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[73] Assignee Intermountain Research and Engineering  
Company

3,382,117	5/1968	Cook.....	149/44 X
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[54] COLUMN OF BLASTING AGENT OF  
CONTROLLED DENSITY  
9 Claims, 6 Drawing Figs.

[52] U.S. Cl..... 149/2,  
149/41, 149/44, 149/60, 149/61  
[51] Int. Cl..... C06b 19/00  
[50] Field of Search..... 149/2, 45,  
44, 109, 60, 41, 61; 86/20

[56] References Cited  
UNITED STATES PATENTS

3,288,658	11/1966	Ferguson et al. ....	149/2
3,288,661	11/1966	Swisstack .....	149/60
3,369,945	2/1968	Craig et al. ....	149/44 X

**ABSTRACT:** In order to control slurry density in deep holes, varying amounts of aerating or gasifying agent, preferably a generated essentially insoluble gas, are added. Hydrogen peroxide may be decomposed to produce oxygen, using catalyst such as potassium iodide or manganese dioxide, etc. Gas generating material and catalyst may be added variably, e.g. to produce gas in progressively decreasing proportions as slurry is pumped, starting at the bottom and rising in a borehole, to offset the compressive effect of the column weight thus keeping the whole slurry column at density low enough for reliable detonation.

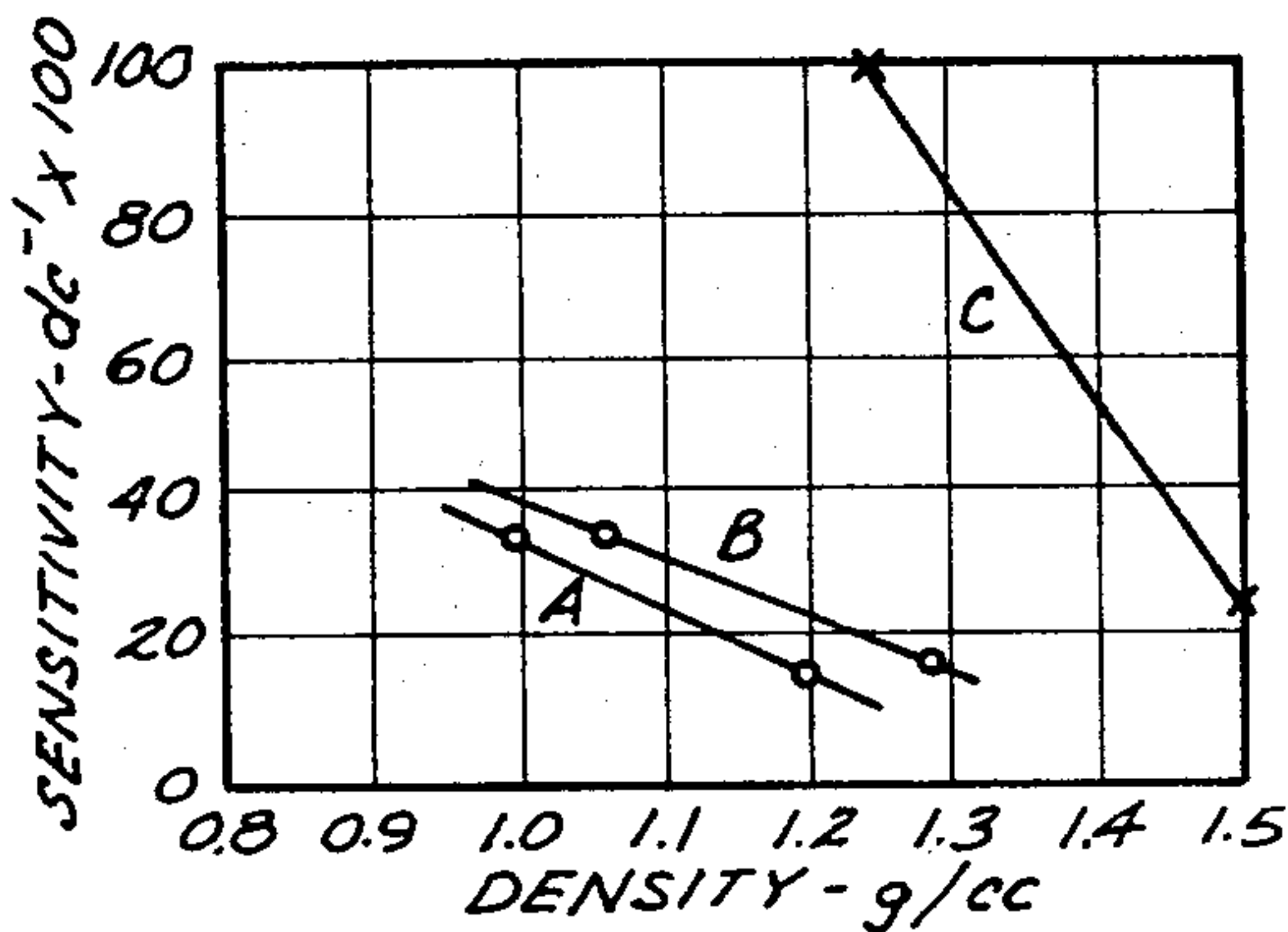


Fig. 1

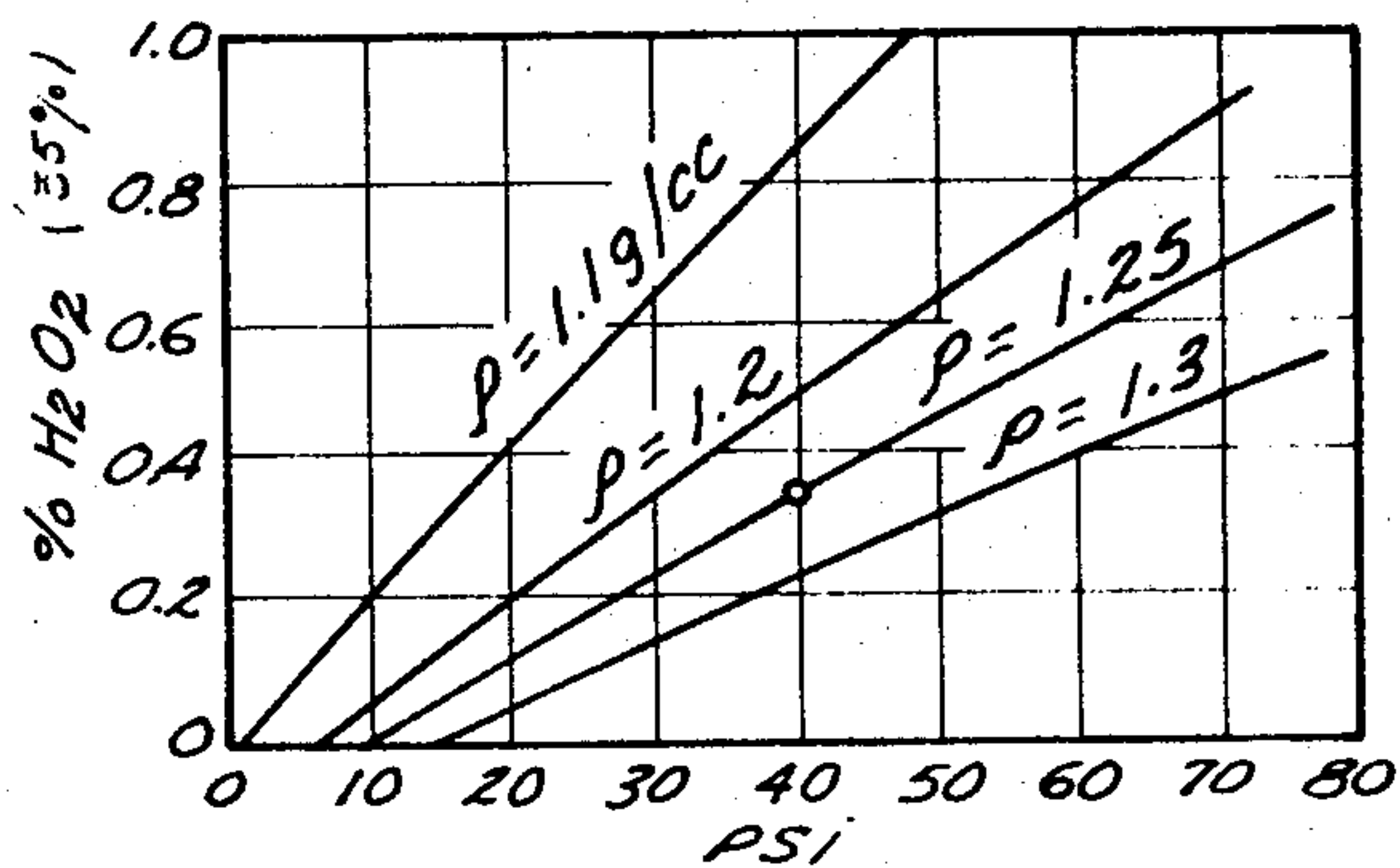


Fig. 2

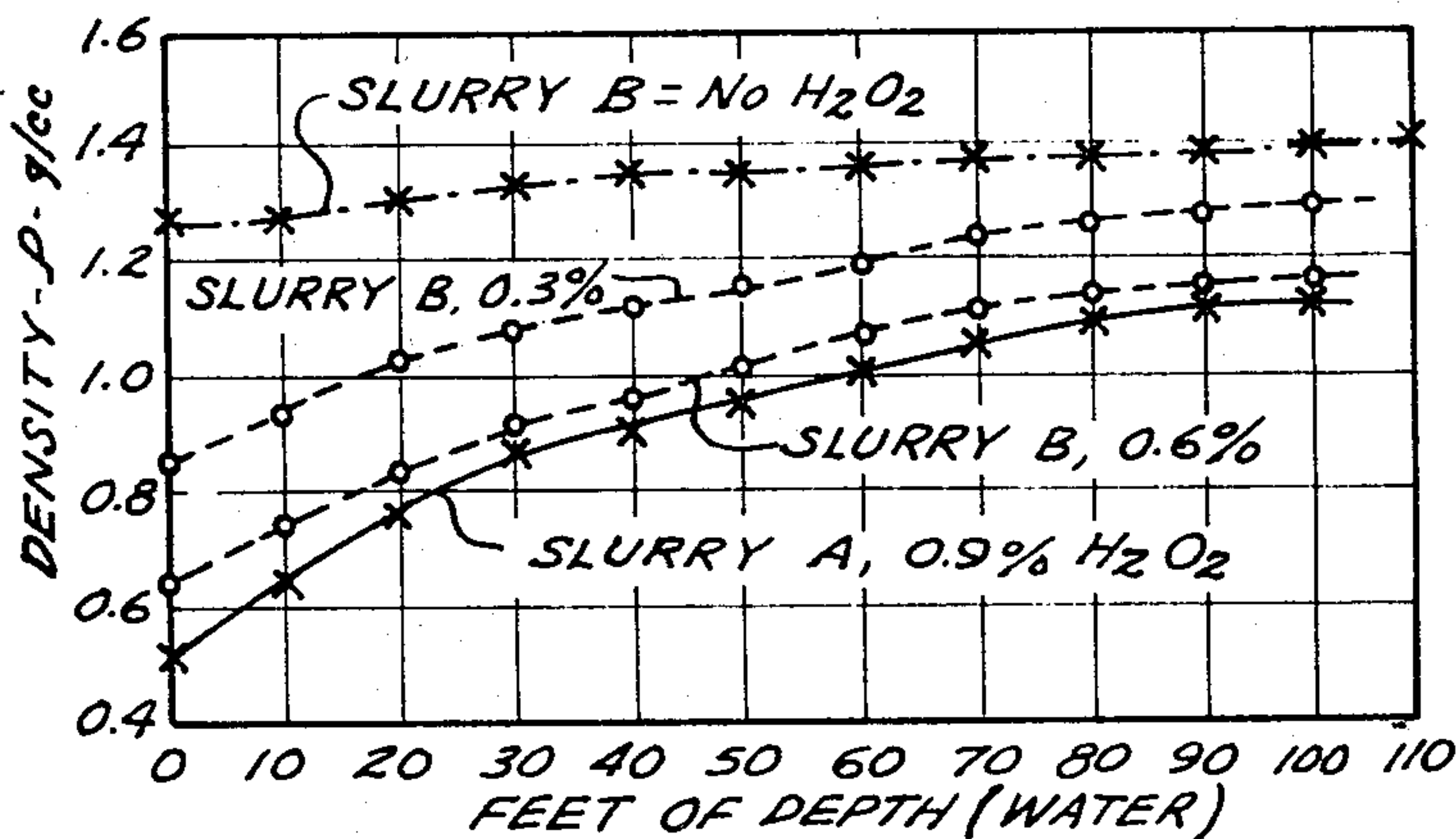


Fig. 3

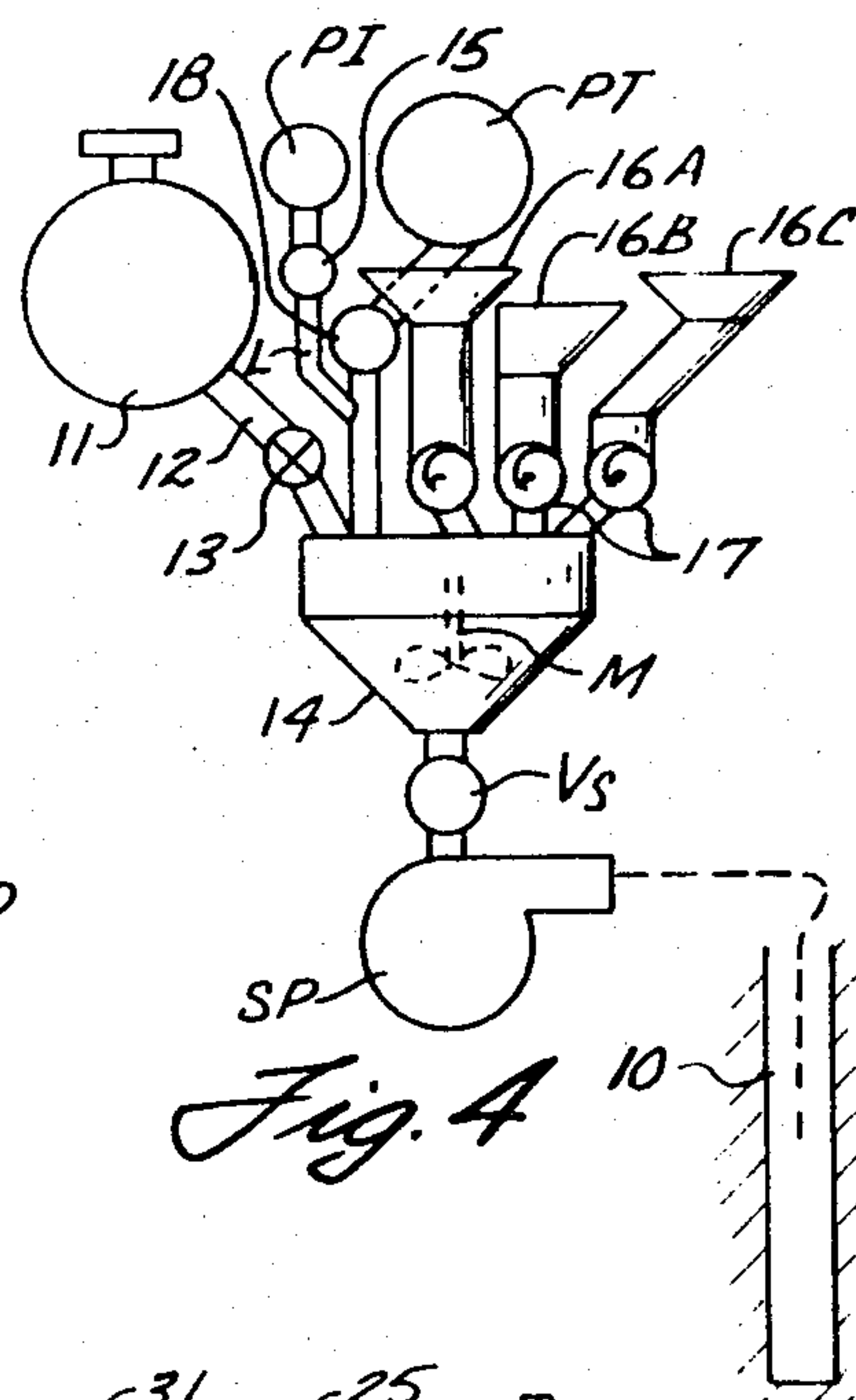


Fig. 4

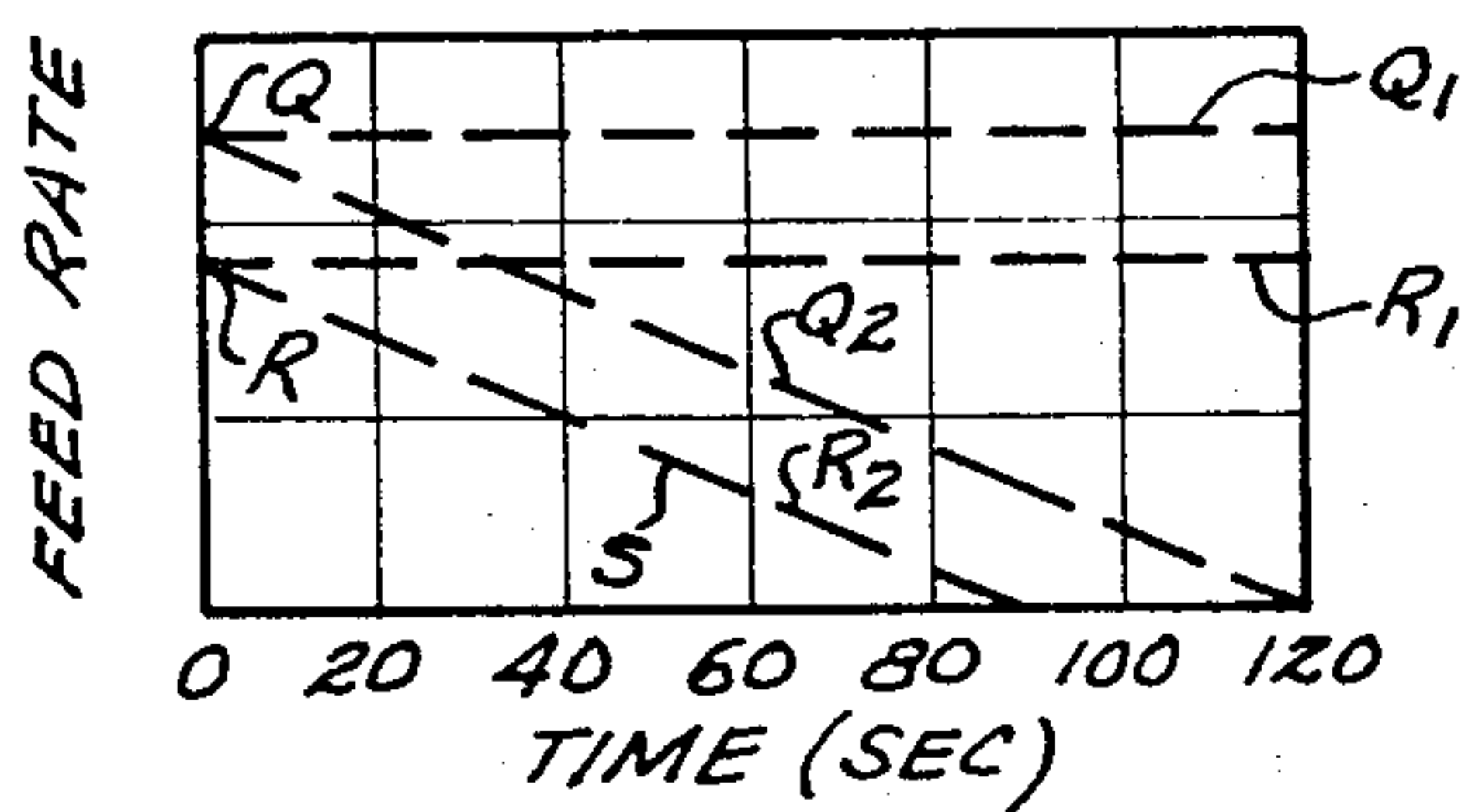


Fig. 5

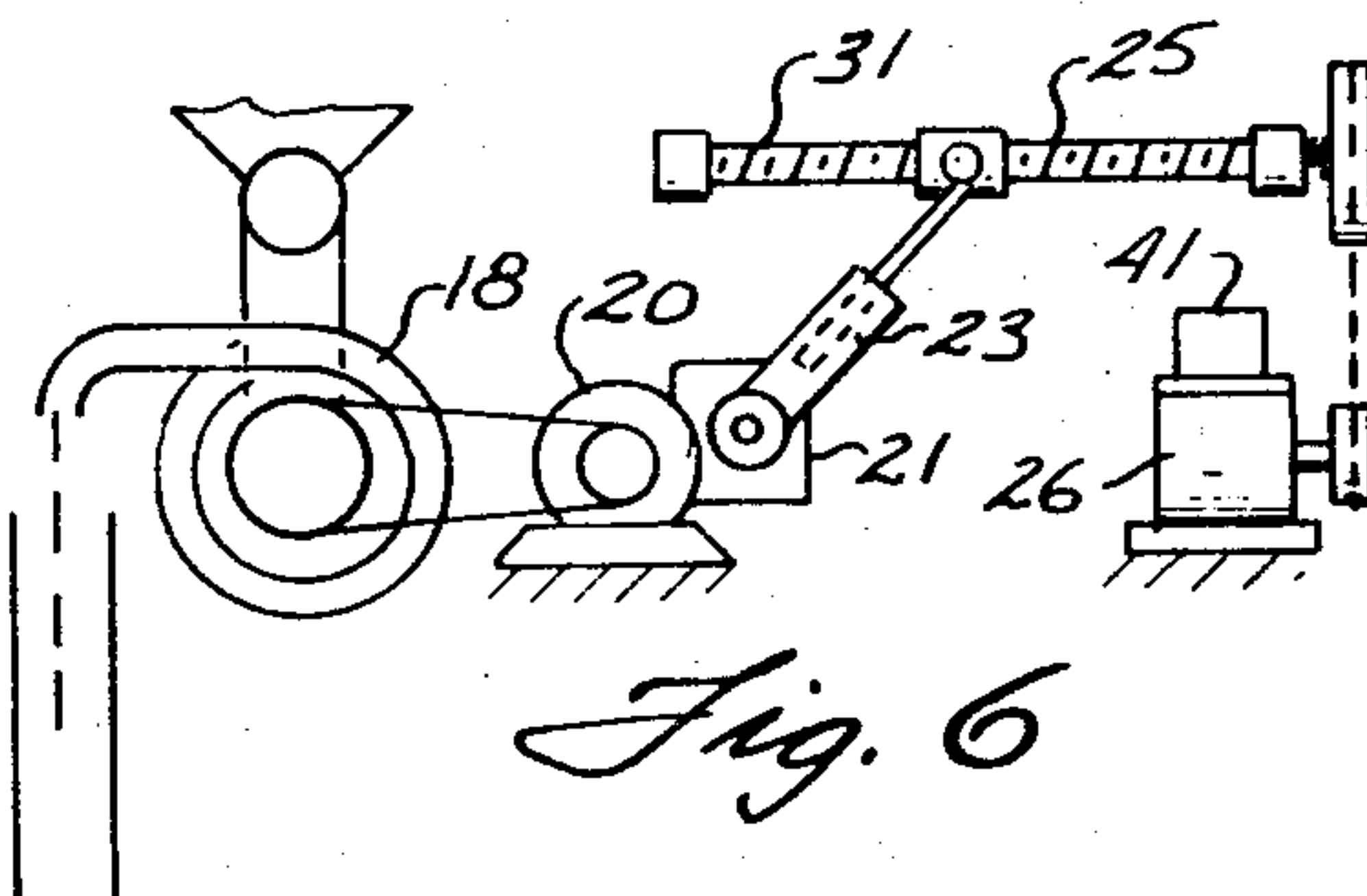


Fig. 6

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# COLUMN OF BLASTING AGENT OF CONTROLLED DENSITY

## BACKGROUND AND PRIOR ART

A number of slurry blasting agents have been proposed and used in recent years in large quantities for blasting hard rock and other analogous materials. These commonly are made up of a water solution of strong oxidizer salts, such as ammonium nitrate, or equivalent, which may include sodium nitrate and other materials. To these are added fuels and sensitizers, usually in solid particulate form and insoluble in the liquid phase, such as carbonaceous materials, finely divided aluminum metal, particles of self explosives such as TNT and the like. The fuel-sensitized explosives, other than those which employ self-explosives, usually tend to become increasingly difficult to detonate when their densities increase. For example, they may become more and more insensitive as they are compressed to higher than normal densities. A certain amount of aeration or gas inclusion is usually included in such slurries, purposely or otherwise. See U.S. Pat. Nos. 3,379,587 and particularly 3,382,117 to Cook, for example.

In columns of slurry placed in shallow boreholes this normally present aeration, which will be understood herein to cover inclusion of other gases as well as air, is often sufficient to keep the density within workable limits. In deeper columns hydrostatic pressures may compress the slurry enough to alter its blasting or detonation properties. Densities greater than 1.4 for grams/cc. for some widely used types of slurry, especially certain aluminum-sensitized slurries containing ammonium nitrate and the like in the liquid phase, are often too great to permit reliable detonation, although this may vary considerably with particular compositions and with ambient and compositional temperatures at the time of detonation. For an aluminum sensitized slurry of one typical composition, for example, it may be quite difficult to detonate at a density of 1.42 g./cc. at normal temperature. The same slurry may be much less difficult to detonate at a density of 1.3 g./cc. and quite easy to detonate at a density of, say, 1.2 g./cc. at the same temperature. It should be noted that while the density is being decreased, the bulk strength of the explosive, which is a function of its explosive power, as well as its weight, may also be decreased, although bulk strength does not necessarily decrease linearly and may not decrease at all in some particular compositions. Obviously, it may be desirable, for this reason, to keep the density of a blasting agent as high as possible, if it can be consistently and reliably detonated, for the purpose of obtaining a maximum blasting effect. On the other hand, economy may dictate aeration to get greater volume of explosive from a given weight of ingredients, even at some sacrifice of bulk strength. If the slurry density, however, becomes so great due to compression, deaeration, or any other cause, that the explosive cannot be detonated at all, or not reliably, the composition, of course, is quite useless.

Various methods have been proposed in the past for incorporating air or other gases in blasting agents of this type. In many slurries, aeration will be included without addition of any special gas-producing components, i.e. by ordinary mixing operations. Thus, in the Cook U.S. Pat. No. 3,382,117 it is pointed out that a reduction in density normally occurs in slurries and that such reductions, up to 25 percent or so, which are due simply to incorporating air into the mixture, not only can be tolerated but may be very useful under some circumstances. The incorporation of air or other dispersed gas in fine bubbles and well distributed throughout the slurry is known to add to its sensitivity to detonation. Other references in addition to those mentioned above have suggested various other means in which aeration may be accomplished. For example, Swisstack, in U.S. Pat. No. 3,288,661, suggests use of a carbon dioxide generating agent. Carbon dioxide doubtless can be useful in some cases but it is not particularly suitable for purposes of this invention because its solubility in water varies widely with temperature and pressure.

In large scale mining, as commonly practiced in the U.S., for example in large iron ore mines, it is common to drill large boreholes which may be from 4 to 12 inches in diameter and extending to a depth which may vary from 20 feet to as much as 50, 70, 80 feet, or up to 100 feet or more. Holes of 3 to 4 inches diameter and great depth are rather commonly used in some areas and these give particular difficulties in achieving detonation. In a hole of 20 feet depth or less, the weight of the superimposed column of a slurry explosive of density of, say, 1.2 or 1.3 g./cc., is not likely to be so great as to cause substantial desensitization due to excessive compression on the lower part of the blasting charge. However, when holes are deeper, say 50, 60, 70 or up to 100 feet or more, as is sometimes practiced, the weight of the column, particularly on the lower portion of the charge, becomes so great that the normal aeration or dispersed gas content present may become quite ineffective for its needed sensitization effect. That is, the normal aeration of an uncompressed slurry is insufficient in many cases to keep the bulk density of a slurry under compression down to a required level for good sensitivity and reliable detonation.

Various suggestions have been made in the past for changing the composition of a slurry explosive to be placed at different levels in a borehole, an example being Clay et al., U.S. Pat. No. 3,303,738. A more powerful explosive may be needed at the bottom of a borehole than at the top. This reference suggests methods or means for changing ingredients or the proportions of certain ingredients from time to time during filling of a single-borehole to incorporate in the slurry various properties required at different depths in the hole. Obviously, gas content or aeration is one property which can be changed as described in said patent, but generally such changes have been accomplished by changing proportions of one or more solid or liquid components.

In many cases, however, it is undesirable to change the composition by altering proportions, for example, of the major solid or liquid ingredients of a blasting slurry. Such a change may introduce undesirable variables in some cases. A good, well balanced explosive containing, for example, an aqueous solution of oxidizing salt, such as ammonium nitrate with or without sodium nitrate, etc., may be well and properly sensitized by carefully selected sensitizer such as a small amount of finely divided aluminum. It may be oxygen balanced with other fuels, such as carbonaceous materials, sulfur and the like, as is now well known in the art. To change proportions of any of these components to any substantial degree might be uneconomical of blasting power. While the present invention does not preclude substantial changes in solid and/or liquid ingredients, it may be highly desirable to be able to merely control the density of the explosive composition, or to keep it constant or substantially constant at different levels in a long vertical column, without significantly changing its composition so far as oxidizer and fuel constituents are concerned. That is, the slurry may be entirely satisfactory and efficient in its combustion and in its blasting effects, as long as it is not too dense to detonate reliably. To keep its maximum density below a desired maximum level throughout the column may be all that is needed in many cases.

One object of the present invention, therefore, is to make possible the control of density of a slurry, whether variable or standard in composition, as far as liquid and solid components are concerned, by simply controlling its gas content or its degree of aeration with finely dispersed insoluble gas bubbles. This may be done by variably adding a suitable gas to the slurry in any desired manner, preferably by adding a gas-supplying agent in controlled and often variable proportions related to the column depth. For example, a uniform or substantially uniform density in a column of slurry may be maintained throughout the length of a slurry column in a deep borehole, from bottom to top. The normal uncompressed density of the explosive may be reduced sufficiently by substantially greater aeration or gas inclusion at the bottom of the hole to compensate for the compressive force of the weight of the column, such aeration being decreased gradually or stepwise as the hole is filled.



According to the present invention then, a borehole of great depth may be filled with a standard or even a variably proportioned explosive composition whose effective density throughout the depth of the hole can be kept constant, if desired, or can otherwise be controlled or varied to insure proper sensitivity to detonation at all levels in the column. This is accomplished quite simply according to a preferred aspect of the present invention, by progressively varying the amount of an aeration or gas inclusion agent, or a material which will generate such an agent. The progressive variation may be stepwise or by steady and uniform decrease in gas-generating material changing as a borehole is filled. The appropriate material or materials are incorporated into the slurry as it is poured or pumped to the borehole. The proportions of at least one such gas-generating material can be substantially directly related, in a preferred case, to the depth at which the borehole is being filled at the moment.

#### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 shows graphically the density-sensitivity properties of certain typical slurry explosives.

FIG. 2 shows graphically the effect on density of adding one gas generating agent in various proportions to explosive slurries of different densities.

FIG. 3 shows a relationship graphically between pressure and density of typical slurries.

FIG. 4 is a diagrammatic view, in elevation, of an apparatus for mixing and pumping an explosive slurry with variable aeration or gas content.

FIG. 5 shows typical time and feed rate correlations.

FIG. 6 shows diagrammatically a simple system for controlling an initial feed rate and a controlled decrease rate for a fluid component of a slurry composition.

#### DESCRIPTION OF PREFERRED EMBODIMENT

The invention will be described with reference to typical and more or less conventional aluminum sensitized aqueous explosive slurries containing ammonium nitrate and various other ingredients which are commonly employed in such slurries. It will be understood, however, that the principles of the invention are not limited to any particular slurry compositions, being applicable to various oxidizer-sensitizer type slurries which display the phenomenon of having their sensitivity decrease as they increase in density, i.e. as they are subjected to increasing pressure or compression.

With many explosives, including fuel sensitized slurries, sensitivity to detonation increases more or less inversely to density. In some cases the relationship is quite linear. With slurries of this invention, it is often found desirable, in order to control sensitivity, to decrease density of in-place explosives by some aeration or gas inclusion but, as a rule, the density should not be decreased excessively by this means.

Ordinarily, the density of the slurry should not be reduced to as little as 1.0 g./cc. for incorporation in a borehole where water is present. Otherwise incoming ground waters would tend to lift the slurry out of its intended position. Floating on water, for example, might move the slurry up a borehole and completely out of place. However, there may be some cases, as where there is no ground water present, where an even lighter slurry than 1.0 density is desired. It should be noted that some other kinds of desensitization than that due to deaeration or gas compression may occur in some aluminized slurries, e.g. when their density drops lower than about 0.5 to 0.6 g./cc. Excessive density reduction usually is not desirable because the bulk strength of the blasting agent becomes low and the slurry is likely to become relatively weak or ineffective in its blasting performance.

There may be additional hydrostatic pressures, above that due to explosive column height, exerted on the borehole by inflowing water, as in the case of excessive ground water which may exert an upward force on the bottom of the slurry column resisted by friction between the slurry and the borehole wall. However, the pressure on the slurry at the bottom of the

borehole ordinarily may be assumed to be caused by the sum of weight of the column of slurry plus any head of water or other materials on top of the slurry, including stemming which may be placed on top of the column.

It has been found experimentally that the critical diameter of most fuel sensitized slurries, particularly aluminum-sensitized ammonium nitrate slurries, etc., which include some gas or aeration, increases as pressure on the slurry increases, at a rate of about 0.07 to 0.1 inches of critical diameter in the slurry, per pound per square inch of pressure increase. That is, a typical slurry of critical diameter  $d_c$  of 4 inches at zero or atmospheric pressure may have a  $d_c$  of about 6 inches at 20 p.s.i.g. Taking a slurry column depth and multiplying it by average density of the slurry, plus the depth of any water present on top of the slurry when the charge is in place, this sum being multiplied by 0.433, will give the pressure in pounds per square inch at the bottom of the hole. This pressure, of course, reduces as one goes up the borehole. From this it will be seen that the critical diameter of a gas-containing or aerated slurry may increase quite rapidly in a deep hole. This must be compensated for by density control, particularly when sensitivity approaches a level where detonation failure might be encountered.

The sensitivity to detonation of aluminum-sensitized slurries which are below their theoretical or unaerated densities is known to decrease at a fairly regular or predeterminable rate as the slurry is subjected to increased static pressure or compression. According to one aspect of the present invention, an agent is added to the slurry which will decompose fairly soon to produce a gas or aerating agent. The aerating gas should be produced in proportion to the need to density control at any particular depth, where control of sensitivity is the main consideration, as it often is.

Hydrogen peroxide is a preferred gas generator, although other materials may be used. When added to the slurry under appropriate conditions and with a suitable catalyst, it will decompose into water and oxygen soon after the explosive is in place in the borehole. The oxygen gas so generated does not dissolve appreciably in the liquid phase and thus lowers the density of the slurry, offsetting reduction in sensitivity due to compression or column weight. At the bottom of a deep borehole, considerable aeration to prevent a compression-induced increase in density may be required. Midway of the borehole, the density decrease due to superimposed slurry, water, stemmings, etc., may be much less. At or near the top of the explosive column it may be entirely unnecessary to have any gasification agent at all since the density may not be substantially affected by the borehole filling. Preferably, the amount of gas-producing material should be adjusted to meet requirements.

Under some circumstances, it may be desirable and simpler to add the gas-generating substance at a fixed and invariable rate, as the slurry is being mixed and delivered to a borehole. In this case, sufficient hydrogen peroxide or equivalent material is added at first to make sure that the compressed slurry at the bottom of the borehole is sufficiently sensitive for detonation. In this case, slurry higher up the column will be less dense and consequently more sensitive than necessary for detonation. It may have less than maximum blasting power too, by reason of its reduction in bulk density. In many, and perhaps in most cases, the most powerful part of the charge is needed at the bottom of the hole. A less dense explosive is still adequately powerful higher up and may be substantially more economical since less weight of explosive is required per unit volume.

Hydrogen peroxide is an unstable molecule which rather easily decomposes to give off an extra oxygen atom. By use of a catalyst, or establishment of other degeneration conditions, such as the aging of a peroxide solution or the use of materials which release the peroxide gradually, one can cause the peroxide to decompose at reasonably controllable rates. For purposes of the present invention a very desirable catalyst is found to be potassium iodide (KI). Manganese dioxide in pro-



portions of 0.05 to 1 percent, preferably around 0.2 percent of weight of total slurry has also been used, as well as ferrous sulfate and mixtures of ferrous sulfate, managanous sulfate and an organic compound such as HMT (hexamethylene tetramine). Ferric nitrate, in proportions of up to 0.2 percent is effective, although it has showed sometimes a tendency to fail in effectiveness, e.g. after extended storage in the premix which contained powdered aluminum and other ingredients discussed more fully below. The use of potassium iodide or manganese dioxide, or a combination of manganese dioxide in the premix with ferric nitrate added to the oxidizer solution, therefore, is presently preferred. However, any catalyst which will cause reasonably rapid decomposition of hydrogen peroxide can be used. It is found that a combination of ferric nitrate with manganese dioxide is a better catalyst than either alone. The ferric nitrate can be added in the form of a 50/50 aqueous solution (by weight) to the solution of oxidizer. Obviously, the decomposition rate of the hydrogen peroxide should be such that the oxygen gas bubbles released are very tiny. Being produced and widely distributed in a viscous medium, which explosive slurries usually are or contain, the small gaseous bubbles once released are not likely to coalesce or to rise to the top to any significant degree. This means that finely distributed aeration or gasification remains in the slurry, even at great slurry column depths and under considerable superimposed pressures. The decomposition preferably should be sufficiently rapid that the slurry is aerated almost or approximately as fast as it fills the borehole, but some delay is permissible.

Hence, with a given explosive slurry composition, such as one comprised mainly of an aqueous solution of ammonium nitrate, sodium nitrate, etc., the insoluble sensitizer and/or fuel particles, which are suspended in the solution to form the slurry, are added in any convenient way and stirred in to make a stable, homogeneous suspension. Particles such as finely divided gilsonite, sulfur, aluminum powder, etc., are commonly used. Oxidizer particles, such as ammonium or sodium nitrate, may also be suspended in the solution without dissolution because the solution is saturated.

According to one system which is quite satisfactory, potassium iodide is first placed directly in the solution in small proportions such as 0.05 to 0.5 percent by weight of total slurry, preferably about 0.2 percent. The hydrogen peroxide is metered into the mixing zone or funnel as the other ingredients, such as the solid particles mentioned, are mixed therein. A small amount, i.e. a fraction of 1 percent of total slurry by weight, is enough hydrogen peroxide to reduce a slurry density from 1.4 to 1.0 or less. The proportions of hydrogen peroxide used at the beginning of a borehole filling operation are high enough to give considerable aeration to that part of the slurry going at the bottom of a borehole. By appropriate control the amount of hydrogen peroxide metered as the mixing proceeds for filling a given borehole, is reduced gradually to zero by the time the borehole is filled. In some operations, the potassium iodide or other catalyst and the hydrogen peroxide additive may be mixed concurrently into the mixing funnel along with the fuel and other solid particles which are stirred into the solution and suspended therein.

According to a preferred embodiment, hydrogen peroxide is placed in a tank in a pump truck which contains a slurry mixer, preferably a mixing funnel. This hydrogen peroxide is metered into the slurry at the mixing funnel at a controlled and preferably decreasing rate for each borehole batch, as indicated above. The pump used for dispensing the peroxide preferably is a peristaltic type, operating by applying a squeezing, pumping action applied to a flexible tube. The rate of pumping the hydrogen peroxide ingredient and, hence, the flow rate thereof, is controlled by a "zero-Max" speed controller. The latter device, of known commercial type, can be set at any pumping speed from zero to its rated maximum simply by moving a control lever.

According to a preferred procedure, the speed control lever is preset to the maximum rate needed for a borehole batch and

is automatically moved toward the zero position over the time required to fill the borehole by a second "Zero-Max" mechanism. This second unit may be attached to the control handle of the first and so arranged that it turns the control of the first unit back to zero in a predetermined time. By knowing the pumping rate and dimensions of borehole to be filled, this time can be preset accurately.

In practical use, the density of a slurry ordinarily should not exceed a value of about 1.3 to 1.4 g./cc., referring now to aluminum sensitized slurries, without being desensitized and failing to shoot on detonation. On the other hand, the slurry density as aerated should not be allowed ordinarily to go below 1.0 g./cc. Otherwise, it will float on any water and be lifted out of the borehole, where ground water is present in quantity, as is commonly the case. A simple calculation shows the maximum amount of the gasifying or levitating agent, that is, of hydrogen peroxide, which is needed at the toe or bottom of the column. None is needed at the top in most cases. The maximum rate is then adjusted as pumping of the slurry proceeds. According to the present invention the reduction in pumping rate is accomplished automatically. The operator needs to set only the desired initial rate and the total peroxide flow time. The controls then start feeding peroxide as borehole filling commences and the feed rate declines to zero by the time the hole is fully charged.

Referring now to the drawings, FIG. 1 shows graphically the effect on sensitivity of variations in density for three different slurries, A, B, and C. FIG. 2 shows the percent of concentrated peroxide which is necessary to obtain different specified densities for slurry at different pressures. A slurry of density 1.1 g./cc. at zero pressure requires about 0.8 percent of hydrogen peroxide (35 percent strength) to maintain the same density under 38 p.s.i. A similar slurry of density 1.2 at near zero pressure requires 0.6 percent of  $H_2O_2$  to maintain the same density under pressure of 47 p.s.i., etc. A simple calculation based on slurry column and desired slurry density (plus depth of water on top of slurry in water filled holes) will show the hydrostatic pressure at the bottom of the borehole. Hence, bottom pressure is calculated for the desired density, and the peroxide is metered into the slurry as filling is started at the indicated rate. The second control is adjusted to gradually cut down the peroxide feed rate to zero by the time the borehole is filled. This time can be calculated by knowing the slurry feed rate and the total charge to be placed in a borehole of specified depth, filled with the selected slurry of desired density. Ordinarily, concentrated 35 percent strength peroxide is used and the charts (FIGS. 2 and 3) are based on that concentration. This peroxide must be used with care because it can be harmful to the human skin.

As a concrete example of a filling operation, a 74 foot borehole to be filled with slurry of density of 1.25 g./cc., FIG. 2, when the normal unaerated density of slurry is about 1.4, will require 0.36 percent by weight of 35 percent strength peroxide, based on the total composition. Slurry of 1.25 g./cc. density in a column 74 feet high is under pressure of 40 p.s.i.g. Knowing the percentage of peroxide required, it can be readily calculated the amount of hydrogen peroxide equivalent to the necessary flow rate for a slurry pumping rate of, say, 300 lbs. per minute, as an example. Pumping rates of 100 to 300 lbs. per minute or more are commonly in use in pump truck mixer-type apparatus of the general type mentioned above.

If the peroxide is diluted half-and-half with water, as may be desirable from the standpoint of safety, the peroxide flow rate, of course, should be doubled to obtain the same quantity of gas on decomposition.

A reading of FIG. 2 together with knowing the desired density of the unaerated slurry and the borehole depth, will permit determination of the peroxide flow rate which is necessary to aerate the slurry at the bottom or toe of the borehole. The next step, obviously, is to calibrate the apparatus to give the required peroxide flow rate.

In a specific example, a mixer-pump truck using straight 35 percent concentrated peroxide, the first step is to set the



peroxide pump at a suitable rate and set the second or rate reduction control to zero so that the peroxide pump will run at a constant speed. A calibration is then made in volume, determining the cubic centimeters of peroxide per minute which will be pumped at the set rate, using water, for example, as the test liquid. In this way appropriate settings of the peroxide pump are determined. The volume of fluid pumped is approximately linear with respect to the setting of the pump rate or volume control for the apparatus shown.

Typical compositions aerated in the manner described comprise the following ingredients:

- 30 to 50 percent by weight of ammonium nitrate
- 10 to 40 percent of sodium nitrate
- 12 to 20 percent of water
- 0 to 10 percent of sulfur
- 1 to 10 percent of carbonaceous fuel (gilsonite or bituminous coal)
- 0 to 10 percent of aluminum, preferably 0.1 to 8 percent, a small part of which preferably is fine flaked grade, typified by paint grade aluminum
- 0.2 to 2 percent of thickener, such as quar gum, preferably with a small amount of Borax or other cross-linking agent.

A small amount of an inhibitor to prevent premature aluminum-water reaction is desirable when fine reactive aluminum is used, as set forth more fully in U.S. Pat. No. 3,113,059.

By use of suitable proportions of sulfur, also, the ammonium nitrate content may be reduced and proportions of sodium nitrate increased to exceed the proportions of ammonium nitrate.

Ingredients are adjusted typically to bring oxygen limits within  $\pm 10$  percent and, if aluminum is not included, special combinations of sulfur and carbonaceous fuel, etc., are employed, as is known in the art. Use of about 0.1 to 0.2 percent of a 50 percent solution of potassium iodide, with appropriate quantities of hydrogen peroxide, as shown in FIG. 2 (up to about 1 percent) is recommended. The alternative catalysts already described may be substituted or used as a part of the catalyst in suitable proportions and in the manner mentioned above.

For convenience of the operator, a table may be made up listing the setting of the controls vs. borehole depth for a given composition. Knowing the pumping rate and the original or desired density of the slurry, it is easy to calculate the amount of peroxide or other aeration agent that should be added.

FIG. 4 shows a typical apparatus in general form for mixing slurry and pumping it into a borehole 10. The apparatus comprises a tank 11 for a concentrated solution of ammonium nitrate, which may include some sodium nitrate and a small amount of thickener in water. Line 12, having a cut off valve 13, feeds the solution to mixing vessel 14 having a suitable stirrer or mixing device M. Bins 16A, 16B and 16C supply particulate ingredients, such as aluminum, fuels, supplemental oxidizer, etc. The latter are fed by augers 17 or equivalent at various rates, depending on the composition of the slurry. A small tank PT carries a supply of gas-generating material, preferably hydrogen peroxide. Another tank PI for solution of catalyst potassium iodide or the like, may be connected to supply catalyst at a controlled rate. Only a small amount of catalyst is needed. The latter flows through a line L, provided with a cutoff valve 15 to metering pump means described further below. A slurry pump SP, driven by a suitable power source, pumps the finished slurry through a hose or other conduit into borehole 10. A valve  $V_s$  may be provided to hold slurry in the mixer vessel 14 until pumping is started.

The time of flow of peroxide or other aerating agent is governed by the amount of slurry to be pumped into the borehole. Knowing the pumping rate, the time is easily calculated. Apparatus shown in FIG. 6 includes pump 18 driven by a motor 20 and involves a control 21 for pump motor 20. An arm 23 sets control 21 and changes its setting under control of a rotating shaft 25 driven by motor 26. The latter has screw threads 31 which may be counted to determine the number of

rotations of this particular element required to accomplish a given result. Control 41 for motor 26 controls the rate at which the threaded shaft 25 is turned and therefore determines the setting of its control 21. These relationships determine the elapsed time required for the pump rate of the peroxide additive to go from maximum to zero.

The time required to reduce the feed rate of pump 18 to zero from its maximum starting position, as each borehole is filled, may be measured experimentally or calculated from the number of turns or threads on the shaft.

Once these calibrations are made, the operation of the device is quite simple. The borehole depth determines the maximum or initial rate of peroxide flow and the pumping time required to fill the borehole gives the total peroxide flow time. Of course, if desired, the peroxide may be cut off before the full charge is inserted since the upper part of the charge may not be much affected by hydrostatic compression. Assuming that 500 lbs. of slurry are to be treated with peroxide all the way and placed in a 40 ft. depth borehole, the chart may be used as follows. The 40 ft. borehole depth is used to calculate hydrostatic pressure and, hence, to determine its effect on slurry, per FIG. 2. 500 lbs. of slurry pumped at 300 lbs./min. requires 100 seconds of pumping time. FIG. 5, of course, shows the slope S or rate of decrease to go from maximum feed rate to zero in 100 seconds.

Determining the initial flow rate from FIG. 2, the electrical switches for motors 20 and 26 and peroxide valve 15 are turned on. The apparatus runs automatically while the pump delivers the peroxide. When a series of holes of equal depth are to be filled, and the slurry is not changed in composition, it is a simple matter to reset the control 21, 23 back to the starting position with each hole. If the slurry pumping time is changed, or the hole depth from hole to hole, the procedure must be modified by changing control 41 to compensate for this. Likewise, for a change in composition it is necessary to change the setting of one or both controls 21, 41.

As noted above, hydrogen peroxide is a strong oxidant and can cause fires when spilled on or in any combustible materials. It is hazardous to the body and can cause blistering of skin and severe irritation. Human eyes are particularly sensitive to it and care should be taken in handling the material. Peroxide solution usually is dyed a distinctive color so that it will not be mistaken for a less energetic or less harmful fluid.

FIG. 5 shows graphically how the apparatus of FIG. 6 may be used to control the feed rate of the gassing agent. The initial feed rate may be adjusted at any desired level such as indicated by the points Q or R. If not changed by the second control 41, the feed would continue at a uniform rate, i.e. on a horizontal line  $Q_1$  or  $R_1$ . By setting the zero-max controller 41, the rate of rotation of screw 25, FIG. 6, is adjusted to determine the slope of the desired control rate  $Q_2$  or  $R_2$ , etc. Determination of (a) initial feed rate Q or R, plus (b) the required pumping time, e.g. 100 seconds, or 120 seconds, or some other time, to fill a borehole thus is used to set controls 21 and 41. These will control pump 18 to incorporate the right amount of gassing agent at any depth in the borehole. The catalyst from tank PI may also be metered, if desired, by this same pump or by another. Usually, it is not necessary to change catalyst feed rate but it may be desirable under some circumstances.

While substances other than hydrogen peroxide may be substituted,  $H_2O_2$  is preferred for the purpose of the present invention. It will be obvious, however, to those skilled in the art that other materials producing other gases, e.g., carbon dioxide, etc., could be used and the same principles apply.

We claim:

1. A tall aerated blasting charge in the form of a compressible column of explosive composition having tendency to lose sensitivity under increasing density conditions, which comprises an elongated detonable mass of thickened blasting slurry having a continuous or substantially continuous liquid phase and including an oxidizer salt in solution in said liquid phase, sensitizer-fuel material distributed throughout said



solution, and an aerating gas finely dispersed and distributed in at least the lower part of said column in proportions at least sufficient to maintain detonability throughout the entire column of explosive by offsetting loss of sensitivity in the slurry due to the increase of density in the composition resulting from compression of said column.

2. A blasting charge according to claim 1 wherein proportions of said aerating gas decrease from the bottom towards the top of the column.

3. A blasting charge according to claim 1 which contains decomposable hydrogen peroxide as an aerating agent.

4. A charge according to claim 1 which contains hydrogen peroxide as an aerating agent and a small proportion of hydrogen peroxide-decomposing catalyst, said catalyst being uniformly distributed and said hydrogen peroxide being non-uniformly distributed throughout said charge.

5. A blasting charge according to claim 1 which contains

sufficient aerating gas to keep its bulk density in all parts of the column below about 1.4 grams per cubic centimeter.

6. A blasting charge according to claim 1 which contains a substantially uniformly decreasing proportion of aerating gas from the bottom of the explosive column to the top.

7. A charge according to claim 1 wherein the gas is oxygen.

8. A charge according to claim 1 which includes a gas-generating substance unequally distributed with a high concentration in the lower part of the charge and a lesser concentration in the upper part.

9. A charge according to claim 1 which comprises a substantially uniformly distributed small concentration of gas-producing agent sufficient to insure detonation at the bottom of a deep column of slurry and more than adequate for insured detonation at higher levels.

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