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COMBINATION HYDRAULIC-EXPLOSIVE EARTH FORMATION FRACTURING PROCESS

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This invention relates to a novel process for treating an earth formation and more particularly is concerned with a new and useful process for initiating, enlarging and extending cracks and fissures in earth formations.

It is a principal object of the present invention to provide a novel process for fracturing earth formations, particularly oil-bearing earth formations.

It is another object of the present invention to provide a novel fracturing process employing in combination specific and integrated hydraulic and explosive fracture stages.

It is a further object of the present invention to provide an earth fracturing process utilizing explosive wherein the explosive composition is formulated in the formation.

It is another object of the present invention to provide a fracturing process wherein one of the explosive components serves as a propping agent during an initial hydraulic fracture stage.

It is also an object of the present invention to provide a combination hydraulic-explosive earth formation fracturing process which engenders high energy for good fracturing and the promotion of permeability of earth formations.

These and other objects and advantages will become apparent from the detailed description presented hereinafter.

The novel process of the present invention comprises first treating an earth formation to be fractured with a fracturing fluid consisting of a liquid hydrocarbon having particulate light metals admixed therein. The liquid hydrocarbon-metal slurry is injected into the formation at a predetermined locus at pressures sufficient to initiate fractures in the earth formation. The slurry is injected at a pumping rate to provide a high pressure sufficient to part or fracture a formation surrounding a well bore or other earth formation, i.e., to achieve formation breakdown pressure as is understood by one skilled in the hydraulic fracturing art. As the fractures initiated by this hydraulic action propagate and extend themselves, the light metal particles become lodged therein serving as propping agents. Following the hydraulic fracture step, an oxidizer solution which forms an explosive composition with the light metal particles is injected into the fractured formation displacing the hydrocarbon hydraulic fracture fluid. As the hydrocarbon fluid is displaced by the oxidizer, a metallized explosive composition forms in situ. This composition is initiated by conventional detonators or by autodetonation in certain instances. Upon detonation, further extension and propagation of the fractures in the formation occur thereby producing a marked increase in the permeability and fracturing of the formation over that obtained with hydraulic fracture alone.

Hydrocarbon fracturing fluids to be used are those ordinarily utilized in earth and well fracturing operations. These include, for example, petrolic liquids, such as crude oil and liquid hydrocarbon derived or fractionated therefrom as well as petroleum based liquids to which various additives, improvers, fluid loss control agents, thickeners and stabilizers have been added. Specific examples of hydrocarbons suitable for use as fracturing fluids are crude oil, fuel oil, lubricating oil fractions and mixtures thereof, soap thickened gasoline and

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kerosene. Preferably, liquids of low volatility such as the fuel oils and lightweight lubricating oils are to be preferred.

Light metals for use in the present process are those materials which commonly are used as fuel components in explosive compositions. Magnesium, aluminum, silicon, magnesium alloys, aluminum alloys, silicon alloys and mixtures thereof are particularly suitable for use in the present process.

Ordinarily to assure propagation of the resulting explosive through small width cracks in the formation, magnesium, aluminum and alloys and mixtures thereof of particle size of less than about 200 mesh U.S. Standard Sieve are used. Coarser metals, i.e., up to about 30 mesh U.S. Standard Sieve can be employed, preferably if used in admixture with a finely divided metal, e.g. minus 325 mesh U.S. Standard Sieve. Both spherical particles and irregular, non-equiaxed chips and flakes are suitable for use. The latter materials are particularly suitable in that they provide a high surface area per unit volume. The smaller particles which have high specific surface area per unit volume also offer an added advantage in that the resulting exotherm of the autoreaction during formation of the metallized explosive composition can be rapid enough to cause autodetonation of the resulting explosive.

Oxidizer solutions for use in the process are those which provide an explosive composition with the metal fuel. Ammonium and alkali metal nitrates and perchlorates preferably are employed. Preferably these solutions will be concentrated so as to be near the saturation point. Nitrogen tetroxide and solutions of oxidizing acids, e.g., HNO_3 , also can be employed.

A very suitable oxidizer solution is Divers liquid, i.e., a saturated ammoniacal solution of ammonium nitrate. Also aqueous and aqueous ammoniacal solutions of ammonium nitrate substantially saturated with respect to the ammonium nitrate solute are satisfactory for use in the present process.

The relative amounts of particulate metal and oxidizer solution in the explosive composition, based on the final composition, range from about 5–60 weight percent metal to about 95–40 weight percent oxidizer solution. Preferably the resulting explosive composition contains metal and oxidizer solutions such that the amount of fuel and oxidizer solution solute are stoichiometrically fuel-oxidizer balanced. The amounts of the components present in the formation can be ascertained from the material flow rates and total amount of reactants introduced into the formation.

Initiation of the resulting explosive composition produced in situ in the formation is accomplished by autodetonation with certain type metal components or by a conventional booster detonator or jet perforating gun positioned in the bottom of the bore hole or adjacent the strata from which the earth fracturing was initiated. Also a small primer charge of an explosive, e.g., nitroglycerine, TNT, RDX, dynamite, blasting gelatin, ammonium nitrate-fuel oil, metallized ammonium nitrate compositions, etc. can be placed in the bore hole opposite the loaded fractures and detonated.

Autodetonation of the explosive composition can be achieved by use of metal powders having a high specific surface area per unit volume where the exotherm of the autoreaction of metal and oxidizer becomes rapid enough to cause detonation of the mix.

In the present process wherein the explosive is confined and generated in an earth strata, the conditions are favorable for forming an explosive which undergoes autodetonation. Control of detonation time can be achieved by coating the fine metal particles with a heavy oil, wax, plastic, alkali metal dichromate, or the like protective

material to decrease the rate of contact of the oxidizer solution with the metal, thereby slowing the autoreaction and rate of rise of the resulting exotherm, thus extending the time before autodetonation occurs.

The actual size, shape and amount of metal to be employed in preparing an autodetonatable mix can be determined by one skilled in the art. In any event, the mass and particle size of the metal is to be selected such that premature autodetonations do not occur.

Material handling equipment, pressure pumps, mixing tanks, transport lines, well connectors and the like to be employed are those ordinarily employed for pressurizing and fracturing earth formations.

The following examples will serve to further illustrate the present invention but are not meant to limit it thereto.

Example 1.—A slurry of low viscosity petroleum fraction oil having about 20 weight percent of -80 mesh magnesium particles is injected into an oil-bearing formation at the bottom of a well at a pressure sufficient to fracture the formation. As the fracturing proceeds out from the well bore the metal particles lodge in the generated fissures and prop open these cracks.

Following the fracturing treatment a substantially saturated solution of ammonium nitrate dissolved in ammonia to which is added up to about 6 percent water is injected into the formation displacing the hydrocarbon oil fracturing fluid. The amount of solution injected is calculated to be such that the resulting explosive composition contains from about 10 to about 60 weight percent metal, the balance being oxidizer solution. Following the displacement of the hydrocarbon liquid by the oxidizer solution, an explosive initiator is positioned in the well bore adjacent the fractures loaded with explosive. Conveniently, a small primer charge of a high explosive, e.g., nitroglycerine, trinitrotoluene or dynamite is positioned in the well bore and detonated. Also, shaped charges held in a standard perforating gun or other holder and directed into the formation are satisfactory for detonation of the explosive produced in the fissure. The resulting explosive work provided as the ammonium nitrate-magnesium explosive in the fissures explodes markedly promotes and extends the fracture pattern and permeability of the earth formation.

An advantage of the present ammoniacal ammonium nitrate solution-particulate magnesium explosive composition formed in situ in the formation is that the reactant materials individually are safe to handle during the injection stages. Further, a relatively insensitive explosive composition forms upon first admixing these components. However, after a period of several minutes or more contact time, the ammonium nitrate solution and magnesium react in the formation to provide a solid, sensitive explosive which readily is initiated and gives excellent explosive power and work. Instead of magnesium, magnesium alloys or metal mixtures containing a reactive magnesium component which reacts with ammonium nitrate solution to give a desirable autoreaction with the ammonium nitrate solution upon standing can be employed to advantage in the present process.

Example 2.—A laboratory study was carried out to confirm the propagation in thin sections of a metallized ammonium nitrate explosive composition produced in situ in the present process. For this test a 1/8 inch thick by 4 1/4 diameter standard asbestos-Teflon filled stainless steel wound gasket was positioned between two 4 inch steel blind flanges. One of the flanges was fitted with a fitting and inlet valve attached to a pressurizable container which in turn was connected to a cylinder of pressurized nitrogen gas. A mixture of about 16 1/2 parts by weight of magnesium powder (<1% +40 mesh, at least about 96% +40/140 mesh, about <4% minus 140 mesh U.S. Standard Sieve) and about 3 parts by weight of minus 325 mesh U.S. Standard Sieve magnesium powder was placed in the open area inside the gasket and the two flanges assembled and tightly held together by a series of nuts and

bolts around their outer periphery. About 50.6 parts by weight Divers liquid was forced from the pressurizable reservoir into the volume between the flanges holding the magnesium powder. It took less than one second to inject the Divers liquid into the test apparatus after which time the inlet valve was closed. The resulting mixture was allowed to stand and in about 5 seconds an explosive type reaction initiated. Initiation of the detonation occurred through sudden heating of autoreaction of the mixture in the confined area of this test rig. This in reality gave the same action as is achieved by a Thermit initiator placed in contact with the explosive in a fracturing operation. Following the explosive reaction, the assembly was taken apart and examined. The mix was found to have undergone violent and rapid explosive reaction as evidenced by the appearance of magnesium oxide and actual rupturing of the thick stainless steel wound gasket.

In a second run to demonstrate propagation of the explosive through small cracks and fissures about 20 parts by weight of minus 200 mesh magnesium powder were mixed with about 20 parts by weight of aluminum powder (100 percent minus 40 mesh and 40 percent minus 325 mesh). The powdered mixture was spread over the surface of a wooden board 2 units thick by 4 units wide by 8 units long. Sixty parts by weight of an ammoniacal solution substantially saturated with ammonium nitrate (69.9 percent NH_4NO_3 , 5.5 percent H_2O and 24.6 percent NH_3) was poured over the powdered metal mixture. A matching board was placed on top of the resulting explosive composition and pressed down until there was a layer of explosive about 1/8 unit thickness between the two boards. A No. 8 electric blasting cap was placed adjacent to this layer at one side of the boards and initiated. Detonation of the mix occurred and the top board was thrown approximately 100 feet into the air. This board was recovered and upon examination showed indentation of the softer grains of wood over its entire surface which faced the explosive. This served to show that the explosive had propagated throughout its entire extent in that detonation had extended across the entire surface of the board.

In another run, a mixture of about 10 parts by weight of a spherical magnesium powder (nominal mesh size about minus 80 mesh) and about 10 parts by weight of the aluminum powder of the same mesh size as for the previous run was wet with about 80 parts by weight of the ammoniacal ammonium nitrate solution. The resulting mix was pressed between two wooden boards as described for the preceding run to form a layer explosive of the same thickness as in the previous run. This mix also was detonated by a No. 8 electrical cap. Good detonation of the explosive and propagation throughout the mix were evidenced the same as in the previous run by the throw of the board and examination of its surface after the explosion.

In a further test, a 300 part by weight mixture of 50 percent minus 70 mesh Mg_2Si and about 50 percent of the ammoniacal ammonium nitrate solution were poured onto a plastic sheet on level ground. This provided an explosive configuration which was about 1/2 unit thick in the center and tapered to about 1/8 unit thickness over about a 7 unit radius. The mixture was detonated in the unconfined condition by means of a No. 8 electric blasting cap positioned in the center of the mix. Examination of the explosive site after detonation indicated that propagation extended out to a point where the thickness of the explosive layer was about 3/16 of a unit. With confinement the thickness for propagation would be even smaller.

Various modifications can be made in the present invention without departing from the spirit or scope thereof for it is understood that we limit ourselves only as defined in the appended claims.

We claim:

1. A process for producing fractures in an earth formation which comprises:

(a) introducing a hydraulic fracturing fluid into an

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earth formation at a pressure sufficient to initiate fractures in said earth formation, said fracturing fluid consisting of a slurry of a liquid hydrocarbon having particulate light metal admixed therewith, said light metal particles becoming lodged in the fractures initiated by the hydraulic fracturing action,

- (b) introducing an oxidizer solution into the fractured formation thereby displacing the hydrocarbon fracture fluid from contact with the light metal particles, said oxidizer solution forming an explosive composition with the light metal particles in the formation,
- (c) introducing an explosive detonator adjacent the explosive composition, and
- (d) initiating said detonator thereby to promote explosion of said explosive composition in the fractures of said formation further extending said fractures and promoting the permeability of said formation.

2. A process for promoting fractures and permeability of an oil-bearing earth formation which comprises:

- (a) introducing through a well bore into an oil-bearing formation at a pressure sufficient to fracture said formation a slurry of a petroleum oil having a particulate light metal admixed therewith, said light metal comprising a magnesium component which undergoes autoreaction with ammonium nitrate solutions to provide a substantially solid explosive composition,
- (b) injecting into said formation after the hydraulic treatment an ammoniacal ammonium nitrate solution substantially saturated with ammonium nitrate, said solution displacing the hydrocarbon oil fracturing fluid from said light metal particles lodged in the fractures of said formation, the amount of said ammonium nitrate solution injected being such that an explosive composition forms with said metal particles, said composition containing from about 10 to about 60 weight percent metal at from about 90 to about 40 weight percent of the ammonium nitrate component,
- (c) positioning an initiator for said explosive in the well bore adjacent the fractures loaded with said explosive composition, and
- (d) detonating said initiator thereby to initiate said explosive composition in said fractures, the detonation of said explosive composition promoting and extending the fracture pattern and permeability of said oil-bearing formation.

3. A process for promoting fractures and permeability of an oil-bearing earth formation which comprises:

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- (a) introducing through a well bore into an oil-bearing formation at an injection rate sufficient to achieve hydraulic formation breakdown a slurry of a petroleum oil fraction having about 20 weight percent particulate magnesium therein and lodging said particulate magnesium in the fractures produced in said formation, said petroleum oil fraction being of low volatility and a consistency of a lightweight lubricating oil, said particulate magnesium being a mixture about 85% flake ranging substantially from about 40 to about 140 mesh U.S. Standard Sieve and about 15% minus 325 mesh U.S. Standard Sieve magnesium powder,
- (b) injecting into said formation after the hydraulic treatment with said petroleum oil fraction-magnesium slurry an ammonium nitrate solution in an amount to provide an explosive composition substantially stoichiometrically fuel-oxidizer balanced with respect to the weight of said magnesium particles and the ammonium nitrate content of said ammoniacal ammonium nitrate solution, said ammonium nitrate solution being substantially saturated with ammonium nitrate and containing about 6 weight percent water,
- (c) displacing with said ammoniacal ammonium nitrate solution the petroleum oil fracturing fluid from said light metal particles lodged in the fractures of said formation and providing in said fractures an explosive composition of said ammonium nitrate solution and said particulate magnesium, autoreacting the particulate magnesium with said ammonium nitrate solution of said explosive composition in the fractures of said formation to provide a rapid exotherm and initiation of said explosive composition in said fractures thereby detonating said explosive composition in said fractures, the detonation of said explosive composition promoting and extending the fracture pattern and permeability of said oil-bearing formation.

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