GAS-GENERATING DEVICE FOR STIMULATING THE FLOW OF WELL FLUIDS

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ABSTRACT OF THE DISCLOSURE

A gas-generating device for use in a well, including a plurality of spaced combustible charges adapted to be ignited in sequence to form a supply of high pressure gas which is admitted to the well to stimulate the same.

A summary of the invention

The present invention relates in general to a means for stimulating the flow of fluids in wells, such as in oil wells, to initiate or increase production therefrom and, more particularly, to a means for increasing the permeability of a productive formation into which the well bore extends so as to increase the flow of oil, or other fluids, from the formation into the well bore.

This invention involves the production of a controlled, gradually increasing volume of gas generated at a varying rate in a water-tight container, the pressure of the gas therein at a predetermined pressure unsealing a seal in a port communicating between the interior of the container and the exterior, so that in a well bore containing fluids proximate to a productive formation the continuing but varying evolution of gas from the container exerts increasing pressure upon the fluids, the high pressure fluids ultimately initiating a fracture of the productive formation and infiltrating the formation and thereby extending the fracture. Thus, in the practice of the present invention no catastrophic pressure is generated during the stimulation of a well.

In the past the stimulation of a well has generally been undertaken by the injection of substantially large volumes of fluid under high pressure into a well bore, necessitating the use of extensive equipment, such as surface pumps and high pressure casing or tubing extending from the vicinity of the producing zone to the surface. Many wells have not responded to such stimulation, generally because of too high a breakdown pressure required or because friction losses of fluid in the casing or tubing have not permitted sufficiently high injection rates, irrespective of the power of the surface pumps which have been used.

Repeated attempts have been made to eliminate the need for such surface pumps by the use of explosive, propellant and rocket charges, which have been lowered into wells and actuated in the vicinity of a productive formation. Successful stimulation has resulted as long as the weight of the charges has been maintained below a certain level, which is particularly important when multiple zones are sought to be produced from the same well and fracturing of the productive formation is undertaken through perforations in a well casing. The use of excessive pressure in a well has often broken the cement bond used between casing and the productive formation and has thus permitted undesirable communication between different zones, including oil, gas, and water zones.

It is characteristic of any conventional propellant that changes in temperature and backpressure have a pronounced effect on its burning rate, and the foregoing factors are even more pronounced when the size and weight of a propellant charge are increased. Since the combination of well conditions, such as temperature, pressure, and effective orifices or permeability, are never the same, even for adjacent wells, the utilization of propellants or similar gas-generating means has often been hazardous to wells which have been sought to be stimulated by such means, many times because seemingly insignificant changes in the well conditions from those anticipated have altered the burning rate of the propellant sufficiently to provide catastrophic gas pressure increases with what has otherwise been a safe charge.

In addition, in the manufacture of propellants mistakes have often been detected, the mistakes at times producing disastrous results.

The present invention enables the successful stimulation of a well by the use of means to generate a just-high-enough gas pressure to initiate the fracture of a desired formation and to maintain a sufficiently high fluid injection rate into the fractured formation to thus extend the fracture. The present invention minimizes unusual pressure developments in a well bore.

A primary object of the invention, therefore is to provide apparatus which will fissure a productive formation generally radially outwardly from the well bore in a controlled manner, with little or no shattering or compaction of the formation, to increase the permeability of the formation and to initiate or increase production therefrom without adversely affected the overall consolidation of the formation.

A further object of the invention is to produce controlled fissuring of the productive formation by igniting and burning a charge, particularly a propellant charge, in a well bore in a variable but controlled, manner so that as the charge burns it produces in the fluids adjacent to the productive formation and communicates thereto gas pressure sufficient to fissure the formation in a controlled manner, but of insufficient magnitude to shatter or otherwise destructively affect the formation. The use of various barriers, such as thermal-insulating members, and the like, permits the use of a much larger quantity of gas-generating material, without the danger of losing control of the charge. Thus, if one of the gas-generating units burns too rapidly, one of the thermal-insulating members or one of the cigarette-burning-like units, and the like will prevent the entire charge from uncontrollable burning.

Thus, after unsealing of a seal or rupture of a frangible disc in a port or ports communicating the interior of the container in which the charge is stored to the exterior of the container, or after the port is otherwise opened, the varying gas pressures are transmitted directly, or through a casing to fluids in the well bore proximate to the productive formation, the fluids subject to the pressures causing a shifting of the formation layers with respect to each other. The fluid pressure tends to force fluid in the well bore into the shifting interfaces of the productive formation. In a cased well, this occurs at the point or points where the casing has been provided with perforations of adequate diameter. This action establishes permanent breaks in the productive formation and one or more fissures, which are extended away from the well bore as the gas continues to evolve from the charge in the container and more fluid is forced into the fissure or fissures. Of course, these fissures may be further extended, if desired or required, by the application of additional gas-generating apparatus, as described, in the vicinity of the formation. They may also be extended by acidizing or by similar means.

A further object of the invention is to control the rate of combustion of the gas-generating charge, such as by regulating the ignition, the size of the particles or grains.
of a propellant and the pattern thereof, and the mass of each of a plurality of units which may comprise the charge.

Typical gas-generating units include, for example, a propellant mass combustible substantially at once over its section; a relatively narrow mass of propellant; a relatively narrow mass of propellant at least partially surrounded by an inert member; a relatively narrow mass of propellant at least partially surrounded by a heat-insulating member; a propellant mass combustible initially only over a limited portion of its cross section; a charge of burning material, the latter material comprising, for example, a tube or cord, or a tube or cord impregnated with a slowly combustible material, such as a slow or cigarette-burning-like fuse, and the like, the cigarette-burning-like material also serving as a hot, high pressure gas seal; a propellant mass surrounded at least partially by a resilient bonding material or sealant; a propellant mass having a heat exchange member in contact with the entire cross section of its end nearest the means for igniting the charge, so that the heat produced from the combustion of an adjacent or proximate unit is conducted through the heat-conducting member and ultimately ignites the next unit; and a propellant mass having a similar heat exchange member, but in contact with only a limited portion of the cross section of its end nearest the means for igniting the charge. Nonuniform ignition of a unit of gas-generating substance may include, for example, igniting the unit at one end only, igniting it at its center throughout a substantial portion of its length, igniting it at a plurality of axially spaced points, igniting it longitudinally but nonaxially, and the like. By varying some or all of the foregoing factors, the frequency and impulse of the gas pressures produced in the fluids in the well bore to fissure the productive formation may be varied.

A further object is to submerge the container carrying the gas-generating charge beneath a head of liquid sufficient to produce the desired fissuring of the productive formation. The head of liquid required will vary, but generally should be at least equivalent to 200 feet of liquid having a specific gravity of approximately one. In other words, the gas-generating charge should be preferably positioned above the productive formation to be fissured and beneath a head of at least 200 feet of oil, water, or a mixture thereof compatible with the particular formation, to obtain proper fissuring, a lesser head being possible where the density of the liquid is above unity due to the presence of drilling mud, for example. The container should preferably be positioned about 500 to 1000 feet above the formation to be fissured. In certain instances where other considerations dictate locating the container in closer proximity to the formation to be fissured, the amount of gas-generating charge may have to be reduced to prevent contact of the hot gases with the productive formation. It will be recognized that primarily the container should be so positioned within the well bore to permit gas evolving from one or more ports in the container to exert pressure upon fluid in the well bore. Thus, the container may be positioned above a head of liquid, but preferably should be submerged beneath the liquid and preferably above the productive formation.

The container, also may be located either below, or adjacent to perforations in a well bore having a casing. Most wells respond primarily to fluid pressure, while other wells may respond to high temperature gases, or a combination of the two.

A further object is to provide one or more gas exit ports in the container, the ports having seated therein a seal or frangible disc, or the like, so that at a predetermined pressure within the container the port or ports will open. A disc or plug which has been found particularly suitable is one resistant to both high pressure and high temperature, such as a steel plug, among the like. The port or ports may be located in the side or sides of the container or may be at either end, or at both ends, or any combination of the foregoing, provided the gas evolving from the port or ports is permitted to exert pressure upon the well bore fluids.

A further object of the invention is to provide a gas-generating charge, predominantly a gas-generating propellant charge, contained in an elongated container or cylinder, which preferably should have a diameter which is sufficiently less than the diameter of the well bore, so as to provide a liquid space alongside the charge, this liquid space being an annulus if the charge is centered in the well bore. For example, for a well bore of about 4 inches in diameter, or more, the diameter of the container should preferably be approximately 3 inches. The length of the container is made sufficient to accommodate the total mass of charge necessary to produce the desired fissuring of the formation. The container may be of any suitable material, a water-tight container capable of withstanding a reasonably high internal gas pressure being preferred. In using the present invention, for example, it has been discovered that it is possible to produce controlled gas pressures as high as about 3,000 to 4,000 p.s.i. for approximately 36 seconds or more.

A further object of the invention is to provide a series of housings, each containing at least one gas-generating charge, the housings being detachably connectable. Thus, a gas-generating apparatus may be assembled of any desired length and with any combination of housings and/or charges. The open end of the lowermost housing should be closed or capped. In addition, waterproof seals may be provided between the units, so that if water is permitted to infiltrate one of the units, the adjoining unit will not be affected thereby. The seals also prevent the charge from rising in the container because of a pressure differential between the units.

A further object is to provide a protective material in which one or more units of charge may be at least partially encased or carried, if desired. An elastomeric or similar sealant will serve to protect one or more of the units of charge from hot, high pressure gas. In addition to the container, an outer cover for a unit or units of charge, or for the unit or units of charge having a sealant, may be provided. The outer cover may consist of any suitable material, such as cardboard, asbestos, and the like.

A further object of the invention is to provide means for positioning the container in a well bore, preferably substantially above the productive formation. Typically, a cable is connected to the upper end of the container, the cable being of sufficient length to reach the surface of the earth above the well bore. The position of the container in the well bore should preferably not permit hot gases generated within the container to enter the productive formation, since it appears that an undesirable sealing effect can possibly take place due to "cooking out" of the lighter constituents of hydrocarbon. Preferably, only the well bore fluids should be injected into the formation. In some instances, for example where a suitable acid is provided in the well bore, hot gas damage in the productive formation may not occur, however, or may be cancelled out by the corrosive action of acid, etc.

Disclosure

The foregoing objects, advantages, features, and results of the present invention, together with various other objects, advantages, features, and results thereof which will be evident to those skilled in the art, may be attained with the exemplary embodiments of the invention illustrated in the accompanying drawings and described in detail hereinafter. Referring to the drawings:

FIG. 1 is a vertical sectional view illustrating in a well bore an apparatus of the invention.

FIG. 2 is an enlarged, vertical sectional view taken along the arrowed line 2-2 of FIG. 1, showing a plurality of housing units, each containing one or more units of gas-generating charge, and an igniting means
therefore, the housing units being positioned in a well bore; FIG. 3 is a transverse sectional view taken along the arrowed line 3—3 of FIG. 2; FIG. 4 is a view similar to FIG. 2, but showing a charge of propellant after partial combustion; FIG. 5 is a vertical sectional view illustrating another embodiment of the apparatus of the invention; FIG. 6 is a vertical sectional view illustrating another combination of units of the gas-generating substance; FIG. 7 is a vertical sectional view illustrating still another combination of units of the gas-generating substance; and FIG. 8 is a vertical sectional view illustrating yet another combination of units of the gas-generating substance.

Referring particularly to FIG. 1 of the drawings, illustrated therein is a well bore 10 which extends from the surface 12 into or through a productive formation 14, the permeability of which is to be increased by controlled fissuring generally-radially outwardly from the well bore, in accordance with the invention. In the particular installation illustrated, the well bore 10 is cased in the usual manner by a casing 16 which may be provided with perforations 18 communicating with the productive formation 14. Preferably, a casing packer 20 is provided to preclude a body of liquid 22 from surging upward in the well bore 10. The invention further involves positioning in the well bore 10, preferably above, or near, the productive formation 14, an elongated container 24 in which a gas-generating charge 26 (illustrated in FIGS. 2, 3, and 4) is carried in a plurality of housing units 28, 29, 31 and 33 which are connected in series, each of the housing units containing one or more units of the gas-generating charge, the details of the charge being set forth hereinafter. The lowermost housing unit is closed or capped by a lower closing cap 30. It is preferred that the container 24 be cylindrical and have a diameter considerably less than the diameter of the well bore 10, or considerably less than the inside diameter of the casing 16, to insure the presence of liquid alongside the container for the purpose of providing pressure in the liquid 22 in a manner to be described. The liquid 22 alongside the container 24 will have more or less the form of an annulus, depending upon whether the container is located to one side of center. The container 24 is supported in the well bore by a cable 32 which is joined to one end of the container, the cable extending to the surface 12.

Referring particularly to FIGS. 2 and 3, the charge 26 comprises predominantly a propellant which is relatively slow burning and non-detonating, propellants of this type being well known in the art, so that it is unnecessary to discuss specific examples herein. The charge 26 consists of a variety of units 34, 36, 38, 40, 41, 42, 44, and 46 of combustible material carried in the housing units 28, 29, 31 and 33. The housing units are joined together by threads 47, with high-pressure fluid and gas seals 49 being provided at each union. Ignition of the charge 26 is initiated by actuation of a conventional electrical igniter 48 carried in an upper or firing head 50, first flash-lighting the unit 34. The flash generated by the igniter is sufficient to ignite the unit 34, although an air gap is present between the unit and the igniter. The unit 34 comprises at least one grain of propellant and is not restricted as to its burning area. As combustion of the unit 34 progresses, the gas pressure generated in the housing unit 28, at a predetermined pressure therein, unscrews one or more discs 52 which are initially seated in their respective ports 54 carried by the housing unit 28, and the gas generated in the housing unit is permitted to begin to escape therefrom into the body of liquid 22, as indicated in FIG. 4, and the body of liquid 22 is thus subjected to gradually increasing pressure, which ultimately begins to force the liquid through the perforations 18 in the casing 16.

While combustion of the unit 34 is in progress an end-burning unit 36 is ignited, which, being of a cigarette-burning-like material, is consumed at a relatively much slower rate than the unit 34, and in turn ignites a unit 38. The unit 38 comprises a mass of propellant which burns at a faster rate than either the unit 34 or the unit 36, and produces an intensified flame which is capable of igniting the unit 40, although an air gap is present between the two units. The unit 40 may comprise the same propellant as the unit 34 or the unit 38, or may consist of a different composition. The mass of unit 40 and its burning rate may also be the same as unit 34, or may differ therefrom. As the unit 40 continues to burn, it ultimately ignites combustible adjacent units in the train and eventually ignites the unit 41, which is another unit consisting predominantly of propellant.

While combustion of the unit 41 is in progress, a unit 42, similar to the unit 36, but which may differ therefrom, is ignited and undergoes combustion, igniting, after another delayed period of time, a unit 44, similar to the unit 38, but which may also differ therefrom. As combustion of the unit 44 is in progress, the face of a unit 46 is ignited.

The unit 46 comprises an end-burning propellant charge, encased except for its upper end in an elastomeric sealant 56, which is in turn carried by an outer cover 58. The sealant 56 serves to protect the propellant from hot, high-pressure gas. The outer cover 58, which may be used in addition to the sealant 56, may consist of any suitable material, such as cardboard, asbestos, and the like. An outer cover 58 and the sealant 56 protect all the surfaces of the propellant charge unit 46 (except for its upper end) from the heat, and combustion of the unit thus progresses from the uninhibited exposed cross-section only, and, as combustion of the unit progresses, one or more of the discs 52 are unseated from their respective ports 54 carried by the housing unit 33. As the varying gas pressure builds up in the well bore 10 and is exerted on the fluids therein, the fluids eventually fissure the formation 14 adjacent to one or more of the perforations 18, and after fissuring the formation, further infiltrate and extend the fissure.

In other embodiments of the present invention the same reference numerals have been assigned for similar apparatus and units as hereinbefore described.

Referring particularly to FIG. 5, a container 60, which is shown positioned in a casing 62, is characterized most particularly by an electrical cable 64 and an electrical igniter 46a, the latter being carried in the lower portion of the container relative to the container's position in the well bore 10. It will be readily recognized that the casing 62 differs from the casing 16 of FIGS. 1, 2, and 4 in that the casing 62 does not show perforations. The container 60 may be located away from any perforations in the casing 62, the perforations being located either above or below the container, and preferably being located below the container.

Another distinctive characteristic of the embodiment shown in FIG. 5 resides in the nature and arrangement of the plurality of gas-generating units which are provided. Of course, any desired number of gas-generating units may be provided, as required. In all other respects, except as described, the operation of the container 60 is similar to the operation of the container 24, as discussed earlier. A plurality of propellant units 66 of combustible, non-detonating, gas-generating propellant are illustrated in FIG. 5, several of which are shown interposed between cigarette-burning-like units 68, which are respectively surrounded by inert members 70. The members 70, as well as the propellant units, are sealed against an elastomeric or similar sealant member 72. An outer cover 74, which may consist of cardboard, asbestos, and the like, may also be provided, the outer cover and the sealant member 72 both serving to protect the units 66 from high pressure
gas and heat and to laterally support the inert members 70. In operation, as illustrated in FIG. 5, the container 60 is submerged in the body of liquid 22, above the productive formation 14. An electrical impulse is sent from the surface through the electrical cable 64, actuating the igniter 48a, which ignites the lowermost of the units 66, which then burns over its open end, over its entire cross section, generating a certain volume of gas per unit of time. A split ring 67 at least initially aids in maintaining the lowermost of the units 66 and the contents of the container 60 above the lowermost of the units 66 in a fixed position upward of the split ring. Upon early combustion of the lowermost of the units 66, a plug or frangible disc 69 is unseated from the bottom of the container 60 by the gas pressure created therein, and the gas in the container is permitted to begin to escape into the body of fluid 22 and to exert pressure thereon. As the lowermost of the units 66 is consumed, the flame reaches the lowermost of the units 68, which burns slowly relative to the rate of burning of the units 66 and generates a much lower volume of gas per unit of time. As soon as the lowermost of the units 68 is burned nearly completely, the next of the units 66 is ignited, initially over only a limited portion of the entire cross section of its open end, and as the latter of the units 66 burns it unseats the lowermost of the inert members 70 from the elastomeric member 72. Similarly, the remainder of the units 66 and 68 are ignited and consumed, and during the burning thereof increasing pressure, of varying but progressive intensity, is produced in the well bore 10, similar to that described in regard to the embodiment illustrated in FIGS. 1, 2, 3, and 4, namely initiating a fissure in the productive formation 14, the high pressure fluids in the well bore then infiltrating and extending the fissure.

In FIG. 6 is shown a plurality of the propellant units 66 separated by a plurality of heat-conducting members 76, preferably consisting of a metal such as aluminum or other metal which is highly heat conductive. Accordingly, as each of the units 66 is consumed the heat therefrom is transferred to the adjacent member 76, which accepts the heat from the previously burned unit 66 and then donates the heat received therefrom to the adjoining of the units 66 across the entire cross-sectional area. The thickness and nature of the material used in the members 76 may be adjusted to control the rate of heat transfer, and thus the rate at which the units 66 are consumed. The members 76, as well as the units 66, are sealed against the elastomeric member 72 carried in the outer cover 74.

FIG. 7 is similar to FIG. 6, except that the units 66 are separated from each other by relatively small diameter heat-conducting members 78 carried in thermal-insulating members 80 which, as well as the units 66, are sealed against the elastomeric member 72, and in turn carried by the outer cover 74. Since the members 78 are of much smaller diameter than the members 76 of FIG. 6, only the center portion of the next adjoining unit 66 will be ignited, and thus gas evolution will proceed at a different, and slower, rate than in FIG. 6. The combustion of the adjacent unit 66 will unseat the adjacent thermal-insulating member 80.

Referring to FIG. 8, a plurality of the units 66 are sealed against the elastomeric member 72, the latter being carried by the outer cover 74. Interposed between the units 66 are relatively fast-burning propellant units 82 and the relatively slow-burning units 84. The units 82 and 68 are being carried by the inert members 70, which are sealed against the elastomeric member 72. As each of the units 66 is consumed, it in turn ignites the adjacent unit 82, which burns rapidly until reaching the adjacent unit 68, the burning of which has already been generally described. As the burning of the adjacent unit 68 reaches the next adjacent unit 66, it ignites the adjacent unit 66 over only a limited portion of its cross section, and thus gas evolution proceeds at a different rate. The combustion of the adjacent unit 66 unseats the adjacent inert member 70.

Of course, any gas-generating units suitable for the practice of the present invention may be used and, in addition, any combination of any of the described gas-generating units, and devices, or reversals thereof, may be employed.

Thus, the present invention provides a means for effectively stimulating wells by means of the fissuring of productive formations in a controlled and gradual manner while at the same time causing little or no damage to the well bore, or any casing therein, by avoiding catastrophic pressure increases. The result of which a fracture is extended in using the present invention is generally much more rapid than in the prior art, without the distinct disadvantages of the prior art described.

Although exemplary embodiments of the invention have been disclosed herein for purposes of illustration, it will be understood that various changes, modifications and substitutions may be incorporated without departing from the spirit of the invention as defined by the following claims.

1. In a gas-generating device for stimulating a well, the combination of:
   a housing comprising a plurality of housing units detachably connected in series, each of the housing units having at least one gas exit port communicating to the outside of the housing;
   a high pressure gas seal in each of said ports, each seal being so seated therein that upon a predetermined pressure within the housing unit the seal will unseat to permit generated gas to evolve therefrom;
   a combustible gas-generating charge contained in each of said housing units, each charge upon ignition being capable of sustained and gradually progressive combustion at predetermined varying rates and with generation and an evolution of a volume of gas generally directly in proportion to the rate of combustion and its mass, the charges having varying masses, the charges being aligned relative to each other and sufficiently proximate to each other so that they are successively ignited; and
   means for igniting one of said charges.

2. In a gas-generating device for stimulating a well, the combination of:
   a rigid metal housing, including a column of a plurality of vertically spaced separate container areas, each of said container areas having port means communicating between the interior of each container area and the exterior of said housing;
   seal means in each of said port means, normally closing said port means but releasable in response to a predetermined pressure rise within its container area to permit gas generated within said container area to escape to the exterior of said housing;
   a combustible gas-generating charge in each of said container areas, each charge upon ignition generating gas in its container area;
   separating means between each pair of adjacent container areas and adapted to transfer the ignition of the charge in one container area to ignite the charge in its next adjacent container area so that said charges ignite progressively; and
   ignition means for igniting the charge in one of said container areas.

3. A device as defined in claim 2, in which each of said separating means includes a combustible material for transferring the ignition of the charge in one container area to the charge in a next adjacent container area.

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