

United States Patent Office

2,712,355

Patented July 5, 1955

1

2,712,355

HYDRAULIC FRACTURING OF EARTH FORMATIONS

Jean M. Hoff, Evanston, Ill., assignor to Standard Oil Company, Chicago, Ill., a corporation of Indiana

No Drawing. Application December 20, 1949, Serial No. 134,117

7 Claims. (Cl. 166—36)

This invention relates to the treatment of oil and gas wells and more particularly it pertains to methods of controlling the productivity of fluids from strata traversed by a well.

In the art of controlling productivity of oil and gas wells methods have been proposed for increasing the drainage area within the selected producing zone or for preventing the flow of undesired well fluids into a well bore and between adjacent strata. These methods include systems for producing fractures or channels within formations by the application of hydraulic pressure on a body of fluid within the well. In one such system employing hydraulic fracturing of well formations a gelled hydrocarbon such as gelled gasoline is pumped into a well adjacent the formation to be fractured and sufficient pressure applied to the gel by surface pumps to separate or lift the formation and thereby produce a fracture or channel extending laterally from the well bore. If desired, solid propping agents can be included in the hydraulic fluid and deposited within the produced channel. The gelled hydrocarbon fluid is then resolved to form a low viscosity liquid which may be withdrawn from the fracture and the well. The resultant fractures, with or without propping agents therein, produce lateral drainage channels from the formation into the well.

In the above systems employing hydraulic fluids for fracturing a well formation and controlling the flow of fluids therein surface pumps have heretofore been provided as a source of pressure. Such operations require expensive pumping systems and are unsatisfactory in porous formations. When very porous formations are encountered, the hydraulic fluid may be lost rapidly to the formation without producing a fracture and it is very difficult, if not impossible, to attain a formation breakdown pressure with conventional pumping equipment.

Therefore, it is an object of this invention to provide a system for controlling the productivity of well formations by fracturing such formations with a hydraulic fluid having a viscosity substantially greater than the viscosity of said liquids under high pressure and forcing the hydraulic fluids into the formations to extend the fracture.

Another object of the invention is to provide a fracturing fluid system which is capable of applying fracturing pressures without being limited by pumping capacity or viscosity of the liquid. A further object of the invention is to provide a system for fracturing well formations by means of a hydraulic fluid which would normally be lost to the porous formation at such a high rate as to preclude the breakdown pressure build-up of greater than formation breakdown pressure by means of mechanical pumps. These and other objects of my invention will become apparent as the disclosure thereof proceeds.

Briefly, I attain the objects of my invention by placing a column of hydraulic fluid adjacent and above the formation to be fractured and provide a slow explosive in or above the hydraulic fluid within the well. The slow explosive used in my invention may comprise a gas produc-

2

ing charge of the type where an oxidizable compound is oxidized. The hydraulic system, including the slow explosive, is confined so that the effective pressure produced by the slow explosive is applied to the fluid within the well adjacent the formation to be fractured. Thus, according to my invention, it is not necessary to employ surface pumping equipment and I provide a means for effectively fracturing formations to which the hydraulic fluid is normally lost since I obtain the necessary pressure rapidly and the operation is not limited by the pumping capacity of surface equipment or the liquid loss characteristics of the fluid.

Explosives particularly suitable for this purpose are those of the deflagrating type, such as black powder. In some cases nitromethane, or liquid oxygen and oil when fed gradually into a confined combustion zone, might be used. I prefer, however, black powder which burns from the surface inward and when a cartridge case is rammed tightly with the material it will burn only on the exposed end surface in rocket fashion. There are now available rocket units of the JATO (jet assisted take off) type which are capable of producing a high thrust for a period of many seconds and these may be modified to be placed within a well casing or confined within a chamber which communicates with the well for injecting the high pressure gases.

One gas producing charge suitable for generation of the gas pressure necessary for propelling the hydraulic fluid for fracturing the formation may comprise ammonium nitrate and oxidizable organic materials. Likewise, mixtures of nitroguanidine and a hypophosphite described and claimed in U. S. 2,470,082, can be used.

It is contemplated that a plurality of slow explosive charges or cartridges may be fired in series. If desired, these cartridges can be pressure sensitive in the sense that each releases its energy at a progressively higher range, thereby providing a large volume of fracturing liquid at increasingly high pressures with the result that the initial fracture may be formed or extended.

As used in this application, "low-penetrating fluid" is defined as a fluid which, with respect to the natural fluids in the well, has a considerably retarded tendency to filter or migrate through the formations to be fractured. Well fluids have a viscosity usually less than about 10 to about 20 centipoises at room temperature with correspondingly lower values at formation temperatures. Fluids which, for example, have a greater viscosity than water or the average crude oil, or which have a tendency to plaster or produce a filter cake in permeable formations are low-penetrating fluids. In the use of Newtonian liquids as the low-penetrating fluids, a viscosity of at least 30 centipoises to about 5000 centipoises or higher, for example, a viscosity of 75 to several hundred centipoises, is preferred. A suitable liquid is a viscous low-penetrating liquid such as a gelled hydrocarbon. Such a gelled hydrocarbon can be prepared by adding a bodying agent to a hydrocarbon fluid such as a crude or refined oil or gasoline.

Although in the case of Newtonian liquids the viscosity is indicative of the non-penetrating characteristics of the fluid, the filter rate is a more precise measure of such qualities and is applicable to fluid suspensions of solids or fluids containing plastering agents as well as to Newtonian liquids. The preferred test of a low-penetrating fluid is therefore the filtrate rate.

Filtrate rate is customarily defined as the volume of liquid collected in a unit time (usually 30 minutes) when a measured sample of liquid under gas pressure is placed in a cylinder closed at the bottom by a supported filter paper. The sample is usually 600 cc.; gas pressure 100 p. s. i., and the filter paper used is Whatman No. 50 or 52. For a suitable low-penetrating fluid a fluid loss of 100 cc.

3
or less, preferably 50 cc. or less, in 30 minutes, is desirable. The filtrate rate of oil field brines and crude oils is usually so great that measurements at 30 minutes are meaningless.

As described above, a hydrocarbon fluid which is initially unsatisfactory for hydraulic fracturing of formations can be converted to a low-penetrating fluid by adding a bodying agent. Such bodying agent may comprise, for example, colloid material; a metallic soap of an organic acid; a high molecular weight olefin polymer, high molecular weight linear polymers such as polypropylene; or plastering agents such as blown asphalt, pitch, or the like.

The salts of fatty acids, particularly the aluminum salts thereof, are in general a preferred bodying agent which produces the desired low-penetrating fluid by mixing with one or more hydrocarbons. A particularly useful bodying agent of this type can be compounded from a mixture of soaps. Thus a mixture of aluminum laurate or a saturated fatty acid soap containing at least 40-50% of this substance or of a functionally related acid soap can be used in admixture with an aluminum soap or soaps selected from a group including soaps of cycloaliphatic and unsaturated acids; i. e., aluminum naphthenate, oleate, oleate-linoleate, or the like. Such combination of an aluminum soap of the laurate type with one or more soaps of the naphthenate-oleate type gives a thickening or bodying agent of distinctive and superior properties not produced by either component alone. When prepared by the precipitation process a mixed solid soap is produced which withstands ordinary handling and storing conditions and which is readily soluble in the oily liquid to produce a highly viscous fluid or gel. It is found, for example, that at about 75° F. from about 0.5% to about 10% of this type soap disperses in gasoline or crude oil in a time of from about 15 seconds to about 2 hours and that gels having a suitable filtrate rate and viscosity to produce non-penetrating liquid result in from about 30 seconds to about 3 hours.

It has been found that from about 0.5% to about 10% of this aluminum soap by weight relative to the oily liquid, preferably between about 3 and about 6%, produces a suitable gel adapted for fracturing most formations in accordance with this invention. However, the greater the amount of soap the more difficult it is to break the gel. By my invention, however, lower proportions of soap can be used.

Soaps produced by or from ammonia or the metals; lithium, magnesium, calcium, lead, nickel, cadmium, strontium and mercury can also be employed. In general it will be found that mixtures of such soaps and light oils including gasoline, kerosene, gas oil, crude oil and the like may be made in the desired consistencies (up to 10% soap) by heating to a temperature in the range of about 200 to 260° F. As in the case of the other soaps, agitation or stirring aids the solvation of the soap.

In accordance with a preferred embodiment preparing the gel, the proportion of soap is added to a measured quantity of the oil liquid while stirring and sometimes the liquid may be heated to advantage during the compounding. It has been found that the gel characteristics will develop in the well and therefore the soap-liquid dispersion may be introduced into a well before the maximum viscosity is reached. Accordingly, when the gellation has proceeded to a point at which the viscosity is sufficient to maintain in suspension substantially all the particles of undispersed soap and the granular propping agent, if such agent is used, the dispersion is pumped into the well. The gel may be injected immediately into the formation or it may be allowed to stand in the well until the main gelation has developed.

However produced, the low-penetrating fluid is placed in a well, preferably through a separate tube at and above the elevation of the formation to be fractured. If desired, packers may be used to isolate and confine a section of the well which is to be fractured. Another fluid may

be placed above the low-penetrating fluid in the well and then pressure is applied by means of the low explosive described above.

During the hydraulic fracturing operation two injection pressure levels are encountered. One is the formation breakdown pressure described and defined above and is ordinarily between about 0.6 and 0.85 pounds per square inch per foot of depth. The pressure required to inject the fracturing gel into the fracture may be referred to as the overburden pressure and is somewhat less than the formation breakdown pressure, ranging from between about 0.5 to about 0.7 p. s. i. per foot of depth. Due to the large volumes of gel being handled and the friction loss in passage through the pipe or tubing, approximately 100 p. s. i. per 1000 feet of depth must be added to the overburden pressure in determining the injection pressure. Accordingly, the sum of the pressure necessary to overcome friction loss and the overburden pressure, less the hydrostatic pressure exerted by the fluid column, is the surface injection pressure necessary to extend the produced fracture.

Generally about 1% breaker based upon the volume of the fracturing liquid and diluted with a suitable solvent such as gasoline is introduced following the fracturing liquid to reduce the viscosity or break the gel so that when the well is produced the sol or liquid will flow out of the formation. Also, a peptizer or gel-breaker may be incorporated in the viscous liquid and reverts the gel to a sol or liquid after a time delay. For example, from about 1% to about 3% by volume of water may be emulsified or otherwise incorporated in the viscous liquid and becomes effective several hours after the non-penetrating liquid has reached the formation and been placed within the fracture. Likewise, other gel breakers which become effective at the temperatures of the formation may be incorporated in the viscous liquid.

Among suitable materials for breaking the gel and reducing the viscosity of soap-hydrocarbon gels it has been found that the water-soluble amines such as ethanolamines or similar ammoniacal compounds, and the oil soluble sulfonates are particularly effective. Other suitable gel-breakers are ammonia, alkali, oxides and hydroxides and the stronger acids.

While, as indicated above, a gel breaker is usually necessary, it has been found that some of the gels, particularly those produced by the hydroxy-aluminum soaps, may be broken by the connate aqueous fluids found in most formations. Breaking the gel by this means is necessarily slow since the gel must be adapted to withstand the effect of the gel-breaking for a time sufficient to permit placement of the gel. In some instances hot gases produced by the low explosive in accordance with my invention will also have the effect of breaking the gel but such effect is necessarily slow with respect to the pressure surge exerted by the gases and therefore the fracture is effected before the gel is broken.

As pointed out above, propping agents, preferably sand or the like, may be incorporated in the viscous liquid. These props, due to the high suspending forces of the gelled viscous liquid, are carried into the formation fracture and deposited in the fracture when the temporary viscosity of the liquid is broken. The props are held within the fracture when the formation is collapsed and the sol flows from the formation, leaving the permeable channel in the produced fracture.

In preparing to treat a well, the rods and tubing are pulled from the well and rerun with a suitable packer or packers to isolate the formation to be fractured. The packers may be of the hydraulically inflatable type and are adapted to segregate a relatively small area of the formation traversed by the well. It should be understood, however, that the operation can be also conducted in cased wells, and in that event the casing is perforated between the packers.

A fracturing liquid is made up by adding about 6% by

volume of aluminum soap as described above to about 25 barrels of crude oil with agitation and at a temperature of about 75° F. Agitation is continued for about an hour, at which time the viscosity increases to approximately about 200 centipoises on a Stormer viscosimeter operating at about 600 R. P. M. Such a non-penetrating liquid has a filtrate rate of about 20 cc. in 30 minutes.

When the viscosity of the fracturing liquid reaches a minimum of about 200 centipoises it is injected into the well through the tubing at a rate of about 4 to 5 barrels per minute. About 0.15 pound of sand or other prop per gel is mixed into the fracturing liquid at the well head. After the fracturing liquid has been introduced into the tubing, it is followed immediately by about two barrels of crude oil to act as a separating plug between the fracturing liquid and the gel breaker which is to follow immediately at substantially the same rate.

A suitable gel breaker is compounded from about 25 barrels of gasoline containing about 35 gallons of 60% oil-soluble sulfonates and 40% aromatic petroleum solvents. In order to later displace the gel breaker from the tubing and well into the formation about 25 additional barrels of crude oil are pumped into the well following the gel-breaker solution.

Up to this point of the operation ordinary mechanical pumps are satisfactory for the introduction of the fracturing fluid. However, the injection rate and viscosity relationship for fracturing a porous formation may be determined by the following formula:

$$Q = \frac{0.0389 \ h K \Delta P}{u}$$

Q =injection rate in gallons per minute
 h =thickness of the formation exposed to the gel
 K =horizontal permeability of the formation in Darcys
 ΔP =formation breakdown pressure in p. s. i.
 u =viscosity in centipoises

It will be seen therefore that lower viscosity materials can be used only when the injection rate is high and in porous formations ordinary mechanical pumps are not capable of applying a sustained flow at a sufficiently high rate even where gelled materials are used. By my invention this rate-viscosity relationship is considerably broadened, since the pumping rate can be increased infinitely by propelling the hydraulic fluid into and against the formation by means of a large volume of gas produced by a deflagrating explosive.

In general, the smaller the quantity of gel or gel plus gel breaker used in hydraulic fracturing, the smaller the quantity of powder needed. This is due to the fact that the taller the column of liquid remaining in the well after the fracturing, the less space there is to be filled by the gaseous products of the slow explosive at atmospheric or superatmospheric pressure. Accordingly, the slow explosive propulsion method is particularly advantageous when no gel breaker is added or when the fracturing is done in one step and the gel breaker fluid is forced into the formation in a second step. Between the two steps or stages additional crude oil can be added to the casing and a second charge of slow explosive used to propel the gel breaker or additional gel into the produced fracture. Likewise, the second stage of the operation can be effected by mechanical pumping since fluid loss to the formation is not objectionable.

In a typical well having a depth of about 6,000 feet and provided with a 6-inch casing to a point above the formation to be fractured I may inject into the formation between about 1000 and 2000 gallons of gel or gel and gel breaker. The gel weighs about 6.6 pounds per gallon and 2000 gallons occupy about 1360 feet of the casing. The casing above the level of the gel is filled with crude oil weighing about 7.2 lbs. per gallon to a point near the top of the well, leaving enough space for the slow explosive material. Thus a column of about 4430 feet of crude oil would be superimposed on the 1360

feet of gel. The hydrostatic head of such a column of gel and crude oil in the casing amounts to approximately 2000 p. s. i. The formation pressure at the bottom of the well is about 800 p. s. i., giving an effective pressure of about 1200 p. s. i. The formation breakdown pressure is calculated at about 0.6 times the depth of the well in feet or about 3600 p. s. i. Accordingly, an additional pressure initially amounting to 2400 p. s. i. is applied by the slow explosive to the fluid in the casing in order to fracture the formation and to permit the gel to enter the fracture.

A suitable slow explosive is a deflagrating powder such as DuPont pellet powder No. 3 grade having a density of about 1.2 and producing about 500 volumes at normal temperature and pressure of non-condensable gas per unit volume of explosive. This particular powder is slow acting and its density is such that a larger volume of gas per volume of powder is produced than with some other slow-burning explosive. Such powders heave and propel slowly but effectively with a minimum shattering effect.

When about 2000 gallons of the fluid in the well have been injected into the formation, the well casing contains about 4430 feet of crude oil and the 1360 feet of gel has been displaced by the gaseous products of the slow explosive. Thus, following the explosion a net hydrostatic head due to the column of crude oil in the well and the friction loss of about 100 lbs. per 1000 feet of casing amounts to about 1200 p. s. i. when the formation pressure is about 800 p. s. i. Accordingly, the hydrostatic head of the crude oil is sufficient to overcome the formation pressure following the fracturing of the well and the 1560 feet of casing above the crude oil is filled with the decomposition gases at approximately atmospheric pressure.

About 45 to 50 pounds of the slow explosive comprising DuPont Powder #3 will provide such a gas volume at a well temperature of about 150° F. and give the desired force for hydraulically fracturing the formation at the base of the well and displace the 2000 gallons of liquid into the formation. This quantity of powder occupies about 4.5 feet of a 6 inch casing and can be disposed within an inverted cartridge case adapted to be fired from the bottom to the top.

If additional fluids, such as a gel breaker, are to be injected, more crude or filler can be added to the casing and a second explosive charge (or ordinary mechanical pumps) used to propel the fluid downwardly within the well and into the produced fracture. Finally, the hydrocarbon liquid can be produced from the formation and through the tubing.

Although specific embodiments of my invention have been described, it should be understood that these are by way of illustration only and that the invention is not limited thereto since alternative procedures and separating conditions will become apparent to those skilled in the art in view of my disclosure. For example, the technique can also be applied to cased wells where the fracturing is done through casing perforations. However, when treating such a well it is usually necessary to fill the annulus between the tubing and the casing to prevent collapse of the case. Accordingly, modifications of my invention are contemplated without departing from the spirit of my described invention or from the scope of the appended claims.

I claim:

1. A method of increasing the productivity of a porous producing formation traversed by a well bore which comprises disposing adjacent and above said formation a column of hydrocarbon gel, applying to said gel a greater-than-formation breakdown pressure produced by initiating a deflagrating explosive to liberate a high pressure gas above said column, the said gas being sufficient in volume and pressure to continue the application of the pressure of said gas on said column for a sustained period until

at least a part of the gel enters a fracture in the formation whereupon a drop in pressure occurs, subsequently reverting the gel within said fracture to a hydrocarbon liquid by adding a gel breaker thereto, and producing the hydrocarbon liquid from the fracture.

2. The method of increasing the productivity of a porous formation into which a well extends, which method comprises placing a large mass of a hydrocarbon gel in said well at and in a column immediately above the level of said formation, also placing in communication with said well an amount of a deflagrating explosive sufficient to produce a volume of propelling gas at greater-than-formation breakdown pressure, sealing said well, initiating said explosive to create a pressure sufficient to force said gel from said column into the region of said formation at a sufficiently rapid rate to overcome the fluid loss to the formation and to fracture said formation whereby at least a portion of the gel is positioned in the fracture, breaking the hydrocarbon gel in the fracture to a liquid, and withdrawing the resolved hydrocarbon liquid from the well.

3. A method of increasing the productivity of a porous producing formation traversed by a well bore which comprises disposing within said well adjacent and above said formation a column of a gelled liquid, applying to said column a greater-than-formation breakdown pressure produced by chemically generating high pressure gas above said column at a rate greater than the rate of fluid loss to the formation the volume and pressure of the gas being sufficient to continue the application of the pressure on said column for a period of seconds to produce a fracture in the said formation, to introduce at least a part of the gelled liquid into said fracture in the said formation, subsequently resolving the gel characteristics of the liquid in said fracture within the formation, and flowing the resolved gel from the fracture into the well bore.

4. A method of increasing the fluid productivity of a formation penetrated by a well, which method comprises pumping a low-penetrating liquid fracturing medium into a confined zone in said well including said formation, applying gas pressure progressively produced by a deflagrating explosive to said low-penetrating liquid in said confined zone whereby the pressure on the liquid at said formation is above about between 0.6 and 0.85 pounds per square inch per foot of depth to said confined zone and until a fracture occurs and the pressure is substantially decreased below that existing immediately after initiating the deflagrating explosion, decreasing the low-penetrating characteristics of the low-penetrating liquid while retaining the low-penetrating liquid within said formation for a substantial period of time, and withdrawing the liquid from said formation.

5. The method of increasing the fluid productivity of a formation penetrated by a well, which method comprises introducing into the well a pumpable fracturing liquid

compatible with said fluid, said fracturing liquid having a viscosity substantially greater than the viscosity of the said fluid, pumping additional liquid into the well as a follower for said fracturing liquid, confining said fracturing and follower liquids within the well in contact with the formation, applying pressure to the confined liquids by means of a deflagrating explosive to increase the pressure exerted at the formation by the fracturing liquid whereby a formation fracture occurs, resuming the pumping of follower liquid after the production of the fracture to displace at least a part of the fracturing liquid from the well into passages formed in the formation, reducing substantially the viscosity of the liquid in said passages, and withdrawing the liquid of reduced viscosity from the passages by flowing liquids from said well.

6. The method of increasing the productivity of liquids from formations traversed by a well bore which method comprises placing in said well at the level of said formation a large mass of a low-penetrating fluid which remains fluent in the well, said mass extending a substantial distance in a column above said level, confining said mass within said well, placing in communication with said mass an amount of a deflagrating explosive sufficient to produce a formation fracture, initiating said explosive to create a sustained propellant force on said low-penetrating fluid from said column onto the formation sufficient to fracture said formation, and displacing at least a portion of the low-penetrating fluid into the produced fracture.

7. The method of claim 6 which includes the additional steps of decreasing the low-penetrating characteristics of the low-penetrating fluid while retaining the displaced low-penetrating fluid within said formation for a substantial period of time, and withdrawing the fluid of decreased low-penetrating characteristics from said formation.

References Cited in the file of this patent

UNITED STATES PATENTS

Re. 4,770	Noble	Feb. 27, 1872
1,588,643	Alexander	June 15, 1926
1,856,912	Grebe et al.	May 3, 1932
2,171,416	Lee	Aug. 29, 1939
2,316,596	Kennedy	Apr. 13, 1943
2,596,845	Clark	May 13, 1952
2,618,343	Conrad	Nov. 18, 1952

FOREIGN PATENTS

28,030	Great Britain	1911
--------	---------------	------

OTHER REFERENCES

Clark, "Hydrafrac Process for Increasing the Productivity of Wells," The Petroleum Engineer, Reference Annual, 1949, B-3.

Clark, "Hydrafrac Process for Increasing Productivity of Wells," The Oil and Gas Journal, Oct. 14, 1948, page 76.