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R. HÜBNER
METHOD OF AND DEVICE FOR FOLLOWING COMBUSTION
IN MINES AND THE LIKE
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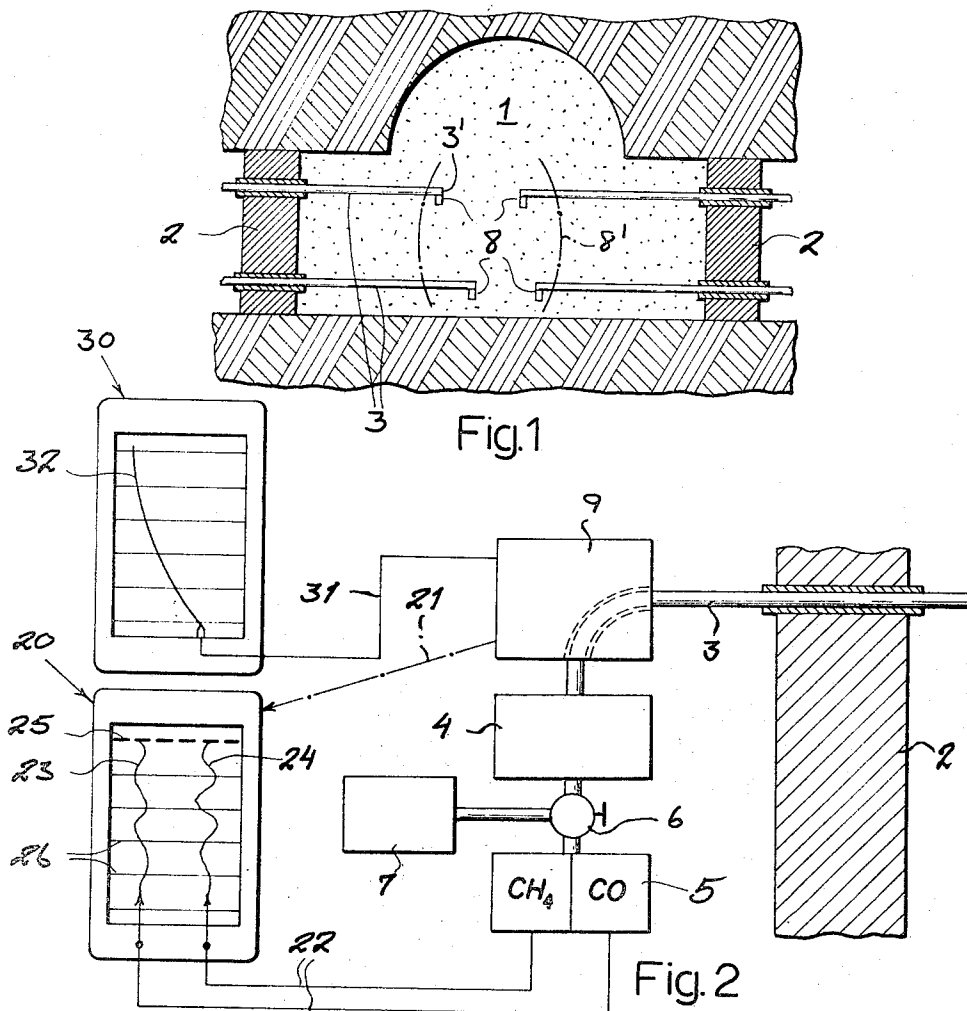
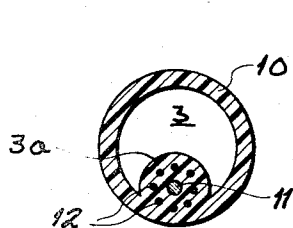


Fig. 3

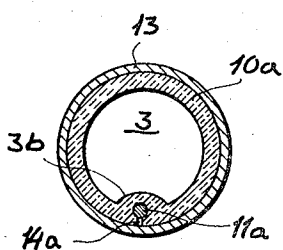


Fig. 4

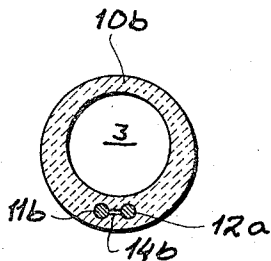


Fig. 5

Rolf Hübner
INVENTOR.

BY

Karl F. Ross

Attorney

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METHOD OF AND DEVICE FOR FOLLOWING COMBUSTION IN MINES AND THE LIKE

Rolf Hübner, Westfalendamm 267, Dortmund, Germany

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ABSTRACT OF THE DISCLOSURE

Method of and device for following the movement of a flame front through a mine or other subterranean structure wherein a sampling tube of thermally destructible material is inserted through a fire wall into the mine tunnel and is provided with conductors which short-circuit in step with the advance of the flame front to indicate the location thereof, while the tube decomposes so that gases withdrawn therethrough at the receding mouth of the tube are known to be at the location of the flame front.

My present invention relates to a method of evaluating the extent and location of combustible zones, of determining the rate of advance of a flame or combustion front, of determining the presence or absence of combustion conditions at a plurality of locations and, in general, of following the development of combustion in subsurface structures such as the tunnels or shafts of mines or other caverns. More particularly, the present invention relates to a method of monitoring combustion in mines or the like in which the reacting gas mixture is retained between fire walls and to devices for carrying out this method.

The dangers of the development of fire or explosion conditions in subsurface structures such as mine shafts and tunnels have long concerned the industry, governmental agencies involved in safety and health management and engineers concerned with efficiently operating the caverns. It has already become a more or less common practice to provide means, in mine tunnels and shafts of comparatively large volume and possibly intricate configuration, for sensing the presence of combustion conditions by gas analysis. Thus it has been proposed to confine a subterranean region or chamber between fire walls or bulkheads designed to prevent the passage of a flame front and to sealingly restrict the flow of gases therpast, through which "sniffing" or sampling tubes are inserted for drawing specimens of the gas mixture within this chamber into an analysing arrangement responsive to the combustionable components of this mixture. These prior art devices have, however, the important disadvantage that their utility is limited because of the fixed nature of the mouth of the tube and the impossibility of determining the movement of the flame front. When the flame front migrates past the mouth of the tube in the direction of the fire wall through which it is inserted, the analysis fails to provide a satisfactory evaluation of combustion or explosion conditions which may be present. On the other hand, when the mouth of the tube is remote from the flame front or the combustion zone, the analysis again fails to represent the true conditions prevalent in the chamber. In practice, therefore, it has turned out that the detection of critical conditions (e.g. methane content of the gas mixture) within the chamber is not continuously or closely followed by the detection or analysis system. Thus far it has not been possible to follow precisely the combustion conditions in a subterranean cavern such as a mine tunnel or shaft.

It is, therefore, the principal object of the present invention to provide an improved method of monitoring the

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developments of combustion conditions in a subsurface chamber and especially of following the development of combustion therein.

A further object of this invention is to provide a method of following the propagation of a flame, burning zone or flame front which will permit the analysis of the gas conditions in advance of this front and also provide an accurate picture of the location thereof to an observer.

Yet another object of my invention is to provide a method of analyzing mine-gas mixtures or combustible or other components proximal to a combustion zone and of determining precisely the location within the chamber from which the gas sample is derived. A further object of this invention is to provide an improved sniffing-tube or sampling-tube arrangement whereby gas analysis at spatially determined locations can be carried out simply and efficiently.

These objects and others which will become apparent hereinafter are attained, in accordance with the present invention, by a method of monitoring the combustion conditions within a mine shaft, tunnel or other space which essentially comprises the steps of enclosing the space with at least one fire wall or bulkhead, inserting through this wall and into the space a longitudinally extending sniffer tube a thermodestructive material adapted to deteriorate in the presence of heat (approaching temperatures of gas combustion within this chamber) so that the tube is foreshortened by heat action as the flame front progresses or the combustion zone advances toward the fire wall, and withdrawing continuously or at intervals samples of gas from the enclosed space through this tube whereby gas sampling is always effected by the retrogressing mouth of the tube in advance of the combustion zone. Thus the present invention involves the use of a sniffer tube whose portions within the chamber can be fused, burned or melted away upon advance of the combustion zone or upon development of intense heat throughout the zone or even vaporized or otherwise disintegrated. It is possible, in accordance with the present invention, to recover gas samples from a chamber sustaining gas combustion etc. to accurately determine the composition of the gases at various locations, by inserting a relatively long sniffer tube of the character described through one or more fire walls and permitting the tube to deteriorate while continuously drawing gas samples through the receding mouth of the tube. The tube is provided, in accordance with a specific feature of this invention with electrical means for indicating the length of tube remaining (e.g. short-circuiting conductor means) thereby providing a simultaneous indication of the location of the chamber from which the sample is abstracted.

The electrical indicating means may, consequently, include at least two conductors extending along the tube in spaced-apart relationship and forming a short circuit or shunt path between them in step with the rearward movement of the mouth of the tube. Such a system can be used to determine the gas conditions in advance of an enlarging or migrating flame front or combustion zone, for following the advance of the combustion zone, for analyzing critical gas conditions within an enclosed chamber undergoing a heat-generating or combustion reaction while always providing a precise indication of the location in the chamber from which the sample is withdrawn. The means for withdrawing and analyzing the gas samples can include a suction pump connected to the sniffer tube behind the fire wall and the analyzing system may include any conventional gas analysis means responsive, for example, to carbon monoxide and methane concentration. Suitable analyzing systems of this type are these described in my Patents Nos. 3,266,293, 3,242,715 and 3,276,241 or the copending applications Ser. No. 427,047 of Jan. 21, 1965 and Ser. No. 440,223

of Mar. 16, 1965 (now U.S. Patents No. 3,375,700 and No. 3,343,402). In all of these systems, the gas sample is induced by pump means into an analysis chamber whose resistance is affected by the concentration of the gas component to be measured. The analysis chamber is connected in a bridge circuit capable of providing a signal convertible into a visual reading of the gas concentration. The tube of the present invention can be a thermally fusible synthetic resin (i.e. a thermoplastic) while the conductors may likewise be made of a fusible metallic material so that they flow together to short-circuit at the mouth of the tube. It is, however, also possible to dispose the conductors in such closely spaced relationship that, upon melting of the thermoplastic tube, they will contact one another without fusion.

According to another feature of this invention, the parallel conductors are spaced apart from one another and embedded in the thermally fusible wall of a low-melting synthetic resin tube so that upon melting of the latter under the thermal effect of the combustion in the chamber, the conductors are brought into contact with one another. When the synthetic resin of the tube is of the low-temperature burnable type, i.e. their thermally decomposable or oxidizing material, care must be taken to consider a contribution to the gas composition from the waste gases generated by thermal destruction of the tube.

In another arrangement, one of the conductors is constituted as a sleeve surrounding the meltable tube while the other conductor is embedded in the thermally fusible material. When the tube melts, the embedded conductor contacts the outer sleeve in step with the recession of the tube. When the sleeve is composed of a metallic foil or a low-melting alloy or is a metal coating upon the thermally fusible tube, the sleeve deteriorates with the plastic tube under the thermal effects of combustion. One or both of the conductors may, as previously mentioned, be composed of low-melting metals so that they flow together upon deterioration of the thermoplastic tube in which they are embedded.

According to another aspect of this invention, the location of the combustion zone or front can be monitored while gas sampling is effected at the original location when the snifter tube is composed of a relatively refractory material and one or both of the conductors is of a low-melting alloy. In this case, I prefer to provide between the parallel conductors, which extend along the snifter tube, a capillary channel through which the liquefied or flowable matter can be passed to short-circuit the conductors in step with the advance of the flame front. A suitable refractory material is thus thermally insulated and resistant to temperatures in the range of the combustion temperatures prevalent in the subterranean chamber.

It will be immediately apparent that the arrangements described above permit a careful monitoring of the location of a flame front and, when a plurality of such sniffers are inserted into the closed chamber, of the extent of the combustion zone. Additionally, dangerous or critical gas conditions in advance of the flame front or gas conditions behind the flame front may be determined and the location of sampling identified without difficulty. The present system is of advantage even when combustion occurs throughout the closed chamber since it provides there as well a picture of the gas conditions. The locating system of progressively short-circuiting conductors may include a resistance bridge connected across the conductors and adapted to provide a signal indicative of position within the chamber.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is a vertical diagrammatic cross-sectional view

of a stretch of mine tunnel provided with the system of the present invention;

FIG. 2 is a block diagram of the analysis and detection system associated with each of the snifter tubes of FIG. 1; and

FIGS. 3 to 5 are cross-sectional views of several snifter tubes according to this invention.

In FIG. 1, I show a mine gallery having a subterranean chamber 1 which is closed off by fire walls or bulkheads 2 so that any combustion condition (e.g. increase of inflammable-gas concentration, represented by stippling) will be confined to the chamber 1. By a "combustion condition" is meant the development of a ratio of combustible gas (e.g. carbon monoxide and methane) to combustion-supporting gas (e.g. air) at which ignition and exothermic reaction can occur. According to the principles of the present invention, combustion conditions within the subterranean chamber 1 are detected by means of snifter tubes 3 extending through the walls 2 for substantial distances into the chamber 1. The snifter tubes 3 may have cross-sections as illustrated in FIGS. 3-5.

Referring now to FIG. 2, it will be seen that each of the snifter tubes 3, which may be of the thermodestruct type, is connected externally of the chamber and of its fire wall 2 with a pump 4 adapted to continuously or intermittently aspirate gas samples from the interior of the chamber through the mouth 3' of the tube. The analysis system includes any conventional analyzing means of the type represented at 5 for the continuous determination of the methane or carbon monoxide proportion. Such analysis devices have been described in my issued patents and copending applications set forth above. Gas chromatography systems or the like may be used as well.

The analyzer 5 is connected with the discharge side of the pump 4 via a three-way valve 6 which permits the gas stream to be supplied continuously to the analyzer 5 (e.g. for CO analysis) or intermittently to a sampling chamber 7 (e.g. for CH₄ determination). The latter can be an intermittent methane analyzer as described in my copending applications and the aforementioned patents or may represent manual sampling for subsequent analysis.

The short-circuitable conductors extending along the snifter tube 3 are connected to a resistance bridge (represented at 9) of the Wheatstone type whose output is directly proportional to decreasing conductor resistance and is connected to a recorder 20 which may be of the multipen strip type. The strip drive is represented at 21 and is in step with the progressively decreasing effective length of the conductors while the outputs from the analyzer 5 (diagrammatically shown at 22) trace graphs 23 and 24 representative of methane and carbon monoxide concentration. The plots thus represent gas concentration as a function of location. If the mouth of the tube is known and marked as a reference 25, the subdivisions 26 of the graph represent distances from the original end of the tube. When a refractory tube of the nondestruct type is employed, a constant-speed-drive recorder 30 may be employed and the output of the resistance bridge 9 fed to the pen (line 31) thereof so that the rate of advance and location of the flame front may be traced (graph 32). It will be evident that with progression of the flame front represented by the dot-dash line 8' in FIG. 1, the mouths 3' of the tubes 3, now shown to be located at the original sampling locations 8, will recede just ahead of the front 8' toward the respective walls 2. Corresponding readings will be given upon the recorders 20 and 30 and the corresponding gas concentration indicated on the traces 23 and 24.

In FIGS. 3-5, I show various modifications of the snifter-type cross-section which have been found to be highly advantageous. The tube 10 of FIG. 3, for example, is composed of a thermally fusible synthetic resin (e.g.

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polyvinyl chloride or polyethylene) and forms the sampling duct 3. Along the interior of this type, I provide a longitudinal reinforcing ridge 3a having a core 11 forming a central conductor. The synthetic resin electrically insulates this center conductor 11 from an area of parallel spaced-apart outer conductors forming a cage around the center conductor 11. Upon thermal fusion of the tube 10, at least one of the conductors 12 will short-circuit to the center conductor 11 thereby reducing the resistance through the circuit formed by the short-circuited conductors in step with the flame front. The resistance is measured by the bridge 9 as previously indicated.

A modified tube 10a is illustrated in FIG. 4 and again forms a duct 3 for the sampled gases. Here, however, one of the conductors is formed by a metallic sleeve 13. The conductor 11a embedded in the ridge 3b which restricts bending of the tube even under thermal stress prior to melting, is composed of a thermally fusible or low-melting alloy (e.g. 50-50 lead/tin solder) so that contact is made through a capillary 14a between the conductor 11a and the sleeve 13 upon melting of the wire 11a. When the tube 10a is composed of plastic or a resin-impregnated paper, the capillary 14a may be omitted since the thermally destructible tube permits contact between the outer conductor 13 and the inner conductor 11a. In the modification of FIG. 5, the ceramic tube 10b has a capillary gap 14b extending the entire length of the tube between a low-melting-point conductor 11b and a further wire 12a. Gas sampling in this case is continued from a predetermined location since the mouth of the tube does not recede. However, short-circuiting between the conductors 12a and 11b occurs in step with the advance of the flame front or combustion zone to provide a reading of this advance upon the recorder 30. The tubes may easily be formed with the embedded conductors by extrusion of a plastic mass and the conductors through a die by conventional techniques.

The invention described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the appended claims.

I claim:

1. A method of monitoring combustion conditions in a subterranean space, comprising the steps of:

- (a) closing said space with at least one fire wall;
- (b) inserting through said fire wall into said space a longitudinally extending sampling tube having a mouth opening into said space;
- (c) withdrawing gas samples from said space through said tube;
- (d) following the advance of combustion along said tube by sensing the progressive advance of a heat front therealong, said tube being thermally destructible so that the mouth thereof recedes with advance of said heat front; and
- (e) measuring the gas composition withdrawn through the receding mouth of the tube as a function of the length of the tube remaining.

2. The method defined in claim 1 wherein the progressive advance of heat along said tube is sensed by mounting on said tube an electrical conductor having an effective length foreshortenable by the advance of said heat front therealong, and measuring the remaining effective length of said conductor.

3. The method defined in claim 2 wherein a pair of conductors extend along said tube in spaced-apart relationship, and are progressively short-circuited by the advancing heat front.

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4. A system for the monitoring of the combustion conditions within a closed subterranean chamber, comprising:

- (a) at least one sample tube extending into said chamber and having a mouth open therein;
- (b) aspirating means for withdrawing gas samples through said tube from said mouth; and
- (c) measuring means extending along said tube and responsive to the advance of a heat front therealong for providing an indication externally of said chamber of the development of combustion therealong, said measuring means including conductor means extending along said tube and having an effective length thermally foreshortenable upon the advance of said front along said tube.

5. The system defined in claim 4 wherein said conductor means includes a pair of conductors extending along said tube in spaced-apart relationship, said tube being composed of a thermally sensitive material normally holding said conductors apart but permitting short-circuiting thereof upon deterioration of the tube in the vicinity of the flame front.

6. The system defined in claim 5 wherein one of said conductors is a center conductor embedded in said tube and the other of said conductors is one of a nest of conductive wires surrounding said one of said conductors and embedded in said tube.

7. The system defined in claim 4 wherein at least one of said wires is a thermally fusible material, said tube having a capillary gap between said conductors for permitting the flow of molten metal to short-circuit the conductors in the region of the flame front.

8. The system defined in claim 4 wherein one of said conductors is a metallic sleeve surrounding said tube and the other of said conductors lies within a wall of said tube.

9. The system defined in claim 4 wherein said tube is composed of a thermally fusible synthetic resin adapted to melt under the heat of said flame front whereby said mouth recedes with the advance of said front.

10. The system defined in claim 9, further comprising means connected with said conductor means for providing an indication of the gas composition of the sample gases as a function of location of said mouth within said chamber.

11. A system for the monitoring of combustion conditions within a closed subterranean chamber, comprising at least one elongated sampling tube extending into said chamber and having a mouth open therein, said tube being thermally destructible so that the mouth thereof recedes with the advance of a heat front therealong; means for withdrawing gas samples from said chamber through said mouth of said tube; and means for measuring the composition of gas samples withdrawn to the receding mouth of the tube as a function of the length of the tube remaining.

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ERNEST R. PURSER, *Primary Examiner*.

U.S. Cl. X.R.

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