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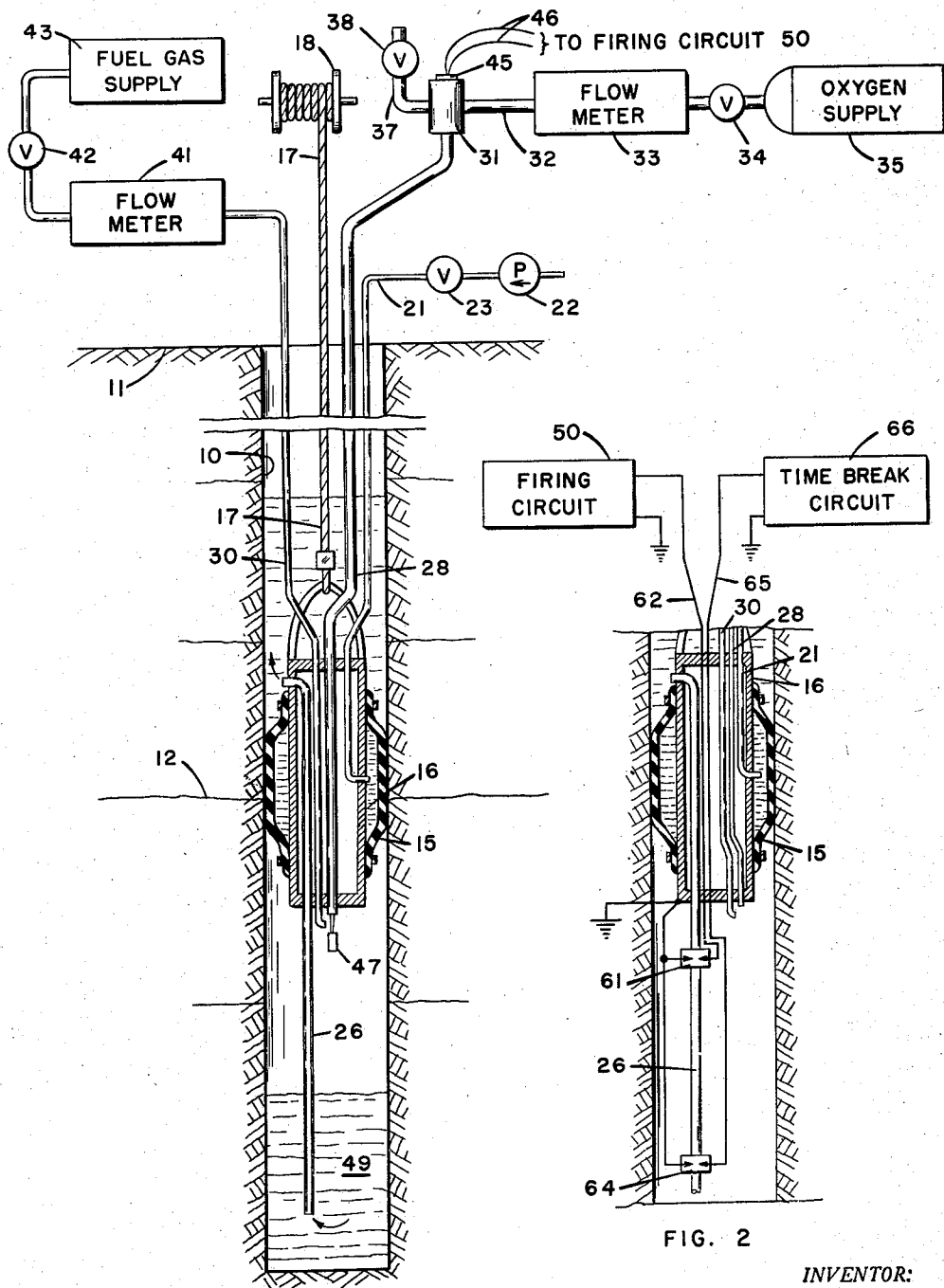
H. M. LANG

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GENERATING SEISMIC WAVES

Filed Nov. 7, 1955

2 Sheets-Sheet 1



INVENTOR:

HAROLD M. LANG

BY

Newell Pottorf

ATTORNEY

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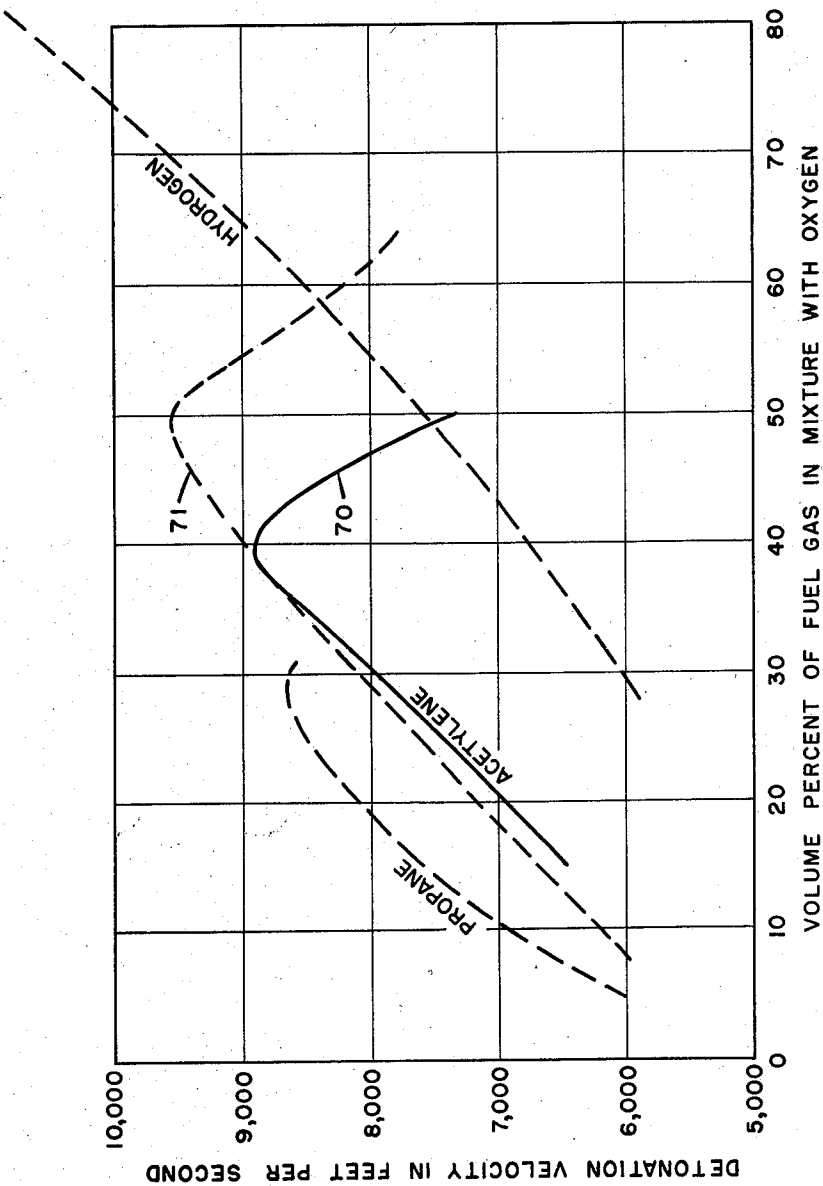


FIG. 3

INVENTOR:
HAROLD M. LANG
BY *Newell Pottorf*
ATTORNEY

2,846,019

GENERATING SEISMIC WAVES

Harold M. Lang, Tulsa, Okla., assignor to Pan American Petroleum Corporation, a corporation of Delaware

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6 Claims. (Cl. 181—5)

This invention relates to seismic geophysical surveying and is directed particularly to a novel method and apparatus for generating seismic waves. More particularly, it is directed to an improvement in the generation of seismic waves by elongated charges of explosive material having a linear detonation velocity approximately matching the seismic-wave-transmission velocity of a surrounding earth medium.

Ever since the beginning of geophysical surveying by the seismic method, the detonation of explosive charges in drilled shot holes has been the most commonly used method of wave generation. While other methods of producing the desired seismic waves have been proposed and have been used on some occasions, the detonation of explosive charges in shot holes continues to be the preferred method, even though it frequently gives rise to undesirable interfering waves.

Some of the latter can be eliminated by particular arrangements of the charge material. It has been found, for example, that certain types of interfering waves can be eliminated by distributing the explosive charge material throughout a considerable length of the shot hole and detonating it from the top downwardly, with the velocity of propagation of the detonation along the length of the charge approximately matching the seismic-wave-transmission velocity in the formations surrounding the shot hole.

Such elongated or distributed velocity-matching charges, however, are not available commercially and have heretofore been rather expensive and time-consuming to prepare and use. One method of preparing such charges is that disclosed in Silverman Patent 2,609,885 wherein one or more strands of Primacord detonating fuse are wound in a helix about a supporting means, the helix having a pitch such as to provide a lowered effective detonation velocity equal to the wave-transmission velocity of the formations in the direction of the helical axis. Only relatively small weights of explosive charge material can be easily formed into a helix in this manner, however. Furthermore, the danger to personnel is in some degree increased due to the additional handling of explosive materials required to form them into a helix.

It can be said, in general, that the difficulty of providing a charge detonation velocity matching seismic-wave-transmission velocities arises from the fact that the great majority of explosive compositions that detonate reliably under bore-hole conditions have detonation velocities much too high to match the formation wave-transmission velocity satisfactorily. Thus, where the seismic-wave-transmission velocities below the weathered layer most frequently fall in the range from 5000 to 10,000 feet per second, the detonation velocities of most reliable bore-hole explosive materials are considerably above 10,000 feet per second and sometimes are in excess of 20,000 feet per second.

It is accordingly, a primary object of my invention, to provide a novel method and apparatus for generating

seismic waves while utilizing the principle of elongated, velocity-matching charges. Another object is to provide a novel wave-generating method and apparatus by which elongated, velocity-matching explosive charges are formed in a bore hole quickly, inexpensively, and in a completely safe manner. A still further object is to provide a method and apparatus for forming such charges wherein the effective velocity of the charge detonation can be conveniently adjusted as desired to match different values of formation wave-transmission velocity. Other and further objects, uses, and advantages of the invention will become apparent as the description proceeds.

Briefly stated, I have found that seismic waves can be very effectively and inexpensively generated in a bore hole by filling a portion of the bore hole with any one of a number of combustible gaseous mixtures and then igniting the gaseous column in such a way that detonation occurs. Substantially complete safety is assured because the components of the gaseous mixture are maintained separate until after they have been introduced into the shot hole. As the composition of the gaseous mixture chiefly determines the velocity with which detonation proceeds along the bore hole, variations of the composition can accordingly be made, to adjust the detonation velocity to any desired value within a substantial range of such values.

This will be better understood from the description to follow, taken with the drawings forming a part of this application, and illustrating typical embodiments of the invention. In these drawings,

Figure 1 shows diagrammatically and in cross section an apparatus embodying the invention in operating position in a bore hole;

Figure 2 is a view of a portion of the bore hole and apparatus of an alternative charge-igniting means, similar to the view of Figure 1;

Figure 3 shows graphically the relation of detonation velocity and composition for various detonatable gaseous mixtures of typical fuel gases and oxygen.

Referring now to these drawings in detail, and particularly to Figure 1 thereof, a shot hole 10 is shown as extending from the ground surface 11 to a substantial depth below the boundary 12 between the weathered upper layer of low seismic-wave-transmission velocity and the sub-weathering or lower strata of substantially higher wave-transmission velocity. Seated at some depth within the shot hole 10, preferably near the weathering boundary 12, is an expansible or inflatable packer 15, attached to and surrounding a cylindrical mandrel 16, which is preferably closed at the ends and is adapted to be lowered into shot hole 10 to any depth therein by a flexible cable 17 wound on a reel 18 at ground surface 11. A tubing 21 opening into the annular space surrounding mandrel 16, between it and the inside of sleeve 15, extends to the ground surface to a control valve 23 and a pump 22, by which means liquid or gas can be forced into sleeve 15 to expand it, or released therefrom to allow it to contract. After expansion, the fluid pressure is maintained within the sleeve by closing valve 23.

Extending through the body of mandrel 16 is a hose or tubing 26, open at both ends and preferably flexible. The upper end of hose 26 terminates just above packer 15, while the lower end extends preferably to a depth near the bottom of shot hole 10. Also passing through the mandrel 16 to a point just below it are a pair of tubes 28 and 30 which extend upwardly to the ground surface 11, where the tube 28 is attached to a manifold 31, from which a tubing 32 extends through a flowmeter 33 and a control valve 34 to an oxygen-supply vessel 35, such as a high-pressure cylinder. From the manifold 31 a

second branch line 37 extends to a control valve 38 which may be opened to the atmosphere.

The tubing 30 similarly connects at ground surface 11 through a flowmeter 41 and a control valve 42 to a pressure cylinder 43 containing a supply of fuel gas. Through a packing device 45 on manifold 31 passes a wire 46, containing a pair of insulated electrical leads, extending to an igniting device 47, such as an electric blasting cap, which may thus be lowered through the tubing 28 to a point just below its lower end in the gas space below packer 15.

In operation, packer 15 with its associated tubes, is lowered uninflated, into the shot hole 10 by means of the cable 17 to the desired depth. This will normally be close to the interface 12, at or near which will normally be found the level of the liquid 49 standing in well bore 10. With the valve 23 open, pump 22 is then operated to inject gas or liquid through the line 21 into the interior of sleeve 15 to inflate it and thereby form a firm seal against the wall of hole 10. Closing valve 23 maintains this pressure within the sleeve of packer 15.

Valves 42 and 34 are then opened, and, by observation of the flowmeters 41 and 33, these valves are adjusted to introduce below the packer 15 fuel gas from the supply 43 and oxygen from cylinder 35 in the proper ratio to form a mixture of the desired detonation velocity. As the pressure of the gas mixture increases below packer 15, liquid 49 in the bottom of the shot hole 10 is displaced upwardly through the tubing 26 to a point above the packer 15 or outwardly into porous formations of lower hydrostatic pressure. From the standpoint of introducing the desired quantity of gaseous mixture into bore hole 10, it is not important where liquid 49 goes, but for the purpose of maintaining the seal of packer 15 and withstanding the pressure increase upon detonation, it is preferred that it go upwardly through tubing 26. In fact, to prevent loss of liquid 49, and possibly some of the gaseous mixture also, to porous formations, materials well-known in the drilling-fluid art for forming an impervious filter cake or seal over the porous formation face may be incorporated in liquid 49.

After the desired amount of fuel-gas and oxygen mixture has been thus introduced into the shot hole 10 and the liquid 49 therein displaced, so that the desired length of the shot hole below the packer 15 is filled by the gaseous mixture, valves 34 and 42 are closed, and the insulated leads of wire 46 are connected to a firing circuit 50 (Figure 2). Then, when generation of seismic waves is desired, circuit 50 is actuated to detonate cap 47 and create a shock wave in the gaseous mixture. This causes substantially immediate detonation of the column of gas below packer 15, with the detonation wave traveling in a downward direction.

The velocity with which this detonation proceeds through the gaseous mixture is predetermined by choice of the ratio of fuel gas to oxygen in the mixture, allowing for the effect of any diluent gas present, so that the final detonation velocity substantially matches the seismic-wave-transmission velocity of the formations penetrated by bore hole 10 below weathering interface 12. Upon the occurrence of detonation, the frictional force between the sleeve of packer 15 and the wall of well 10, and the weight and inertia of the liquid 49 above the packer combine to hold in the pressure of the exploding gas column.

As compared with a column of solid explosive material, an important factor of improvement in the efficiency of energy transfer from the exploding gas to the surrounding formation is due to the lower peak pressure in the gas detonation-wave front, plus the fact that this gas is in intimate contact with the formation face throughout the gas-filled bore-hole length. Consequently, a substantially greater percentage of the energy released by the chemical reactions of the detonation is transferred to the

formation in the gaseous detonation than is true of the detonation of a solid explosives column.

At the conclusion of the travel of the detonation wave and resulting combustion of the gaseous mixture, rapid cooling and condensation of the reaction-product gases take place to reduce the pressure below packer 15. By opening valve 38 the non-condensable combustion products of the gaseous detonation are vented to the atmosphere, with the aid of the pressure of liquid 49 which then flows downwardly through the tube 26 and refills the well-bore space below the packer 15. As many subsequent charges may be shot as desired simply by repeating the foregoing steps of filling the well bore below packer 15 with a gaseous mixture of the proper composition and lowering a new igniting device 47 through the tubing 28 each time ignition is desired.

In this embodiment the use of the blasting cap 47 is ordinarily sufficient to insure that detonation of the gaseous mixture takes place promptly. Other ways of igniting the gaseous mixture in the well bore 10 may be used, however, such as that shown in Figure 2 where the principle of spark ignition is employed. Thus, there is mounted on the hose 26 a short distance below the lower ends of tubes 28 and 30 a spark gap 61, having one electrode connected by an insulated lead 62 to a high-voltage firing circuit 50 at the ground surface. The other electrode of gap 61 is grounded. At some additional distance below the spark gap 61, also mounted on hose 26, is an ionization gap 64, similar to spark gap 61, having one electrode grounded in the same manner as gap 61 and the other connected by an insulated lead 65 to a time-break circuit 66 at the ground surface.

With a detonatable gaseous mixture present in bore hole 10 below packer 15, application of a sudden high-voltage impulse from circuit 50 over lead 62 to the gap 61 creates a spark through the gaseous mixture and ignites it. Detonation of the mixture, however, does not ordinarily ensue immediately, but there is a brief interval of time, which is frequently somewhat variable, during which propagation of the combustion in the gaseous mixture occurs at flame, rather than detonation, velocity. This velocity of propagation of the combustion initiated at gap 61 increases until a point is reached at which shock-wave generation begins, and thereafter the detonation wave front proceeds with the characteristic detonation-wave velocity.

This wave front is detected as it passes the ionization gap 64, to which a potential is applied over the lead 65. As the ionized gases in the detonation-wave front sharply reduce the resistance between the electrodes of gap 64, there is created a surge of electric current in the time-break circuit 66 when the detonation wave passes the gap. This impulse, together with the known depth of the ionization gap 64, is used as the time reference or time break on the resulting seismic record, rather than the time of energizing the spark gap 61. Instead of being located close to gap 61, the ionization gap 64 may of course be located near the bottom of the gaseous column in well bore 10, where it will serve to provide not only time-break information but further to assure, by the time interval between the energizing of gap 61 and the arrival of the detonation-wave front at the gap 64, that detonation of substantially the entire length of gas column has taken place satisfactorily.

Figure 3 shows graphically the relationship between gas-mixture composition and the resulting detonation-wave velocity for a few typical mixtures of different fuel gases and oxygen. One convenient gaseous mixture which has been found to detonate reliably under bore-hole conditions with a good release of energy comprises chiefly acetylene and oxygen. The solid-line curve 70 is plotted from data obtained in bore-hole detonation-velocity measurements. This shows that the detonation velocity of a mixture of acetylene and oxygen varies almost linearly from about 6500 to about 9000 feet per

second, as the concentration of acetylene in the mixture varies between about 15 percent and about 40 percent, the balance of the mixture being oxygen and such water vapor as occurs due to the bore-hole walls being water-wet. This range of detonation velocities is clearly adequate to provide for a very large majority of sub-weathering formation wave velocities.

The solid-line curve 70 is to be compared with the dash-line curve 71, which is the detonation velocity of acetylene-oxygen mixtures under laboratory conditions. It may be observed that the linear portions of these curves agree reasonably well, the velocity in the bore hole being generally slightly less than that under laboratory conditions, the difference being possibly due to experimental error, but more probably to the effect of the water vapor known to be present. The major difference to be noted appears to be that, in the bore hole, the peak velocity obtainable is lower and occurs at a lower relative concentration of acetylene, being 40 percent as compared to about 50 percent. This is not serious, however, as velocities of detonation in excess of about 9000 feet per second are rarely needed to match formation wave velocities, and as long as the mis-match between detonation and wave-transmission velocities does not exceed about 10 percent, the major effects of velocity matching are preserved.

Of a considerable number of other fuel gases which will detonate with oxygen in the proper concentrations, two are shown in Figure 3. Thus, propane in amounts varying from about 5 percent to about 25 percent or 30 percent will detonate with oxygen at velocities ranging between about 6000 and 8500 feet per second. Hydrogen is another possible choice of fuel gas, as, over the range of hydrogen concentrations from about 30 percent to about 80 percent, the detonation velocity of the mixture will vary from about 6000 to nearly 11,000 feet per second.

Over most of the velocity range of interest the curves of Figure 3, which are representative of a great many fuel gases, may be considered to be straight lines of the general formula

$$F = K_1 V - K_2$$

where

F is the volume percent of fuel gas in admixture with oxygen,

V is the sub-weathering seismic-wave velocity to be matched by the detonation velocity, and

K_1 and K_2 are constants for any particular fuel gas.

For the three fuel gases of Figure 3, K_1 and K_2 are shown in the following table:

Fuel Gas	K_1	K_2	m	V_0	Range of V
Propane.....	.0088	48.4	113.7	5,500	6,500-8,500
Acetylene.....	.0100	49.0	100.0	4,900	6,500-9,000
Hydrogen.....	.0121	42.3	82.8	3,500	6,500-9,000+

K_1 and K_2 are respectively equal to

$$\frac{1}{m}$$

and

$$\frac{V_0}{m}$$

V_0 and m are also given in the table. m is the average slope of the detonation velocity-percent fuel gas curve in the region of interest where it is approximately linear, and V_0 is the zero-percentage intercept of the assumed straight-line curve. The last column of the table shows the range of seismic-wave velocities for which the above general formula holds. It will be apparent that the great majority of sub-weathering seismic-wave velocities are included.

In general, the effects of varying the temperature or pressure of the gaseous mixture over a substantial range are small compared to the effect of varying the relative concentration of fuel gas to oxygen in the mixture. The effect of diluent gases, however, is more prominent, the most marked effect being to lower the detonation-velocity values somewhat below those shown by the dashed-line curves, which thus represent probable maximum values of this velocity for the composition obtainable under bore-hole conditions. That is, the velocities obtainable where water vapor is normally present are somewhat lower than those shown by the dash-line curves, but within the plus or minus 10 percent allowable mis-match of detonation and formation velocities it is considered satisfactory to use the compositions shown by the dash-line curves.

In general, the total energy released is directly proportional to the amount of reacting gases present. Thus, for any given length of bore hole, increasing or decreasing the pressure of the gas mixture correspondingly increases or decreases the seismic-wave-creating energy with negligible change of detonation velocity. Conversely, at constant pressure, the energy will vary in proportion to the length of bore hole filled.

While I have thus described my invention in terms of the foregoing specific embodiments thereof, it is to be understood that other and further modifications will occur to those skilled in the art. In particular, many other gaseous compositions than those disclosed specifically herein can be made to detonate under bore-hole conditions and with the desired velocities for the generation of seismic waves. The invention therefore should not be considered as limited to the details and compositions specifically set forth, but its scope is properly to be ascertained by reference to the appended claims.

I claim:

1. The method of generating seismic waves in a bore hole in the earth which comprises the steps of filling a substantial length of said borehole below the weathering-velocity interface with a mixture of fuel gas and oxygen capable of combustion by detonation, during said filling step adjusting the relative flow rates of said fuel gas and said oxygen so that the volume percent F of fuel gas in the mixture with oxygen is equal to $K_1 V - K_2$, where K_1 and K_2 are constants for any given fuel gas, and V is the seismic-wave-transmission velocity of the sub-weathering formations penetrated by said borehole, and initiating detonation of the column of gases at the upper end thereof.

2. The method of generating seismic waves in a bore hole in the earth extending to a substantial depth below the weathering interface therein, which method comprises the steps of establishing a partition in said bore hole at approximately the depth of said weathering interface, separately introducing through said partition to a point therebelow a fuel gas and oxygen capable of forming a detonatable mixture, adjusting the relative flow rates of said fuel gas and said oxygen to produce a mixture in which the percentage F of fuel gas is equal to $K_1 V - K_2$ where K_1 and K_2 are constants for any given fuel gas and V is the seismic-wave-transmission velocity of the sub-weathering formations penetrated by said bore hole, filling a substantial length of said hole below said interface with said mixture, and initiating a detonation wave front in the gaseous column at a point immediately below said partition.

3. The method of claim 2 wherein said fuel gas is chiefly acetylene, K_1 and K_2 have values approximately .0100 and 49.0, respectively and V is between about 6500 and 9000 feet per second.

4. The method of claim 2 wherein said fuel gas is chiefly propane, K_1 and K_2 have values approximately .0088 and 48.4, respectively, and V is between about 6500 to 8500 feet per second.

5. The method of claim 2 wherein said fuel gas is chiefly hydrogen, K_1 and K_2 have values approximately

.0121 and 42.3, respectively, and V is between about 6500 and 9000 feet per second.

6. The method of claim 2 including also the steps of producing an electrical impulse coincident with the passage of said detonation wave front past a point at a known substantial depth below said partition, and recording the time of occurrence of said impulse as a reference point.

5

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