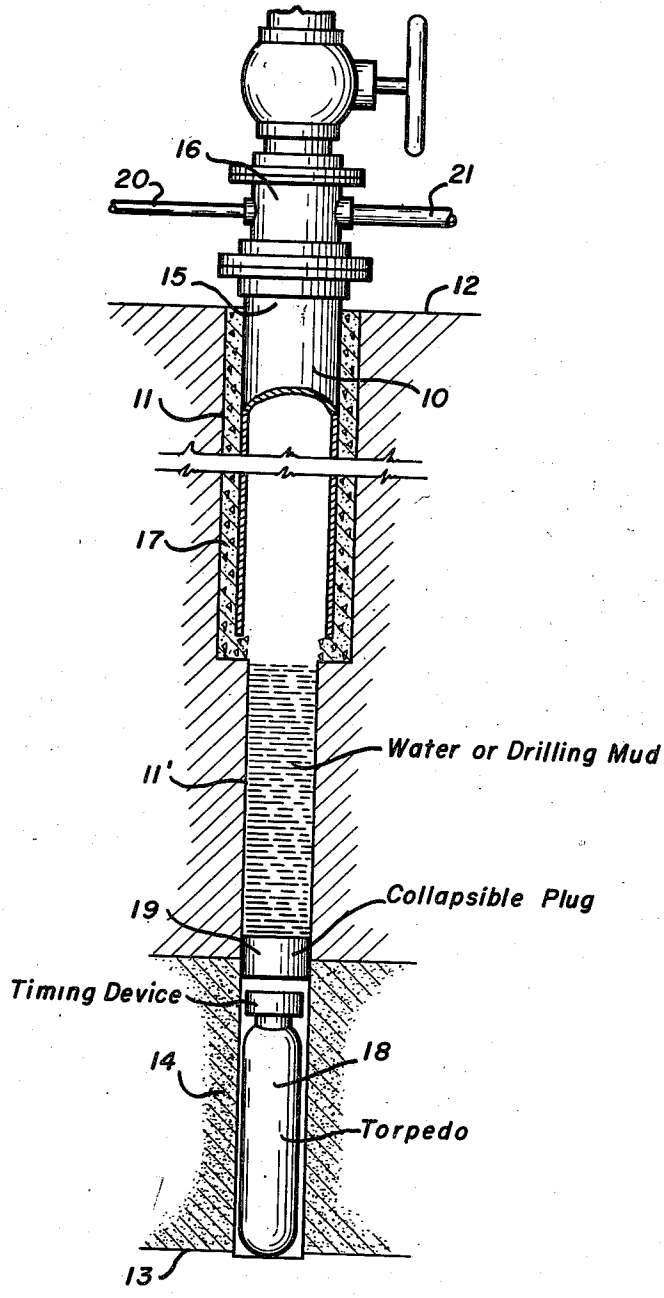
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METHOD OF FRACTURING SUBSURFACE FORMATIONS

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METHOD OF FRACTURING SUBSURFACE FORMATIONS

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The present invention is directed to the blasting of subsurface formations and, more particularly, is directed to a method for fracturing subsurface formations surrounding a borehole drilled from the surface.

It sometimes becomes necessary to increase the productivity of wells producing petroliferous fluids, such as oil and gas, and one well known means of accomplishing this objective consists of lowering a charge of explosive, such as nitroglycerine or dynamite, into the well to the level of the petroleum bearing stratum and detonating the explosives, thereby breaking up or shattering the immediately surrounding rock and enlarging the diameter of the borehole at this point. The art of blasting subsurface formations, although carried out rather crudely in the beginning, has been gradually developed over the past few years.

For many years the oil industry, for example, lowered the explosive charge down the open borehole into place opposite the formation to be fractured and then detonated the explosive charge. The well, after the explosion, was allowed to clean itself through the casing into the air. In other words, no means was employed for confining the explosive effect of the charge to the area of the productive formation. This crude method resulted in many expensive and dangerous oil and gas well fires and often caused considerable damage to derricks and machinery and sometimes resulted in injuries to workmen. This method also permitted the column of fluid in the well to vary in height, which condition permitted concussions to be set up in the fluid column, thereby on occasion doing considerable damage to the casing in the well.

During the past 20 years it has become common practice in the oil industry to place a time bomb in contact with the explosive charge, after which both are simultaneously lowered into the well and set opposite the formation to be fractured. Various combinations of explosive charge and detonating means have been developed and used for this purpose. For example, it has been common practice to arrange the explosive charge in a torpedo-shaped container provided with a detonating means adapted to be set off instantaneously by the application of an electric current through a suitable conductor from the surface of the ground or by means of a timing mechanism associated with the torpedo. These torpedoes were lowered into the well by means of a cable or line. Ordinarily, a torpedo having a timing mechanism was employed in which case the timing mechanism was set so as to discharge the detonator after a predetermined interval of time. This interval of time varied from two to three hours to a much longer period of time, for example 24 hours, depending upon the time consumed in carrying out steps which had to be completed before detonation. In order to confine the explosive effect to the formation which it was desired to fracture, an artificial barrier or plug was set above the explosive charge and below the bottom of the casing. These barriers or plugs usually consisted of gravel packs, or hardened cement or plastic materials. These barriers or plugs effectively confined a major portion of the explosion to that portion of the well bore adjacent the formation to be fractured and also

serve as a protection for the casing, the derrick, the machinery, and the workman. Although this procedure was an improvement over the old method wherein the explosion was not confined at all, it nevertheless is attended by certain disadvantages, among which is the necessity for cleaning out foreign substances from the borehole following detonation of the explosive charge. These foreign matters include, of course, the gravel, cement, or plastic which is introduced to form the barrier or plug. Another disadvantage inherent in the aforementioned method is the constant danger that the explosive charge may be accidentally and prematurely discharged during the placing of the gravel pack, the cement, plastic or other substances.

The object of the present invention is to provide a method of fracturing subsurface formations by the use of explosive charges wherein it is unnecssary to form a plug consisting of materials which must be subsequently cleaned out of the borehole following detonation of the charge. A further object is to provide a method of fracturing subsurface formations by the use of a explosive charges which involves the expenditure of a minimum amount of time in its execution.

The present invention may be briefly described as a method of fracturing a subsurface formation surrounding a borehole which comprises the steps of placing an explosive charge in the borehole adjacent the formation to be fractured and then forming a solid plug of frozen fluid in the borehole above the explosive charge so as to confine the explosion to the area of the formation to be fractured. The solid plug of frozen fluid is formed by introducing into the borehole above the charge a material which is normally fluid at temperatures prevailing in the borehole but which is capable of being converted to a solid when cooled sufficiently. Furthermore, the fluid must not only be convertible to a solid, but the solid, when once formed, must be meltable by the heat available in the borehole. Many fluid materials meet these requirements, and water and drilling mud are both eminently suited for this purpose, particularly because of their availability at the drilling rig and because neither produces any complicating factors in the clean out of the borehole subsequent to detonation. Whatever fluid material is employed for this purpose, at least a portion thereof is cooled to its solidification point by introducing and endothermic reactant therein. As the endothermic reactant, Dry Ice is preferred because of the large cooling effect secured by the use of small amounts thereof. A sufficient quantity of the endothermic reactant is introduced into the fluid material to provide sufficient cooling to cause solidification of a sufficient amount of the fluid material to resist the explosive effect of the charge without movement in the borehole. After the solid plug has been formed, and before the plug has melted, the explosive charge is detonated, thereby fracturing the formation. The heat resulting from the explosion of the charge will melt a portion of the solid plug and in a short time the heat from the formation will melt the remainder of the plug, leaving again in the borehole nothing but fluid. Employment of a fluid which is capable of being converted to a meltable solid eliminates the necessity of cleaning out the borehole, an operation which made the prior art method particularly inconvenient and costly.

The present invention may be more particularly described by reference to the single figure of the drawing. In the drawing numeral **10** designates the casing surrounding borehole **11** which is drilled from the surface of the earth **12** to the bottom **13** of producing formation **14**. The upper end **15** of casing **10** is closed by means of a suitable head **16**, the features of which will not be described herein. Casing **10** is shown as being affixed to the walls of the borehole **11** by means of hardened cement

17 placed between the annulus and the casing in the borehole in the usual manner. It will be noted that portion 11' of borehole 11 is of reduced diameter as compared to the remaining portion of the borehole and is not enclosed in casing.

When it is desired to fracture that portion of borehole 11' which extends through producing formation 14, torpedo 18 containing an explosive charge such as nitroglycerine, for example, and a pre-set timing device for detonating the explosive charge is lowered through well head 16 by conventional means as, for example, by means of a wire line. Torpedo 18 is set on the bottom of the hole after which the line is withdrawn and a wooden or rubber collapsible plug 19 is lowered down borehole 11 until it comes to rest at a point just above torpedo 18. Plug 19 serves as a protection against premature explosion of the explosive charge in that it will cushion the effect of anything inadvertently dropped into the well. Furthermore, plug 19 prevents any fluids introduced into the borehole in the surface of the earth from coming in contact with the torpedo or communicating with the fluids which may come from the producting formation. By excluding introduced fluids from the area immediately surrounding the explosive charge, the introduced fluids are not forced back into the formation at the time of the explosion. After plug 19 has been placed in position as hereinbefore indicated, borehole 11 is then filled with water, drilling mud, or other fluid material having the hereinbefore designated characteristics. This water or drilling fluid may be introduced into borehole 11 in any suitable manner and may be forced therein through pipe 20 by means of pumps not shown. An exothermic reactant, such as Dry Ice (solidified carbon dioxide), is then introduced into the fluid material standing in borehole 11 by any suitable means, such as by means of a fluid bailer introduced through well head 16 or by means of a pump fluidly connecting with well head 16 by means of pipe 21. Regardless of the manner in which the exothermic reactant is introduced into the borehole 11, a sufficient quantity is added thereto to freeze a sufficient quantity of the fluid material, thus forming a solid plug of normally fluid material immediately above collapsible plug 19. In freezing, the fluid material will fill all cavities and irregularities in the face of the borehole and when frozen will give a better friction hold than cement or plastic due to the characteristic of such a fluid of expanding on freezing. It will be understood, of course, that certain conditions may exist in borehole 11 which will cause small fissures, air spaces or other permeable conditions due to the escape of the refrigerant gases. Should this condition arise, it may be remedied by freezing a portion of the column of fluid material in stages. For example, a portion of the column of the fluid material may be subjected to half the carbon dioxide it is intended to employ, the remaining half being subsequently introduced. Porous spaces formed during the first stage are filled with the fluid material before the remaining Dry Ice is introduced in the second stage. By adapting this technique, permeable spaces may be left in the upper portion of the solid frozen plug but it will leave the lower portion of the plug impervious.

After the aforementioned solid plug has been formed, the explosive charge contained in torpedo 18 is exploded by means of the timing device contained theerin. This explosion in itself produces sufficient heat to partially melt the solid plug of frozen material, the remaining portion of the plug being melted by heat supplied from the formation. With the plug thus melted, the only thing remaining in the borehole is the debris resulting from the explosion. Furthermore, if drilling mud is used as the fluid material, this drilling mud will be available for cleaning out the shot hole immediately upon the melting of the plug.

Obviously, various modifications of the method of my invention may be made without departing from the spirit thereof. What I wish to claim as new and useful and to secure by Letters Patent is:

1. A method of fracturing a subsurface formation surrounding a borehole which comprises the steps of lowering an explosive charge into the borehole and placing said charge adjacent said formation; setting a pack-off element in the borehole above said explosive charge and adjacent thereto to divide fluidly said borehole into an upper portion and a lower portion; introducing into the upper portion of said borehole a material which is normally fluid at the temperatures prevailing in the borehole but which is capable of being converted to a solid by cooling to form a column of material standing therein, said solid being meltable by the heat of the borehole; reducing the temperature of at least that portion of said column adjacent said pack-off element to form a solid columnar plug of said material; and detonating said explosive charge while said columnar plug is solid.

2. A method of fracturing a subsurface formation surrounding a borehole drilled from the surface of the earth which comprises the steps of lowering an explosive charge into the borehole and placing said charge adjacent said formation; setting a pack-off element in the borehole above said explosive charge and adjacent thereto to divide fluidly said borehole into an upper chamber and a lower chamber containing said explosive charge; filling the upper chamber of said borehole with a material which is normally fluid at the temperatures prevailing in the borehole but which is capable of being converted to a solid by cooling, said solid being meltable by the heat in the borehole; introducing an endothermic reactant into the upper chamber of the borehole in sufficient quantity to convert at least that portion of said fluid material adjacent the pack-off element into a solid plug; and detonating said explosive charge while said portion of said fluid material is solid.

3. A method of fracturing a subsurface formation surrounding a borehole drilled into the formation from the surface of the earth which comprises the steps of lowering an explosive charge into the borehole and placing said charge adjacent said formation; setting a pack-off element in the borehole above said explosive charge and adjacent thereto to divide fluidly said borehole into an upper chamber and a lower chamber containing said explosive charge; filling the upper chamber of said borehole with an aqueous fluid; introducing Dry Ice into said upper chamber in sufficient quantity to freeze at least that portion of the aqueous fluid adjacent said pack-off element to form a solid columnar plug of said aqueous fluid in the borehole; and detonating said explosive charge while said columnar plug is solid.

4. A method of fracturing a subsurface formation surrounding a borehole which comprises the steps of lowering an explosive charge into the borehole and placing said charge adjacent said formation; setting a pack-off element in the borehole above said explosive charge and adjacent thereto to divide fluidly said borehole into an upper chamber and a lower chamber containing said explosive charge; filling said upper chamber of the borehole with drilling mud; introducing Dry Ice into the drilling mud in the upper chamber in sufficient quantity to freeze at least that portion of the drilling mud adjacent the pack-off element to form a solid columnar plug of drilling mud; and detonating said explosive charge while said columnar plug is solid.

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