object.

Further objects and attendant advantages of the invention will be apparent from the following detailed description taken in conjunction with the accompanying claims.

I have discovered that friction loss in an aqueous liquid being subjected to turbulent conditions can be reduced by incorporating in the aqueous liquid a specific soap system

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in a quantity sufficient to induce the property of viscoelasticity to the aqueous liquid. The viscoelastic liquid containing the soap system has a pH greater than about 7. The specific soap system is (a) an alkali metal soap of a fatty acid and a strong electrolyte, (b) an ammonium soap of a fatty acid and an electrolyte, or (c) a substituted ammonium soap of a fatty acid. The fatty acid is an aliphatic monocarboxylic acid which contains from 12 to 18 carbon atoms, inclusive. The substituted ammonium soap includes the amine soaps and the alkanolamine soaps.

The ability to reduce friction loss appears and disappears concurrently with viscoelastic behavior. Thus, while I do not wish the claims to be limited to the consequences of a particular theory as to the operation of the invention, it appears that it is the ability of a viscoelastic liquid to store mechanical energy, in a manner somewhat analogous to the storage of mechanical work in an elastic solid, which retards the onset of, or moderates, energy-dissipating turbulence.

The property of viscoelasticity is a well-recognized property. Viscoelasticity and tests for determining whether or not a liquid possesses this property may be found in published references such as: (a) J. D. Ferry, *Viscoelastic Properties of Polymers*, Wiley Publishing Company, New York, 1961, (b) A. B. Metzner, *Flow of Non-Newtonian Fluids*, in V. L. Streeter, Ed., *Handbook of Fluid Dynamics*, McGraw-Hill Book Company, Inc., 1961, and (c) W. L. Wilkinson, *Non-Newtonian Fluids*, Pergamon Press, 1960.

Stated briefly, some of the tests which are useful in noting pronounced viscoelasticity and hence adequate in detecting viscoelasticity of aqueous solutions of the specific soap systems are:

(1) Recoil motion of suspended air bubbles when the liquid stops after a swirling motion has been imparted to the liquid,

(2) The pulling away of liquid threads when a rod is withdrawn from the liquid,

(3) The expansion in diameter of a liquid jet issuing from a capillary die to a diameter several times that of the die opening, and

(4) The inward flow of a liquid against the action of centrifugal forces such that the liquid climbs a rotating stirring shaft against the force of gravity.

In the practice of the invention, the concentration of the specific soap system required to achieve viscoelasticity, as discussed hereinafter, is incorporated into the aqueous solution which is to be subjected to turbulent conditions.

Each of the specific soap systems requires as one constituent at least one of the soaps of a fatty acid which, as noted before, contains 12 to 18 carbon atoms, inclusive. Suitable fatty acids from which soaps for use in the invention can be prepared are described at page 484 of *The Condensed Chemical Dictionary*, Sixth Edition, edited by Arthur and Elizabeth Rose, Reinhold Publishing Corporation, New York, 1961. Illustrative of the fatty acids are lauric acid, myristic acid, palmitic acid, stearic acid, elaidic acid, and oleic acid. It is not necessary to use purified fatty acid in preparing the soap for use in the invention since the commercial grade crude fatty acid reacts to form a soap which is effective in preparing a viscoelastic solution.

The nature of the aqueous solution which is to be subjected to turbulent conditions will generally decide the cation of the soap which is chosen to reduce the friction loss therein. For example, if the aqueous solution contains a strong electrolyte in a concentration above about 3 percent by weight, it will generally be advantageous to employ an alkali metal soap. An alkali metal soap is readily prepared by neutralizing the selected fatty acid with an alkali metal base such as the alkali metal hydroxides. The alkali metal soaps require the presence

of a strong electrolyte to form viscoelastic solutions and reduce friction loss.

As another example, if the aqueous solution to be subjected to turbulent flow contains a weak electrolyte, it may be desirable to employ an ammonium soap. The ammonium soap is formed by neutralizing the selected fatty acid with ammonium hydroxide. The ammonium soaps require the presence of some electrolyte, whether weak or strong, to form viscoelastic solutions and reduce friction loss.

As a further example, if the aqueous solution to be subjected to turbulent flow contains no electrolyte, it may be advantageous to employ a substituted ammonium soap instead of also adding the electrolyte required if the other soaps are employed. The substituted ammonium soap is prepared by neutralizing the selected fatty acid with a substituted ammonium base. Illustrative of such substituted ammonium bases are methylamine; ethylamine; higher amines, such as sec-butylamine; or the alkanolamines, such as ethanolamine. The substituted ammonium soaps do not require the presence of either a weak electrolyte or a strong electrolyte to create viscoelastic solutions when added to water. However, aqueous solutions of the substituted ammonium soaps form viscoelastic solutions in the presence of either weak or strong electrolytes in limited concentrations as discussed hereinafter.

Two or more compatible viscoelastic liquids, or two or more compatible soap systems to provide a viscoelastic liquid, may be combined to tailor the viscoelasticity to the conditions under which the resulting aqueous solution is employed.

The reaction to prepare the soap may be carried out by adding the appropriate amount of the fatty acid and at least an equimolar amount of the base directly to the aqueous solution to form the viscoelastic aqueous solution. Alternatively, the soap may be prepared by reacting the fatty acid with the base and the finished soap then added to the aqueous solution to prepare the viscoelastic solution.

Strong electrolytes are discussed and their requirements set forth at page 506 of *Outlines of Physical Chemistry*, Farrington Daniels; John Wiley and Sons, Inc., New York, 1948. Water-soluble inorganic salts are illustrative of strong electrolytes and form the preferred strong electrolytes to be employed in the soap system. Common examples include inorganic salts such as sodium chloride, sodium carbonate, potassium chloride, and potassium carbonate. Mixtures of inorganic salts also may be employed as the strong electrolyte.

Weak electrolytes, on the other hand, are those materials which have a much lower degree of ionization than do the strong electrolytes when dissolved in an aqueous solution. Examples of weak electrolytes are ammonia and its derivative compounds, such as ammonium hydroxide.

Once the particular soap has been selected for a given application, the degree of reduction in friction loss is most directly determined by the concentration of the soap additive in the viscoelastic solution. The concentration of the soap required, however, is inversely related to the concentration of the electrolyte and is directly related to the temperature and the shear stress, explained hereinafter. The best concentration of soap may be determined empirically by testing the relative viscoelasticity of different concentrations of soap in the particular aqueous solution to be subjected to turbulence at the pH and temperature to be employed. The following guidelines have been found useful in creating viscoelastic solutions which are effective in reducing friction loss in aqueous systems being flowed under a wide range of turbulent conditions.

A concentration of at least 0.001 percent by weight of a saturated fatty acid soap must be employed in the aqueous solution to achieve any appreciable reduction in friction loss. In general, a concentration of at least 0.01 percent by weight of soap, whether of a saturated or unsaturated fatty acid, should be employed to afford visco-

elastic solutions capable of reducing friction loss under varied conditions of turbulence. It is preferred that at least 0.05 percent by weight of the alkali metal or ammonium unsaturated soaps, such as the alkali metal oleates or ammonium oleate, be employed.

Often no more than 0.1 percent by weight of saturated soaps need be employed to obtain the viscoelastic aqueous solution. In general, a concentration of no more than 1 percent by weight of any soap need be employed and ordinarily further increases in concentration are not economically feasible. However, an amount of soap to effect coacervation, a condition analogous to supersaturation and evidenced by opalescence as visible micelles form, in the aqueous solution may also be employed. Infrequently, it may be desirable to employ a concentration of soap as high as 5 percent for specialized applications where (a) the viscoelastic solutions are to be flowed at temperatures near the boiling point of the solutions, or (b) the shear stress, as discussed hereinafter, is to be high.

The aqueous solution which is to be subjected to turbulent conditions will often determine whether or not electrolyte may be employed therein with the soap to reduce the friction loss and, if so, the type and concentration which may be employed. The following guidelines have been found useful with regard to either selecting the particular soap system or improving the performance thereof in view of the concentration of the electrolyte constituent. The substituted ammonium soaps may be employed in a solution containing no electrolyte or containing a concentration up to about 3 percent by weight of either a weak electrolyte or a strong electrolyte. On the other hand, the ammonium soaps require in the aqueous solution a concentration of at least 0.05 percent by weight of electrolyte to be effective in reducing friction loss. They remain effective through concentrations as high as about 7.5 percent by weight of electrolyte. The alkali metal soaps, such as the sodium or potassium soaps, require in the aqueous solution at least about 2 percent by weight, or more, of electrolyte to be effective in reducing friction loss. They remain effective at concentrations as high as about 14 percent by weight, or more, of electrolyte.

As with the concentrations of soap, higher concentrations of electrolyte within the foregoing limits shift the region in which reduction in friction loss is achieved to higher temperatures and higher shear stresses.

Controlling the pH on the alkaline side, i.e., greater than 7, increases the efficacy of the viscoelastic soap solutions in reducing friction loss. Preferably, a pH greater than about 9 and less than about 12 is employed. The pH at which the solutions are most viscoelastic, and hence achieve the greatest reduction in friction loss, is around 10.5.

The alkali metal soaps, the ammonium soaps, and the amine soaps form alkaline solutions in neutral water. However, the pH of the viscoelastic soap solution is preferably controlled by adding caustic where necessary rather than by adding extra quantities of soap. Caustic includes the alkali metal hydroxides or alkali metal carbonates. Suitable caustic also includes ammonium hydroxide, NH_4OH , although it causes a nondetrimental ion exchange reaction. An alkali metal carbonate is particularly useful because it tends to afford a buffered pH in the desired range even when used in excess of the required amount.

Ammonium chloride can be employed to extend the length of time the system comprising ammonium soap and weak electrolyte remains effective for reducing friction loss of aqueous solutions being subjected to turbulent conditions. The amount of ammonium chloride incorporated into the aqueous solution of ammonium soap and weak electrolyte is at least 0.05 percent by weight of the aqueous solution. No more ammonium chloride than 0.5 percent by weight of the solution is required.

Also, a mixed amine-acid compound can be employed

to improve the long-term effectiveness of the substituted ammonium soaps as additives for reducing the friction loss of aqueous solutions being subjected to turbulent conditions. Illustrative of such mixed amine-acid compound is ethylamine hydrochloride. The amount of the mixed amine-acid compound incorporated into the aqueous solution of substituted ammonium soap is at least 0.05 percent by weight of the aqueous solution. No more mixed amine-acid compound than 0.5 percent by weight of the solution is required.

The amount of reduction in friction loss which a particular soap system will afford is also regulated by the shear stress τ_w to which the aqueous solution will be subjected. In a flowing liquid, in the case of a circular duct and a concentric annular channel, respectively, this parameter τ_w is defined as follows:

$$\tau_w = \frac{DJ}{4} \quad (1)$$

and

$$\tau_w = \frac{D_2(1-\alpha)J}{4} \quad (2)$$

where,

D =internal diameter of the circular duct,
 D_2 =larger internal diameter of the annular channel,
 α =annulus geometric factor, equal to D_1/D_2 ,
 D_1 =smaller internal diameter of the annular channel,
 i.e., outside diameter of interior concentric conduit,
 J =pressure gradient, equal to $\Delta P/L$,
 ΔP =pressure drop, and
 L =length of the circular duct or the annular channel.

Thus, τ_w has the dimensions of a force per unit area, e.g., dynes per square centimeter or pounds per square foot, and for a circular duct of a given D or an annular channel of a given α , τ_w is a direct measure of the pressure gradient or friction loss per unit length. Generally, the reduction in friction loss increases as the pumping rate increases to a certain point, and then it decreases with further increases in pumping rate when a certain critical shear stress $(\tau_w)_c$ is exceeded. However, in contrast to certain drag reducer solutions which undergo a permanent impairment in efficacy as a result of shear degradation, the impairment is of a temporary nature in the case of the soap solutions described hereinbefore. That is, on lowering the shear stress, e.g., by lowering the pumping rate or by flowing into a larger conduit, to a level such that the condition $\tau_w \leq (\tau_w)_c$ is produced, the efficacy of the soap solution is immediately restored. Since the shear stress is independent of pipe diameter, it is a useful parameter in selecting the particular soap system to be employed for reducing friction loss in any given application.

The soap systems are effective in reducing friction loss of liquids being subjected to turbulent conditions under both steady-state conditions and unsteady-state conditions. They reduce friction loss in an aqueous solution in the presence of electrolytes within the concentration limits outlined hereinbefore. Further, the reduced friction loss is effected even after being subjected to turbulent conditions over prolonged periods of time. The soap systems remain effective even at elevated temperature and in the presence of bacterial and oxidative attack. They continue to afford a reduction in friction loss even in the presence of high solids content in the aqueous solution.

In view of the above-noted advantages of these viscoelastic aqueous soap solutions, many practical applications are technically feasible to make use of this ability to reduce friction loss in the aqueous liquid being subjected to turbulent conditions.

The flow capacities of certain prime movers can be more than doubled using the method of the invention. Further, sea water may be employed in the aqueous solutions being flowed by these prime movers and still obtain

the reduced friction loss. Such increased flow capacity allows turbo drilling employing turbine-powered drilling apparatus without the expense of adding extra equipment and high pressure piping. The improved flow capacity is particularly beneficial in slim hole drilling wherein small diameter holes are drilled in subterranean formations.

In flowing fracturing fluids through conduits to fracture subterranean formations, the reduction in friction loss using the method of the invention is extremely beneficial.

Another application is in pipeline transportation of products wherein it is economically attractive to use water as a carrier to transport coal slurries, mineral tailings, wood pulp and chips, canned goods, sand and limestone slurries, and other materials through the pipelines.

A particular use for the viscoelastic soap solutions is in fire fighting systems. The viscoelastic soap solutions may be prepared and stored in the storage vessels from which the water will be drawn to fight the fire. Alternatively, a concentrated solution, or dispersion, of the soap system may be fed by a proportioning feeder directly into the water being pumped through the fire fighting apparatus. As a further alternative, the raw reactants, such as the fatty acid and the base and, where employed, the electrolyte, may be added by proportioning feeders to the water being pumped through the fire fighting equipment.

The improvement in extending the capacity of centralized fire fighting systems in industrial plants and of fire fighting equipment on board marine vessels is readily apparent. In addition to the improved hydraulics which result, the viscoelastic properties of these fluids are particularly useful in preventing physical disintegration of the water from the fire hose into droplets, and in improving the directional control in fire fighting in high winds, or in reaching tall or difficultly accessible structures. The jet of a viscoelastic liquid will emerge as a stable sheet or thread because the shear is opposed by the rigidity of the liquid as well as by viscosity. In contrast, a Newtonian or purely viscous liquid would disintegrate into a mass of droplets and form a spray which renders more difficult the fighting of fires at a distance. In addition, the viscoelastic liquids have an adhesiveness which allows them to cling to the structure being wetted such that they exclude oxygen and cool the structure more effectively than does water alone.

Because these viscoelastic aqueous soap solutions reduce turbulent friction loss, they may be employed to reduce skin friction drag on submerged hydrodynamic vehicles, such as torpedoes and ship hulls. When employed to reduce skin friction drag on submerged hydrodynamic vehicles, the viscoelastic solution is flowed at low rates of flow through small openings at the anterior portion of the vehicle. It streams back over the skin of the vehicle, forming a thin layer of the viscoelastic solution adjacent the skin. This enables the vehicle to proceed through the water at a much faster rate. Further, the viscoelastic soap solutions may be used to reduce drag on rotating parts of submerged turbomachinery and thus, for example, enhance the efficiency of centrifugal pumps.

For purposes of further illustrating the invention, the following examples are given. In these examples, water containing a soap system, named and described in the respective examples, was pumped through piping of various diameter sizes and configurations. The pressure drop was then compared to the pressure drop measured when water alone was pumped through the same apparatus at the same flow rates. The details of the general procedure are described below. Where special procedures or apparatus were employed in a particular example, they are described therein.

The apparatus employed consisted of a mixing tank in which the test solution was mixed and stored. The solu-

tion was pumped by means of a centrifugal pump through test sections of pipe 27 feet in length and returned to the storage tank. Pressure drop was determined by measuring the pressure at the entrance and the discharge ends of each test section of pipe by means of differential pressure transmitters. Nominal tube sizes of 1.0, 1.31, and 1.89 inches were employed and are set forth in the respective tables of data. In order to take the diameter of the pipe out of the data as a variable, the pressure drop was converted to and is reported as shear stress.

The solution to be tested was prepared and stored in the storage container. Complete mixing of the solution was assured by circulating the solution through all test sections at a high flow rate or at a moderate flow rate for a period of several hours. Temperature and pressure equilibrium were also established during this period. The rates of flow were measured with a calibrated magnetic flow meter and differential pressure transmitters.

Specifically, the solution to be tested was flowed through the apparatus at various measured rates of flow and the shear stresses calculated for each rate of flow. As noted, the water used in preparing the solution was then pumped through the same apparatus at the same flow rates and the same measurements taken to afford a standard or control liquid against which to compare the friction loss of the solution being tested. Comparative data for each example are summarized in respectively numbered tables. In the tables of comparative data, the flow rate is given in gallons per minute, abbreviated g.p.m.

Example 1

This examples illustrates the effect of different concentrations of a strong electrolyte on the reduction in friction loss achieved by an alkali metal soap of an unsaturated fatty acid containing 18 carbon atoms along with the strong electrolyte in an aqueous solution being flowed under turbulent conditions through a conduit.

In this example, Solutions A and B were prepared by admixing water, sodium oleate, potassium chloride, and potassium hydroxide. Solution A contained proportions of about 96.26 parts by weight of water, 0.2 part by weight of sodium oleate, 3.5 parts by weight of potassium chloride, and 0.04 part by weight of potassium hydroxide. Solution B contained proportions of about 89.2 parts by weight of water, 0.2 part by weight of sodium oleate, 10 parts of potassium chloride, and 0.6 part by weight of potassium hydroxide.

TABLE I

[Temperature=85° F.; pipe diameter=1 inch]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)			Percent Reduction in Pressure Drop	
	Control Liquid	Solution "A"	Solution "B"	Solution "A"	Solution "B"
5.....	12.95	4.745	9.077	63.37	29.94
10.....	43.59	13.41	16.29	69.18	62.55
15.....	83.38	22.69	27.33	74.33	69.08
20.....	146.1	31.97	40.74	78.12	72.12
30.....	295.9	222.8	71.17	24.96	76.63
40.....	490.9	410.5	97.99	16.38	80.04
50.....	724.8	655.0	134.1	9.677	81.50
60.....	997.2	928.4	179.4	6.913	82.01
70.....	1,305	1,253	239.3	3.658	81.67
80.....	1,648	1,619	313.5	1.822	80.98
90.....	2,025	-----	383.7	-----	81.06
100.....	2,434	-----	454.8	-----	80.09
110.....	2,875	-----	618.9	-----	78.48
120.....	3,349	-----	1,031	-----	69.22

The data also illustrates that the region of shear stresses within which the soap solution reduces friction loss and the critical shear stress are shifted to higher values at the higher concentration of electrolyte.

Example 2

This example illustrates the effect of different concentrations of soap on the reduction in friction loss in an aqueous solution being flowed through a linear conduit under conditions of turbulence.

In this example, Solutions D and E were prepared by admixing water, sodium oleate, potassium chloride, and potassium hydroxide. Solution D contained the proportions of 91.84 parts by weight of water, 0.05 part by weight of sodium oleate, 7.5 parts by weight of potassium chloride, and 0.61 part by weight of potassium hydroxide. Solution E contained the proportions of 91.69 parts by weight of water, 0.2 part by weight of sodium oleate, 7.5 parts by weight of potassium chloride, and 0.61 part by weight of potassium hydroxide.

TABLE II
[Temperature=85° F.; pipe diameters=1.31 inches]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)			Percent Reduction in Pressure Drop	
	Control Liquid	Solution "D"	Solution "E"	Solution "D"	Solution "E"
5.....	4.917	2.837	8.241	42.31	-----
10.....	16.28	5.404	10.94	66.82	32.83
15.....	53.93	13.23	19.58	75.47	63.70
20.....	108.6	27.02	48.63	75.14	55.27
30.....	178.6	40.53	75.65	77.31	57.65
40.....	282.6	56.74	99.97	78.49	61.94
50.....	359.8	85.11	114.8	76.35	63.10
60.....	469.8	148.6	132.3	68.37	71.84
70.....	591.7	329.6	151.3	44.30	74.43
80.....	725.2	540.3	170.2	25.50	76.53
90.....	870.0	715.9	191.8	17.72	77.95
100.....	1,025	878.0	221.5	14.41	78.40
110.....	1,192	1,094	270.2	8.241	77.33
120.....	1,369	1,310	310.7	4.816	77.30
130.....	1,556	1,512	391.7	2.834	74.82
140.....	1,753	-----	459.3	-----	73.80
150.....	2,066	-----	516.6	-----	75.00
160.....	2,170	-----	580.8	-----	73.31
170.....	2,402	-----	702.4	-----	70.76

The data also illustrate that the region of shear stresses within which the soap solution reduces friction loss and the critical shear stress are shifted to higher values at the higher concentration of soap.

Example 3

This example illustrates the effect of different concentrations of a weak electrolyte on the reduction in friction loss achieved by ammonium oleate along with the weak electrolyte in an aqueous solution being flowed through a linear conduit under conditions of turbulence. Further, it illustrates the preparation of the ammonium soap by admixing the reactants in the aqueous solution.

In this example, Solutions F, G, and H were prepared by admixing oleic acid, ammonium hydroxide, and water. Solution F contained the proportions of 0.514 part by weight of oleic acid, 2.30 parts by weight of ammonium hydroxide, and 97.186 parts by weight of water. Solution G contained the proportions of 0.514 part by weight of oleic acid, 4.49 parts by weight of ammonium hydroxide, and 94.996 parts by weight of water. Solution H contained the proportions of 0.514 part by weight of oleic acid, 7.49 parts by weight of ammonium hydroxide, and 91.996 parts by weight of water.

TABLE III

[Temperature=85° F.; pipe diameter=1.0 inch]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)				Percent Reduction in Pressure Drop		
	Control Liquid	Solution "F"	Solution "G"	Solution "H"	Solution "F"	Solution "G"	Solution "H"
5.....	12.95	5.673			56.21		
10.....	43.51	23.72	22.17	18.05	45.49	49.05	58.52
15.....	88.39	40.23	43.84	38.68	54.49	50.41	56.24
20.....	146.1	54.67	61.89	59.31	62.59	57.65	59.42
24.....	200.9	64.98	73.75	72.2	67.67	63.31	64.08
28.....	263.1	117.5	85.61	85.1	5.35	67.47	67.66
30.....	296.9	202.1	92.83	91.8	31.93	68.73	69.08
34.....	369.5		102.1	99.54		72.37	73.06
36.....	408.3		107.2	104.1		73.75	74.50
38.....	448.7		148.5	112.4		66.91	74.95
40.....	490.8		202.1	140.2		58.83	71.44
45.....	603.1		408.4	284.7		32.29	52.80
50.....	725.1			536.4			26.03

The data in Table III indicate, as in Examples 1 and 2, that increasing the concentration of electrolyte shifts the region of shear stress within which the additive is effective and the critical shear stress to higher values. However, the improvement is less notable after about 4.49 percent electrolyte is included in the aqueous solution.

Example 4

This example illustrates the effect of a substituted ammonium soap of oleic acid in reducing friction loss of an aqueous solution being flowed through a linear conduit under conditions of turbulent flow. It further illustrates the preparation of the viscoelastic soap solution by admixing unreacted constituents directly into the aqueous solution without preparing the soap independently. Still further, this example illustrates the relationship between shear stress and effectiveness of the soap solution in reducing turbulence, relatively independent of pipe diameter.

In this example, Solution J was prepared by admixing 183.2 pounds, or 83,200 grams, of water; 42.57 grams of sec-butylamine; 165.7 grams of oleic acid; 50.1 grams of ethylamine hydrochloride; and 22.61 grams of sodium hydroxide. Thus, Solution J contained 99.782 parts by weight of water. 0.15 part by weight of sec-butylamine oleate, 0.06 part by weight of ethylamine hydrochloride, and 0.008 part by weight of sodium hydroxide.

TABLE IV
[Temperature=85° F.]

Tube Size (inches)	Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)		Percent Reduction in Pres- sure Drop
		Control Liquid	Solution "J"	
1.0.....	5	12.95	12.37	4.5
	10	43.50	25.27	42
	15	88.38	39.19	56
	20	146	51.57	65
	40	490	103	79
1.31.....	60	997	964	3.3
	10	16.28	11.48	30
	30	108	41.2	62
	50	262	70.9	73
	70	469	118	75
1.89.....	90	725	614	16
	20	13.56	7.86	42
	40	45.23	21.61	53
	60	91.49	37.33	60
	80	150	56.99	63
	100	222	72.71	68
	140	398	106	74
	180	617	518	16

Example 5

This example illustrates the effect of a soap prepared from a saturated fatty acid containing 18 carbon atoms in reducing friction drop of an aqueous solution of the soap system pumped through linear conduit.

In this example, Solution K was prepared by admixing sodium stearate, potassium hydroxide, potassium carbonate, and water in the proportions of 0.228 part by weight of sodium stearate, 0.03 part by weight of potassium hydroxide, 6.18 parts by weight of potassium carbonate, and 93.562 parts by weight of water.

TABLE V
[Temperature=110° F.; pipe diameter=1.0 inch]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)		Percent Re- duction in Pressure Drop
	Control Liquid	Solution "K"	
5.....	13.41	6.39	52.4
10.....	43.32	13.92	67.9
15.....	88.38	23.80	73.1
20.....	146.1	43.32	70.4
30.....	296.9	119.6	59.8
40.....	490.9	25.8	47.9
50.....	724.8	489.9	32.5
60.....	997.2	747.8	25.1
70.....	1,305	1,137	12.9
80.....	1,648	1,547	6.2

The data indicate a maximum percent reduction in pressure drop of about 73 percent was achieved in turbulent flow at about 15 gallons per minute. Further tests with Solution K at different temperatures indicate a shift in effectiveness. For example, at 85° F., a maximum percent reduction in pressure drop at about 49 percent was achieved in turbulent flow at about 8 gallons per minute. This temperature was somewhat below the point at which a coacervate or precipitate began to form. In contrast, at 120° F., a maximum percent reduction in pressure loss of about 74.6 percent was achieved in turbulent flow at about 18 gallons per minute.

Example 6

This example illustrates the effect of a soap prepared from a saturated fatty acid containing 14 carbon atoms for reducing friction loss in an aqueous solution flowed through linear conduit.

In this example, Solution L was prepared by admixing potassium myristate, potassium hydroxide, potassium carbonate, and water in the proportions of 0.926 part by weight of potassium myristate, 0.05 part by weight of potassium hydroxide, 11.6 parts by weight of potassium carbonate, and 87.424 parts by weight of water.

TABLE VI

[Temperature=65° F.; pipe diameter=1.0 inch]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)		Percent Reduction in Pressure Drop
	Control Liquid	Solution "L"	
15.....	88.38	60.86	31.2
20.....	146.1	84.07	42.5
30.....	296.9	138.2	53.5
40.....	490.9	189.8	61.4
50.....	724.8	313.5	56.8
60.....	997.2	577.6	42.1
70.....	1,305	990.2	24.2
80.....	1,648	1,361	17.5
90.....	2,025	1,733	14.5

Example 7

This example illustrates the effect of soap systems in reducing friction loss of an aqueous solution being subjected to turbulent conditions in flowing through an annular channel.

In this example, Solumtion M was prepared by admixing water, sodium oleate, potassium chloride, and potassium hydroxide in the proportions of 94.76 parts by weight of water, 0.2 part by weight of sodium oleate, 5.0 parts by weight of potassium chloride, and 0.04 part by weight of potassium hydroxide. Solution M was pumped through a thin annular passage characterized by a geometric ratio of 0.9085, and a total annular gap of 0.192 inch between a core having an outside diameter of 1.907 inches and a cylinder thereabout having an inner diameter of 2.099 inches.

TABLE VII

Temperature=85° F.; annulus between 1.907-in. (O.D.) pipe and 2.099-in. (I.D.) pipe]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)		Percent Reduction in Pressure Drop
	Control Liquid	Solution "M"	
10.....	120	120	-----
11.....	138	129	6.58
12.....	158	139	12.09
13.....	182	148	18.64
14.....	208	158	23.68
15.....	234	167	28.63
16.....	259	177	31.55
20.....	384	229	40.43
24.....	525	285	45.58
30.....	1,307	375	71.25
34.....	1,627	442	72.80
40.....	2,154	560	74.00

Example 8

This example illustrates the effect of the soap solutions in reducing friction loss through rough conduits of the type employed in oil well drilling operations.

In this example, Solution N was prepared by admixing sodium oleate, sodium chloride, sodium hydroxide, and water in the proportions of 0.25 part by weight of sodium oleate, 3 parts by weight of sodium chloride, 0.05 part by weight of sodium hydroxide, and 96.7 parts by weight of water. The apparatus in which the reduction in friction loss was obtained was commercial 2½-inch oil field drill pipe (10.4 pounds per foot) fitted with an A200SM 2½-inch tool joint, the mean internal diameter of this pipe being 2.151 inches. The control liquid was an aqueous solution containing 3 parts by weight of sodium chloride and 0.05 part by weight of sodium hydroxide.

TABLE VIII

[Temperature=85° F.; pipe diameter=2½-inch drill pipe (2.151 inches I.D.)]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)		Percent Reduction in Pressure Drop
	Control Liquid	Solution "N"	
20.....	9.372	8.257	11.9
30.....	18.96	11.60	38.9
40.....	33.47	18.96	43.4
50.....	51.32	25.66	50.0
60.....	72.53	29.01	60.1
70.....	97.08	34.58	64.4
80.....	127.1	42.39	66.7
90.....	158.4	52.43	67.0
100.....	196.3	59.13	69.9
120.....	272.2	75.87	72.2
140.....	365.9	102.6	72.0
160.....	468.4	133.8	71.5
180.....	580.2	170.7	70.6

The data indicate that in such rough conduits the reduction in friction loss, even at shear stresses above the critical shear stress, is still appreciable. For example, the maximum percent reduction of 72.2 percent was achieved at a shear stress of 75.87, or flow rate of 120 gallons per minute. However, even at a shear stress of 170.7, or a flow rate of 180 gallons per minute, a reduction in friction loss of 70.6 percent was still being achieved. Such data indicates that these additives are particularly useful in fracturing operations carried out in subterranean formations or in slim hole drilling operations wherein small diameter holes are drilled into subterranean formations.

Example 9

This example illustrates the effect of these soap solutions in reducing friction losses in an actual oil well drilling operation. Solution P was pumped at various flow rates through 966 feet of open-ended commercial 2½-inch oil field drill pipe (10.4 lbs. per foot) fitted with A200SM (3½ x 1¾ x 18 inches) tool joints, the mean internal diameter of the pipe being 2.151 inches. The drill string was suspended from a drilling rig in a 9½-inch cased hole, containing a bridge plug at a depth of 1,000 feet. The pump discharge pressure was recorded at the respective flow rates. An aqueous solution containing 3 parts by weight of sodium chloride and 0.05 part by weight of sodium hydroxide was employed as the control liquid. The control liquid was pumped through the same apparatus and the same measurements taken thereon as were taken on Solution P, the solution being tested.

Solution P was prepared by admixing sodium oleate, sodium chloride, sodium hydroxide, and water in the proportions of 0.128 part by weight of sodium oleate, 3 parts by weight of sodium chloride, 0.05 part by weight of sodium hydroxide, and 96.822 parts by weight of water.

TABLE IX

Temperature=75° F. (measured in the flow line); Drilling apparatus configuration]

Flow Rate (g.p.m.)	Pump Discharge Pressure*		Percent Reduction in Pressure Drop
	Control Liquid	Solution "P"	
73.....	50	33	34
94.....	77	23	70
131.....	157	37	76
191.....	353	97	73
210.....	430	133	69
248.....	610	233	62
272.....	729	416	43
308.....	899	632	30
364.....	1,263	982	22

*Sum of losses in drill string, annular channel, and surface lines.

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Example 10

This example illustrates the ability of the soap systems to continue to reduce friction loss in aqueous liquid being flowed under turbulent conditions even after prolonged shearing by the turbulence to which they are exposed.

In this example, Solution Q was prepared by admixing sodium oleate, sodium chloride, sodium hydroxide, and water in the proportions of 0.25 part by weight of sodium oleate, 2 parts by weight of sodium chloride, 0.05 part by weight of sodium hydroxide, and 97.7 parts by weight of water. In addition to the 88 hours of turbulent flow which is reported in Table X, Solution Q was also subjected to turbulent shearing at various rates of flow at elevated temperature conditions and, additionally, subjected to four periods of sustained pumping, each period lasting for 16 hours. It remained effective in reducing friction loss.

TABLE X

[Temperature=85° F.; pipe diameter=1.0 inch]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)					Percent Reduction in Pressure Drop After—					
	Control Liquid	Solution "Q" After—					0 hrs.	16 hrs.	40 hrs.	64 hrs.	88 hrs.
		0 hrs.	16 hrs.	40 hrs.	64 hrs.	88 hrs.					
5-----	13.41	9.07	9.07	8.56	9.28	8.76	32.2	32.2	36.1	30.8	34.6
10-----	43.32	17.02	17.02	18.36	19.39	15.98	60.7	60.7	57.6	55.2	63.0
20-----	146.1	53.12	41.26	46.41	47.45	37.13	63.7	71.8	68.2	67.5	74.6
30-----	296.9	82.52	75.30	77.36	78.39	71.17	72.2	74.6	74.0	73.6	76.0
40-----	490.9	112.4	111.4	109.3	105.2	107.2	77.1	77.3	77.7	78.6	78.2
50-----	724.8	165.0	160.9	167.1	173.2	195.9	77.2	77.8	77.0	77.1	73.0
60-----	997.2	338.3	371.3	489.9	410.5	510.6	66.1	62.8	50.9	58.9	48.0
70-----	1,305	753.0	804.6	876.8	856.1	845.8	42.1	38.2	32.6	34.1	35.0
80-----	1,648	1,279	1,258	1,361	1,299	-----	22.2	23.6	17.5	21.0	-----
90-----	2,025	1,784	1,775	1,815	1,753	-----	12.0	12.5	10.5	13.5	-----

*Extrapolated Values.

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TABLE XI
[Pipe diameter=1.0]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)				Percent Reduction in Pressure Drop after—	
	Control Liquid at—		Solution "R" at—		85° F.	150° F.
	85° F.	150° F.	85° F.	150° F.		
20.....	146.1	136.1	88.71	101.0	39.3	25.8
30.....	296.9	280.5	121.7	140.2	59.1	50.1
40.....	490.9	492.5	155.7	181.5	68.3	63.2
50.....	724.8	711.7	259.9	226.9	64.2	68.2
60.....	997.2	969.6	402.3	278.5	59.7	71.3
70.....	1,305	1,299	505.4	340.4	61.3	72.8
80.....	*1,648	*1,625	593.1	381.6	64.1	76.6
90.....	*2,025	*2,020	696.3	464.2	65.6	77.1
100.....	*2,434	*2,430	773.6	526.0	68.3	78.8

*Extrapolated Values.

Example 11

This example illustrates the effect of the soap systems in reducing friction loss in an aqueous solution being flowed under turbulent conditions at elevated temperatures.

In this example, Solution R was prepared by admixing sodium oleate, sodium chloride, sodium hydroxide, and water in the proportions of 1 part by weight of sodium oleate, 3 parts by weight of sodium chloride, 0.10 part by weight of sodium hydroxide, and 95.9 parts by weight of water. The temperature of the apparatus and solution was controlled at 85° F. and 150° F. for the respective tests.

The data indicate that Solution R is in general more effective, particularly at a flow rate above about 50 gallons per minute, at the temperature of 150° F. than at 85° F. Thus, the data indicate it is profitable to employ a lower concentration of soap for greater efficacy if the environment temperature is lower.

Example 12

This example illustrates the effect of the soap systems in reducing friction loss of aqueous solutions being flowed under turbulent conditions even with a high solids content in the solution.

In this example, Solution S was prepared by admixing sodium oleate, sodium chloride, sodium hydroxide, DMS,

TABLE XII

[Temperature=85° F.; pipe diameter=2 $\frac{3}{8}$ -inch drill pipe]

Flow Rate (g.p.m.)	Shear Stress (dynes/cm. ²)					Percent Reduction in Pressure Drop Following Additions of Clay (in percent by weight)			
	Control Liquid	Solution "S" Containing the Following Proportions of Clay (in percent by weight)				0.25	1.5	3.0	5.0
		0.25	1.5	3.0	5.0				
40.....	33.47	26.78	18.96	22.32	31.21	20.0	43.4	33.4	6.8
50.....	51.32	33.47	32.36	40.17	49.09	34.8	37.0	21.8	4.4
60.....	72.53	39.03	39.03	46.84	53.54	46.2	46.2	35.5	26.2
70.....	97.08	45.73	43.50	51.32	59.13	52.9	55.2	47.2	39.1
80.....	127.1	51.32	51.32	55.80	69.17	59.7	59.7	56.1	45.6
90.....	158.4	60.24	61.35	64.72	75.87	62.0	61.3	59.2	52.2
100.....	196.3	69.17	73.64	78.09	87.01	64.8	62.5	60.3	55.7
120.....	272.2	95.97	98.19	104.8	120.5	64.8	64.0	61.5	55.8
140.....	365.9	124.9	129.4	139.4	156.2	65.9	64.7	62.0	57.4
160.....	468.4	158.4	167.4	172.9	206.4	66.2	64.3	63.1	56.0
180.....	580.2	198.6	212.0	223.2	256.6	65.8	63.5	61.6	55.8
200.....	710.2	227.6	358.8	272.2	312.1	68.0	63.6	61.7	56.1

and water in the proportions of 0.50 part by weight of sodium oleate, 3 parts by weight of sodium chloride, 0.05 part by weight of sodium hydroxide, 0.125 part by weight of DMS, and 96.325 parts by weight of water. DMS is a drilling mud surfactant which is essentially a phenol having an average of about 30 mols of ethylene oxide adducted therewith, and a minor amount of a defoamant of nonyl phenol with about 1 to 2 mols of ethylene oxide adducted therewith. Quantities of Magcogel, a bentonitic-type clay, were added to Solution S, the solids content being increased incrementally through levels of 0.25, 1.5, 3, and 5 percent by weight, respectively, of the soap solution. The soap solution containing the clay was then pumped at various measured flow rates through 2 $\frac{3}{8}$ -inch drill pipe. An aqueous solution containing 3 parts by weight of sodium chloride and 0.05 part by weight of sodium hydroxide was employed as the control liquid.

The data in Table XII indicate that increasing the solids content by a factor of fiftyfold did not seriously impair the effectiveness of the soap system in reducing the friction loss of an aqueous solution being subjected to conditions of turbulence at the high rates of flow.

Having thus described the invention, it will be understood that such description has been given by way of illustration and example and not by way of limitation, reference for the latter purpose being had to the appended claims.

What is claimed is:

1. In a process wherein an aqueous liquid is subjected to turbulent conditions, the improvement which comprises reducing the friction loss due to said turbulent conditions by incorporating in said aqueous liquid sufficient quantities of a soap system to create a viscoelastic liquid, said soap system being selected from the group consisting of:

- (a) an alkali metal soap of a fatty acid and a strong electrolyte;
- (b) an ammonium soap of a fatty acid and an electrolyte; and
- (c) a substituted ammonium soap of a fatty acid; said fatty acid containing from 12 to 18 carbon atoms, inclusive,

said liquid containing said soap system having a pH greater than 7.0.

2. In a process wherein an aqueous liquid is moved through a conduit in turbulent flow, the improvement which comprises reducing the friction loss due to said flow by incorporating into said aqueous liquid sufficient quantities of a soap system to create a viscoelastic liquid, said soap system being selected from the group consisting of:

- (a) an alkali metal soap of a fatty acid and a strong electrolyte;
- (b) an ammonium soap of a fatty acid and an electrolyte; and
- (c) a substituted ammonium soap of a fatty acid; said fatty acid containing from 12 to 18 carbon atoms, inclusive,

said liquid containing said soap system having a pH greater than 7.0.

3. The method of claim 2 wherein said viscoelastic liquid is at a pH of from about 9 to about 12.

4. The method of claim 3 wherein said pH is about 10.5.

5. The method of claim 2 wherein said fatty acid is selected from the group consisting of lauric acid, myristic acid, palmitic acid, stearic acid, elaidic acid, and oleic acid.

6. The method of claim 2 wherein said soap system is an alkali metal soap of a fatty acid which contains from 12 to 18 carbon atoms, inclusive, and a strong electrolyte.

7. The method of claim 6 wherein said strong electrolyte is an inorganic salt containing an alkali metal cation.

8. The method of claim 7 wherein said strong electrolyte is sodium chloride.

9. The method of claim 7 wherein said inorganic salt containing an alkali metal cation is present in a concentration of from about 2.0 percent by weight of said viscoelastic liquid to about 14.0 percent by weight of said viscoelastic liquid.

10. The method of claim 6 wherein said alkali metal soap of a fatty acid is in a concentration of from about 0.001 to about 5.0 percent by weight of said viscoelastic liquid.

11. The method of claim 10 wherein said alkali metal soap is in a concentration of from about 0.01 to about 1.0 percent by said weight.

12. The method of claim 6 wherein said alkali metal soap of a fatty acid is an alkali metal saturated soap selected from the group consisting of alkali metal laurate, alkali metal myristate, alkali metal palmitate, and alkali metal stearate.

13. The method of claim 6 wherein said alkali metal soap of a fatty acid is an alkali metal unsaturated soap selected from the group consisting of alkali metal elaidate and alkali metal oleate.

14. The method of claim 13 wherein said alkali metal soap of fatty acid is sodium oleate.

15. The method of claim 13 wherein said alkali metal unsaturated soap is present in a concentration of from about 0.05 to about 1.0 percent by weight of said viscoelastic liquid.

16. The method of claim 6 wherein said alkali metal soap of a fatty acid is sodium oleate and said strong electrolyte is sodium chloride.

17. The method of claim 2 wherein said soap system is an ammonium soap of a fatty acid containing from 12 to 18 carbon atoms, inclusive, and an electrolyte.

18. The method of claim 17 wherein said electrolyte is selected from the group consisting of ammonia, derivative compounds of ammonia, and mixtures thereof.

19. The method of claim 18 wherein said electrolyte is present in a concentration of from about 0.05 percent by weight of said viscoelastic liquid to about 7.5 percent by weight of said viscoelastic liquid.

20. The method of claim 17 wherein said ammonium soap of a fatty acid containing from 12 to 18 carbon atoms, inclusive, is in a concentration of from about 0.001 to about 5.0 percent by weight of said viscoelastic liquid.

21. The method of claim 20 wherein said ammonium soap is present in a concentration of from about 0.01 to about 1.0 percent by weight of said viscoelastic liquid.

22. The method of claim 17 wherein said ammonium soap of a fatty acid is an ammonium saturated soap selected from the class consisting of ammonium laurate, ammonium myristate, ammonium palmitate, and ammonium stearate.

23. The method of claim 17 wherein said ammonium soap of a fatty acid is an ammonium unsaturated soap selected from the group consisting of ammonium elaidate and ammonium oleate.

24. The method of claim 23 wherein said ammonium unsaturated soap is present in a concentration of from about 0.05 to about 1.0 percent by weight of said viscoelastic liquid.

25. The method of claim 23 wherein said ammonium soap of a fatty acid is ammonium oleate.

26. The method of claim 17 wherein said ammonium soap of a fatty acid is ammonium oleate and said electrolyte is ammonium hydroxide and a minor amount of ammonium chloride.

27. The method of claim 2 wherein said soap system is a substituted ammonium soap of a fatty acid which contains from 12 to 18 carbon atoms, inclusive.

28. The method of claim 27 wherein said substituted ammonium soap of a fatty acid is an amine soap of said fatty acid.

29. The method of claim 27 wherein said substituted ammonium soap of a fatty acid is an alkanolamine soap of said fatty acid.

30. The method of claim 27 wherein said substituted ammonium soap of a fatty acid is in a concentration of from about 0.001 to about 5.0 percent by weight of said viscoelastic liquid.

31. The method of claim 30 wherein said substituted ammonium soap is in a concentration of from about 0.01 to about 1.0 percent by weight of said viscoelastic liquid.

32. The method of claim 27 wherein said substituted ammonium soap of a fatty acid is a substituted ammonium saturated soap selected from the group consisting of substituted ammonium laurate, substituted ammonium myristate, substituted ammonium palmitate, and substituted ammonium stearate.

33. The method of claim 27 wherein said substituted ammonium soap of a fatty acid is a substituted ammonium unsaturated soap selected from the group consisting of substituted ammonium elaidate and substituted ammonium oleate.

34. The method of claim 33 wherein said substituted ammonium unsaturated soap is sec-butylamine oleate.

35. The method of claim 2 wherein said soap system is sec-butylamine oleate and said viscoelastic liquid has incorporated therein at least 0.05 percent by weight of ethylamine hydrochloride.

36. In a process wherein an aqueous liquid is moved through a conduit in turbulent flow, the improvement which comprises reducing the friction loss due to said flow by incorporating in said aqueous liquid a concentration of from 0.05 to 1.0 percent by weight of sodium oleate and a concentration of from 2.0 to 14.0 percent by weight of an alkali metal inorganic salt selected from the class consisting of sodium chloride, sodium carbonate, potassium chloride, and potassium carbonate, adjusting the pH of said aqueous liquid to from about 9 to about 12, whereby a viscoelastic liquid is formed, and passing said viscoelastic liquid through said conduit.

37. In a process for fighting fires wherein an aqueous liquid is pumped in turbulent flow through conduits, the improvement comprising intermixing with said aqueous liquid sufficient quantities of a soap system to create a viscoelastic liquid, said viscoelastic liquid having a pH above 7, said soap system being selected from the group consisting of:

(a) an alkali metal soap of a fatty acid and a strong electrolyte;

(b) an ammonium soap of a fatty acid and an electrolyte; and

(c) a substituted ammonium soap of a fatty acid; said fatty acid containing from 12 to 18 carbon atoms, inclusive,

and passing said viscoelastic liquid through said conduit and onto said fire.

38. The method of claim 1 wherein said aqueous liquid comprises water, wherein said turbulent conditions occur adjacent the submerged skin of a vehicle moving through said water, and wherein said incorporating of said soap system is done by flowing at low rates of flow through small openings at the anterior portion of said vehicle sufficient quantities of a concentrated viscoelastic solution of said soap system to create a thin layer of said viscoelastic liquid adjacent said skin, allowing said vehicle to proceed through said water at a much faster rate.

39. The method of claim 1 wherein said aqueous liquid is subjected to turbulent conditions by moving parts at least partially submerged in said aqueous liquid within turbomachinery and there is incorporated in said aqueous liquid about said parts of said turbomachinery sufficient quantities of said soap system to create said viscoelastic liquid.

40. The method of claim 39 wherein said turbomachinery is a centrifugal pump and the efficiency of said centrifugal pump is increased because of the reduction in friction loss.

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ALAN COHAN, *Primary Examiner*.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,361,213

January 2, 1968

Joseph G. Savins

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 56, for "in", second occurrence, read -- is --; column 7, line 49, after "parts" insert -- by weight --; column 8, line 1, for "illustrates" read -- illustrate --; same column 8, TABLE II, sixth column, line 18 thereof, for "73,31" read -- 73.31 --; column 9 TABLE III, sixth column, line 6 thereof, for "5.35" read -- 55.35 --; same column 9, line 48, for "water." read -- water, --; same column 9, TABLE IV, in the third main heading, for "(dynes/cm.²" read -- (dynes/cm.²) --; column 10, TABLE V, third column, line 6 thereof, for "25.8" read -- 255.8 --; column 11, line 26, for "Solumtion" read -- Solution --; column 12, line 30, for "indicates" read -- indicate --; columns 13 and 14, TABLE X, twelfth column, line 7 thereof, for "48.0" read -- 48.9 --; column 14, line 41, for "date" read -- data --; lines 45 and 46, for "environment" read -- environmental --; columns 13 and 14, TABLE XII, fourth column, line 12 thereof, for "358.8" read -- 258.8 --; column 15, line 33, for "qantities" read -- quantities --.

Signed and sealed this 18th day of February 1969.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
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EDWARD J. BRENNER
Commissioner of Patents