FIG. 7

FIG. 8

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3,482,637

PROCESS AND METHOD FOR QUENCHING INCipient GAS-AIR EXPLOSIONS

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PRESSURE

DISTANCE OF QUENCHING DEVICE FROM WORKING FACE - FEET

FLAME

FLAME EXTENT - FEET

MAXIMUM PRESSURE DEVELOPED - PSIG

0 10 20 30 40 50 60 70 80 90

0 25 50
FIG. 9

FIG. 10
PROCESS AND METHOD FOR QUENCHING INCipient GAS-AIR EXPLOSIONS

Donald W. Mitchell, Bethel Park, and Edwin M. Murphy, Edward M. Kawinski, John Nagy, and Roger P. Williams, Pittsburgh, Pa., assignors to the United States of America as represented by the Secretary of the Interior Filed Oct. 20, 1967, Ser. No. 615,511
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U.S. Cl. 169—1

5 Claims

ABSTRACT OF THE DISCLOSURE

Gas-air explosions, such as those occurring in coal mines, are quenched by sensing the ultraviolet emissions of the developing flame front and dispersing a powdered quenching agent such as potassium bicarbonate into the immediate flame environment in response to the sensed radiation.

Background of the invention

A gas explosion hazard continuously exists in most coal mines. Methane is usually occluded in the coal seam being worked, a ton of unmined coal containing as much as 1000 cubic feet of the gas. Neighboring strata often contain additional methane. The rate of methane release in or near the working face increases with the rate of face advance and with the proportion of fine coal produced. Methane from neighboring strata enters through cracks and crevices that generally form in the strata above and below the coal seam as it is mined.

The potential hazard of a gas explosion in a coal mine is greatest at or near the working face. Here, all factors tend to intensify the hazard; gas emission is greatest, concentration of men and electrical equipment is highest, space is limited, ventilation is difficult and visibility is poor. About 70% of reported coal mine ignitions occur at the working face and these ignitions are usually caused by frictional sparks created by cutting bits striking pyrites or hard rock.

At the present time the ignition hazard is controlled primarily by providing good ventilation at the coal face so as to dilute the methane sufficiently with air to obtain a non-ignitable mixture. Control of frictional sparking from cutting-bit action is possibly impossible. In fact, modern mining methods tend to increase this hazard by increasing the loan on and the speed of the cutting bits.

It has been proposed to minimize the explosion hazard in coal mines by detecting and suppressing a potentially dangerous explosion immediately following ignition and before the explosion has reached a destructive level. One such system is disclosed in the Gendlinning et al. Patent, U.S. 2,693,240. In this patent, the incipient explosion is detected by sensing the abnormal pressure rise characteristic of a developing explosion. A signal is generated by the abnormal pressure rise and this signal is used to trigger the explosive distribution of an extinguishing material such as methyl bromide.

This type of device has many serious disadvantages when used in a coal mine. Use of a pressure rise measurement to detect a developing explosion introduces an inherent lag or delay into the system. For example, in a methane-air explosion in which the methane concentration is about 9–10%, or roughly stoichiometric, the flame front will precede the developing pressure wave for a short period of time. Methane ignitions characteristically have a time lag between initiation and pressure development. This time lag has been found to range from about 100 to 2000 milliseconds, being lowest for stoichiometric homogenous mixtures. The time lag increases with decrease in homogeneity of the mixture and is highest for rich concentrations.

In a typical coal mine gas ignition, men are often working in the immediate area; sometimes within a few feet of the ignition source. The Gendlinning et al. device allows a pressure wave on the order of 0.3 p.s.i.g. to develop before the explosion is quenched. Eardrums rupture and concrete-block walls are collapsed by a peak overpressure of 2 p.s.i.g. A pressure wave of this magnitude will also raise considerable amounts of coal dust into suspension which provides additional fuel for the flame front and increases the severity of the explosion.

The explosive shattering of a rigid, sealed container of fire-extinguishing material can create a pressure pulse well in excess of 2 p.s.i.g. This pressure pulse not only can damage the hearing of a man in close proximity to the rupturing container but also tends to raise coal dust into suspension. Fragments of the shattered container tend to act as missiles having high initial velocities presenting a severe hazard to anyone in the immediate area. Another hazard is from noise damage. This is particularly severe in the relatively confined area which typifies the working face of a coal mine.

It has also been proposed to substitute a radiation detector, such as a photomulipler tube, as the explosion sensing device in place of the pressure rise detector of the Gendlinning et al. device. Exemplary of this approach is the Mathisen Patent, U.S. 2,869,647. Such a radiation detector offers increased sensitivity and decreased reaction time as compared to a pressure-rise device.

A radiation-sensing explosion detector, when used in the environment of a coal mine, is completely unsatisfactory if it responds to non-flame related radiation. Radiation sources present in coal mines include the incoherent light used on mining machines and by miners, gamma ray emission produced by cosmic radiation and by radon gas, electric arcs and by frictional sparks produced by the cutting bits. A satisfactory detector must discriminate between these spurious radiations and those produced by a flame front.

The minimum design criteria for a device capable of suppressing coal mine explosions are as follows:

1. The device should be a self-contained unit capable of being mounted near the face end of a mining machine.
2. The device must be sufficiently rugged to withstand the continual vibration and shock of a mining machine.
3. The flame detector should sense flame radiation anywhere within a solid angle of at least 120°. This requirement is based on typical machine-face cross-sectional area ratios and on observations of flame spread in stratified gas-air bodies.
4. The developing flame should be detected by radiation in the ultraviolet region in order to avoid interference with other normally present coal mine radiations. Response time of detectors sensing an increase in pressure or temperature is too slow for subsequent quenching of burning methane.
5. Flame must be detected and sufficient flame quenching agent must fill the working face within 50 milliseconds after gas ignition.
6. The flame quenching agent must be uniformly dispersed. Non-uniform dispersion will inhibit but will not quench developing explosions.
7. The flame quenching agent must not present a hazard to workers. Many common fire extinguishing
materials cause severe respiration and eye damage in the concentrations necessary to quench an explosion. (8) The means for dispersing the quenching agent should neither promote nor cause injury or destruction. The present invention comprises a process and apparatus, which can be operated in close proximity to workmen without hazard, for sensing and quenching developing explosions before the explosion can cause injury or destruction. The apparatus comprises a radiation sensor which is responsive only to emissions characteristic of a methane-air flame operatively coupled to a flame quenching agent dispersal system having an extremely rapid response time which produces a very low pressure shock wave. Accordingly, it is a primary object of this invention to quench explosions without hazard to adjacent personnel. It is another object of this invention to provide apparatus capable of detecting a developing explosion in a lighted environment and suppressing that explosion by dispersing a flame quenching agent into the explosive environment. A specific object of this invention is to quench gas-air explosions in coal mines by sensing only the ultraviolet emissions characteristic of a methane flame thereby activating dispersing means to distribute flame quenching agent to suppress the explosion within 50 milliseconds of original ignition.

Description of the invention

Certain embodiments of the invention will now be described with reference to the accompanying drawings in which:

FIG. 1 is a general schematic representation of the explosion quenching system.

FIG. 2 is a partial sectional view of a quenching agent dispersing container.

FIG. 3 is an alternative embodiment of the device of FIG. 2 incorporating integral protective means for the quenching agent charge.

FIG. 4 illustrates another embodiment of the quenching agent dispersing container.

FIG. 5 is an alternative embodiment of the device of FIG. 2 incorporating integral protective means for the quenching agent charge.

FIG. 6 illustrates the attitude of the expended device of FIG. 5.

FIG. 7 is a view of a coal mine showing the orientation of the explosion quenching system relative to a mining machine and the working face.

FIG. 8 is a graphical representation of pressure development and flame extent relative to location of the quenching agent dispersing container.

FIG. 9 illustrates the relationship of flame extent and pressure development to the timing of flame quenching agent dispersal.

FIG. 10 shows the spectral distribution for a methane-air flame.

In order to prevent injury to workmen and damage to structure and equipment, a gas-air explosion must be quenched within about 50 milliseconds after ignition. This time period is the total of the individual time intervals for sensing flame, activating the quenching agent dispersing system, dispersion of the flame quenching agent and subsequent chemical and physical flame-extinguishing reactions. As shown in FIG. 9, at time intervals greater than about 50 milliseconds, either the volume of flame is appreciable or explosion pressures are sufficiently high to cause injury and destruction.

As was expected, stoichiometric gas-air mixtures were the most difficult to quench. As shown in FIG. 9, satisfactory explosion quenching of such mixtures was achieved only when the time interval between ignition and actuation of the dispersing system for the quenching agent was no more than 20 milliseconds. When the dispersing system was actuated within 10 milliseconds, flame extinction was less than 5 feet and no measurable pressure developed. When actuated 20 milliseconds after ignition, flame extended about 5 feet and a maximum pressure of about 0.6 p.s.i.g. developed. When actuated 50 milliseconds after ignition, flame extended a sufficient distance to have enveloped and burned the miners.

It is thus clearly evident that a satisfactory detector must have an extremely fast response time; much less than 50 milliseconds and preferably much less than 10 milliseconds.

Referring now to FIG. 1, the explosion suppression device of this invention comprises a radiation sensor 1 which transmits a signal to a photon counter amplifier 2 via connection 3.

Radiation sensor 1 comprises a gas filled photodiode or Geiger-Müller type tube and operates in the photoelectric gas-gain mode. A photon-counter with an adjustable threshold of sensitivity, such as that disclosed in the Friedman Patent U.S. 2,715,195, is an example of a device which may be employed as the sensor. Photons having an energy greater than that equivalent to a wavelength of about 3000 Angstroms (A.), pass through the contained gas and strike the electrode surface producing photoelectrons. These photoemissions are formed under influence of an electric field within the tube creating secondary ionization and resulting in an electron avalanche that is fed into photon counter amplifier 2 as a pulse of current. Photon counter amplifier 2 is a multivibrator pulse shaper that first broadens each pulse of current from the tube so that subsequent electronic components would be capable of sensing what otherwise would be a signal too short in duration for reliable operation of the pulse counting circuitry. The pulse counting circuitry of photon counter amplifier 2 is so constructed that a subsequent triggering circuit is activated only when the photon pulse rate reaches a preset level equivalent to 4 or more pulses per half second. Photon counter amplifier 2 circuitry also is so constructed that the accumulated count is nullified each second; this nullification or "forgetting" circuit reduces the sensitivity of the sensor to non-flames, high-energy radiation sources such as gamma rays from cosmic rays and radon gas (the circuits and tube are unaffected by alpha and beta rays). For example, the gamma-ray activity associated with cosmic rays in coal mines seldom exceeds 1 pulse per second; should the electronic circuitry accumulate those pulses in photon counter amplifier 2 then it is possible for the circuit to be activated in time by a cosmic rather than flame source. In summary, though the detector tube responds to all radiations having a wavelength below about 3000 A., the output from photon counter amplifier 2 is restricted in such a manner that the flame detector unit as a whole can be considered to be responsive only to radiation having a wavelength between about 2000 to 3000 A. In other aspects, photon-counter amplifier 2 is a standard component well known in the art. One example of a commercially-available radiation sensor which may be used in this device is the DP 28/A flame detector manufactured by Melpar, Inc., A rlington, Va.

When the photon rate in photon counter amplifier 2 reaches the above discussed preset level equivalent to 4 pulses per half second a triggering circuit is activated that sends a signal of about 22/2 volts DC through connection 4 which energizes shot-firing condenser 5. The condenser discharges through wires 6 and triggers an electrical blasting cap 7 which in turn ignites the explosive charge used to distribute quenching agent from dispersing system 8. Construction and operation of the dispersing system will be detailed later.

FIG. 10 illustrates the spectral distribution for a methane-air flame and indicates the relative intensities of the spectral radiations. As can be seen from the figure, the
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flame radiates rather strongly in the 2000 to 3000 A. range. The major spectral peak between 4000 and 5000 A. cannot be discriminated from the radiation produced by incandescent lights used on mining machines and by miners. These lights do not emit radiation below about 4000 A. The energy level of a methane-air flame below about 4000 A. is not sufficient to permit use of photo-conductive cells, photo-cells and photosomnographs when these devices are coupled with the necessary optical filters to block out transmission of visible light. Infrared detectors would require filters to avoid interference with incandescent radiation and would respond more to the hot combustion gases and vapors produced by a flame and by heated lubricants on the mining machine rather than to the flame itself. Another disadvantage inherent in using infrared detectors is that water vapor tends to strongly absorb infrared radiation while it is effectively transparent to ultraviolet radiation.

Of the quenching agents studied, potassium bicarbonate has an average particle diameter of about 16 microns, had the best combined qualities with respect to toxicity, effectiveness and cost. The KHCO₃ particles preferably are siliconized to reduce agglomeration and moisture adsorption. It is also preferred to admix with the potassium bicarbonate a small amount of granular, moisture-indicating anhydrous calcium sulfate or other indicating desiccant to reveal the presence of moisture. Conventional-used explosion suppression substances, such as methyl bromide and the like, were ruled out as being unsatisfactory in this application. Methyl bromide is a severe skin and respiratory irritant and can cause death upon short exposure to the concentrations required to suppress a developing explosion. In addition, methyl bromide, with a boiling point of about 35°C., must be contained under pressures of about 10 to 25 p.s.i.g. at the conditions encountered in ordinary coal mines. Explosive rupturing of a container at those pressures generates an intolerably great shock wave as well as projecting parts of the shattered container at velocities sufficient to cause severe injury.

The comparative effectiveness of the quenching agents studied is shown in the following table:

| Table 1 |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Quenching agent | Average particle diameter, microns | Maximum pressure, p.s.i.g. | Flame extent, feet |
| KHCO₃ | 2 | 20 | 50 |
| KHCO₃ | 2 | 20 | 50 |
| KHCO₃ | 2 | 20 | 50 |
| KHCO₃ | 16 | 20 | 50 |
| Na₂CO₃ | 16 | 20 | 50 |
| Na₂CO₃ | 10 | 20 | 50 |
| K₂CO₃ | 2 | 20 | 50 |
| K₂CO₃ | 2 | 20 | 50 |
| K₂CO₃ | 2 | 20 | 50 |
| K₂CO₃ | 2 | 20 | 50 |

1 Pressures below 0.2 p.s.i.g. cannot be determined with present EOM equipment.
2 Quantity probably exceeded that capable of being dispersed by 20 feet of 60-gallon detonating cord.

In order to quench developing explosions in a relatively confined area such as the working face of a coal mine, the flame quenching agent must be dispersed as a relatively uniform dust cloud into the flammable atmosphere. High speed movies show that non-uniformly distributed dust inhibits but will not quench developing explosions. Distribution of a uniform cloud of flame quenching agent must be accomplished within a very short period of time, preferably in less than about 40 milliseconds, yet the peak overpressure resulting from such distribution cannot exceed about 2 p.s.i.g. and preferably should be held well below 1 p.s.i.g. in order to avoid injury to workmen. Conventional explosively-operated dispersing systems develop pressures far in excess of 2 p.s.i.g.

Devices of this invention which meet those requirements are illustrated in FIGS. 2 to 6. FIG. 2 is a partial sectional view of a device for dispersion of a particulate, flame-quenching dust such as potassium bicarbonate. FIG. 3 is a cross-section of that same device taken along line 3-3 of FIG. 2. As shown in the figures, the device comprises a relatively rigid, elongated, trough-like container 10, open at the top and preferably having a uniform cross section. Container 10 may be hemispherical in cross section as is shown in FIG. 1, or it may be bell shaped. Flat-bottomed or channel-shaped containers may be employed but these shapes provide less efficient dispersion of the quenching agent. Disposed within and extending the length of container 10 is thin-walled, easily rupturible bag 11 normally filled with a powdered, flame-quenching agent such as potassium bicarbonate 12. Bag 11 must be constructed from a water-impervious material. Particularly preferred because of its excellent resilience to puncture and to abrasion is urethane vinyl laminated cloth. This Lustron cloth of the met-MIL-D-80069 consists of 2 plies of calender urethane around a single ply of 2-denier nylon mesh; the thickness of the finished cloth is between about 4 to 7 mils. To insure that this bag will be ruptured readily by the relatively weak pressure generating means 13, the edges of the cloth are sealed by electronic welding only, the weld being a simple pinch seal having a width of about 1/4-inch. Another suitable material for bag 11 is a relatively brittle film such as Mylar (polyethylene terephthalate) having a thickness of about 1 mil. Other plastics having greater elasticity, such as polylethylene, polypropylene, vinyl acetate and the like, require greater force for effective dispersion of the quenching agent and so produce a larger shock wave. Container 10 may have open ends or may have suitable plate-like end pieces (not shown).

Extending inside and along the lower side of bag 11 is pressure generating means 13. This pressure generating means preferably comprises a linear explosive charge such as detonating cord. The detonating cord is secured in the lower side of the bag by plastic rings or plastic sleeve 14 which is glued or otherwise permanently attached along the lower side of bag 11 and is preferably constructed of a brittle plastic film such as Mylar. Triggering means 15, which preferably comprises an electrical blasting cap, is located at one end of the device and is activated by an electrical pulse produced by the sensing means (not shown). Within 20 milliseconds of contact of the tip of the explosive cord to the sensor, Protective grid or screen 17 surrounds container 10 and protects bag 11 from puncture due to high tension shock waves or the like. The protective screen may comprise a heavy wire mesh or similar material. An expanded metal grid having 1-inch diamond shaped holes was found to be satisfactory.

The relationship of linear explosive to quenching agent must be carefully balanced in order to insure rapid and thorough dust dispersion into the flammable atmosphere without creating a harmful pressure wave. For example, in the device of FIG. 2, detonating 3, or 50 grams of PETN per foot effectively dispersed 4 pounds of dry potassium bicarbonate per foot of detonating cord and produced an overpressure of about 0.8 p.s.i.g. at a distance of 4 feet from the device. Lower strength detonating cord was less satisfactory; pressures as high as 1.5 p.s.i.g. developed in trials with 25- and 30-grain cord and 2 pounds of KHCO₃ per foot of cord.

FIG. 4 illustrates another embodiment of the quenching device dispersing device. The device comprises a container 21, conveniently of tubular shape and having closed ends 22. It is constructed of a relatively rigid, fragile material such as acrylic tubing. The upper portion 23 of the container is scored so as to break into relatively small fragments upon the application of a sud-
den internal pressure of less than 2 p.s.i.g. and preferably on the order of 1/2 p.s.i.g. Container 21 is normally filled with a powdered, flame quenching agent. Pressure generating means similar to that employed in the device of FIG. 2 extend the length of container 21 and terminate externally in a pair of lead wires 24.

Another alternative embodiment of the quenching agent dispersing device is shown in FIGS. 5 and 6. The outer protective cover of the device comprises two symmetrical elongated sides or wings 31 and 32 flexibly joined or hinged at their bottom side such as by hinge 33. The two wings are constructed of a rigid sheet metal or like material and are normally held in a closed position by clips 34 along their top abutting edges. End pieces 35 and 36 in conjunction with wings 31 and 32 form a normally closed container. Disposed within the normally closed container is an easily rupturable bag 37 containing quenching agent and having associated therewith pressure generating means 38, activating means 39 with lead wires 40 similar to those of the device of FIG. 2.

In operation, activation of the pressure generating means forces the release of clips 34 allowing wings 31 and 32 to move outwardly pivoting on hinge 33. Quenching agent contained in bag 37 is rapidly dispersed upwardly and to the side by the generated pressure. Attitude of the expended device is shown in FIG. 6.

The quantity of flame quenching agent or dust dispersed must be sufficient to provide a concentration capable of almost instantaneously quenching flame. It is theoretically necessary to provide about 2 pounds of 2-micron potassium bicarbonate in a predispersing cloud in order to quench ignitions in a 1300 cubic foot homogeneous mixture containing 10% methane in air. This corresponds to a concentration of about 0.06 ounce per cubic foot of the igniting mixture. However, it is believed that about 13 pounds of predispersing potassium bicarbonate was actually necessary to quench an ignition at those conditions. Dispersal after ignition requires yet higher concentrations of the quenching agent in order to be effective as is shown by Table 2. This table shows the minimum quantity of potassium bicarbonate dust required to quench ignitions in a 1300 cubic foot homogeneous mixture containing 10% methane in air for various dust dispersing systems. Ignition of the gas and dispersion of the dust was effectively simultaneous in all cases.

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Dispersing System</th>
<th>Potassium Bicarbonate (microns)</th>
<th>Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Device of FIG. 2, except that dust was loose in the container and no protective screen was used.</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Same as 1, except that the device of FIG. 2, no protective screen.</td>
<td>16</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>Device of FIG. 2, no protective screen.</td>
<td>16</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>Device of FIG. 2, no protective screen.</td>
<td>16</td>
<td>60</td>
</tr>
</tbody>
</table>

As may be seen from the table, very finely divided (2-micron) potassium bicarbonate is somewhat more effective than coarser (16-micron) material as would be expected. At the present time however, the gain in efficiency of the finely divided material is more than offset by its increased cost. Use of a protective screen over the device also tended to decrease efficiency as shown by experiment 4. A minimum of about 0.5 ounce of potassium bicarbonate per cubic foot was found to be necessary to insure quenching of stochiometric gas-airignitions.

Location of the quenching devices relative to the point of ignition is quite important. FIG. 8 shows the relationship of pressure development and flame extent to the distance from the working face (source of ignition) in a coal mine. As can be seen from the graph, both pressure development and flame extent increased rapidly as the distance between the quenching devices and the ignition source was increased beyond 6 feet.

Orientation of the quenching devices was also found to be important when their long axis parallel to the axis of the entry were found to be much more effective than those which were oriented perpendicular to the axis of the entry. Height of the quenching device above the floor of the entry had no significant effect on quenching efficiency.

FIG. 7 illustrates the use of this invention in a typical coal mine. Entry 51 is conventionally on the order of about 20 feet wide and is defined by side walls 52 and 53 and working face 54. Cross-cuts 55 are conventionally provided to allow ventilation and prevent gas build-up.

Mining machine 56 tears coal from the working face and transports it backward to a conveyor belt or other transport system (not shown). Radiation sensor 57 is preferably mounted near the headlights of the mining machine where it can scan the entire working face and where it is convenient for the miner to clean the protective lens on the detector tube. At this location, the sensor will be subjected to maximum accelerations of about 6 G at a predominant fundamental frequency of about 18 cycles per second. A pair of quenching devices 58 are preferably mounted on each side of the machine. The quenching devices are oriented with their long axes parallel to the axis of the entry with their forward ends within about 6 feet of the working face. Radiation sensor 57 is operatively connected to the quenching devices by means of the lines 59.

During the mining operation, methane is released from the working face as coal is ripped from the seam by the mining machine. Methane concentration is normally held at safe levels by dilution with circulating ventilation air. If methane concentration rises however, at about 6 feet from the initial flame, an ignition and resulting explosion is very likely due to frictional sparking of the cutter bits. At this time, the initial flame is detected by the radiation sensor which triggers the release of flame quenching agent and suppresses the developing explosion.

While the invention has been illustrated as being primarily applicable to the suppression of explosions in coal mines, it is readily evident that it is adaptable to any other type of operation which has similar hazards. For example, the invention would find ready use in such operations as servicing and arming aircraft, particularly in closed hunger areas. It will be understood that a number of adaptations and variations of the disclosed invention are possible without departing from its spirit or scope.

What is claimed is:

1. A device for quenching incipient explosions of gas-air mixtures comprising in combination flame sensing means having an effective sensitivity only to ultraviolet radiation above about 2000 A. and capable of producing a signal in response to said ultraviolet radiation within about 10 milliseconds of the ignition of said gas-air mixture, a longitudinally extended container having an upper surface adapted to rupture or open upon the application of a sudden internal pressure, said internal pressure being limited to a level below that which causes physical injury to personnel adjacent thereto, and normally holding a quantity of finely divided particulate flame quenching agent, pressure generating means disposed within the lower portion of and extending the length of said container and triggering means operatively coupled with and capable of activating said pressure generating means in response to a signal produced by said flame sensing means.

2. The device of claim 1 wherein said flame sensing means comprises a photodiode effectively sensitive only to radiation between about 2000 to about 3000 A.

3. The device of claim 1 wherein said flame quenching agent comprises finely divided potassium bicarbonate, said pressure generating means comprises detonating cord
and said triggering means comprise an electrically activated detonator.

4. The device of claim 3 wherein said longitudinally extended container comprises a relatively rigid trough-like channel having disposed therein and extending the length thereof a thin-walled, relatively brittle, easily rupturable bag surrounding and protecting said potassium bicarbonate.

5. The device of claim 3 wherein said longitudinally extended container comprises a closed tube of a relatively rigid, frangible material and having a portion of its upper surface scored so as to break and fragment upon the application of a sudden internal pressure of less than about 2 p.s.i.g.

6. A device of claim 3 wherein said longitudinally extended container comprises two symmetrical, elongated sides flexibly joined at their lower edges and having their upper edges yieldably clipped together and having disposed therein and extending the length thereof a thin-walled, relatively brittle, easily rupturable bag surrounding and protecting said potassium bicarbonate.

7. A device comprising a longitudinally extended container having a relatively uniform cross section and adapted to rupture or open along a portion of its upper surface upon the application of a sudden internal pressure of less than about 2 p.s.i.g. and having uniformly disposed within said container a quantity of finely divided particulate flame-quenching agent, pressure generating means disposed within the lower portion and extending the length of said container and triggering means adapted to activate said pressure generating means in response to an external signal.

8. The device of claim 7 wherein said pressure generating means comprise detonating cord and said triggering means comprise an electrically activated detonator.

9. The device of claim 8 wherein said container comprises a relatively rigid trough-like channel having disposed therein and extending the length thereof a thin-walled, relatively brittle, easily rupturable bag surrounding and protecting said flame-quenching agent.

10. The device of claim 8 wherein said container comprises a closed tube of a relatively rigid, frangible material and having a portion of its upper surface scored so as to break and fragment upon the application of a sudden internal pressure of less than about 2 p.s.i.g.

11. The device of claim 8 wherein said container comprises two symmetrical, elongated sides flexibly joined at their lower edges, having their abutting upper edges yieldably joined and having disposed therein and extending the length thereof a thin-walled, relatively brittle, easily rupturable bag surrounding and protecting said flame-quenching agent.

12. The method of preventing explosions of gas-air mixtures which comprises detecting only the ultraviolet radiation having a wavelength above about 2000 A. produced by a gas-air flame, producing a signal in response to said detected radiation, explosively distributing a linear charge of finely divided, particulate flame-quenching agent throughout the area adjacent to said flame in response to said signal, maintaining the maximum pressure wave developed during said explosive distribution below the level at which coal dust is raised into suspension and below the level which causes physical injury to workers, quenching said flame by means of physical and chemical reactions between said distributed flame-quenching agent and the developing flame front and accomplishing said steps of detecting radiation, distributing said flame-quenching agent and quenching said flame within 50 milliseconds of the ignition of said flame.

13. The process of claim 12 wherein said flame-quenching agent is potassium bicarbonate.

14. The process of claim 13 wherein the amount of said potassium bicarbonate distributed is sufficient to provide a relatively uniform concentration of at least about 0.5 ounce per cubic foot in the area adjacent to said flame.

15. The process of claim 14 wherein said maximum pressure wave developed is less than about 1/2 p.s.i.g.

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