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APPARATUS FOR SENSING THE COMPOSITION OF GASES, AND GAS BURNER SYSTEM EMPLOYING SAME

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This invention relates particularly to apparatus for sensing and providing indications of the relative proportions of oxygen, fuel gas and inerts in a combustible gas mixture, and to burner systems employing such gas mixtures. In its more particular aspects it relates especially to apparatus for sensing a decrease below a predetermined level of oxygen relative to fuel and inerts in the combustion chamber of a gas burner, and preferably also for operating burner control equipment in response thereto. In further aspects it relates to such systems in which the composition-sensing apparatus also provides a suitable pilot flame for a main gas burner.

A variety of applications exist in which it is desirable to sense and provide indications of the relative proportions of oxygen in a gas. One example of such an application arises in systems in which the venting of a gas burner is subject to possible accidental obstruction or blockage, resulting in a reduced proportion of oxygen in the air which supports secondary combustion and therefore in undesirable, incomplete combustion. An increase in the amount of inerts, for example by the generation of steam in the enclosure, can also have the effect of decreasing the relative proportion of oxygen with a consequent tendency toward incomplete combustion. We have found that by sensing reductions in the proportion of oxygen an indication can thereby be derived of the occurrence of incomplete combustion. Such indications are then useful for operating indicating devices or to actuate control equipment, for example to shut off the supply of gaseous fuel to the main gas burner until the faulty conditions have been corrected.

Accordingly, it is an object of the invention to provide new and useful apparatus for sensing the relative proportions of predetermined components in a gaseous mixture which contains oxygen, a fuel and inerts.

Another object is to provide new and useful apparatus for providing indications of the relative proportions of oxygen and inerts in a gas in an enclosure.

Another object is to provide new and useful apparatus for indicating when the relative proportion of oxygen to fuel and inerts in a combustion chamber is insufficient to insure complete combustion of the fuel.

Another object is to provide such apparatus which is simple, reliable and especially adapted for use in gas-burning systems.

Another object is to provide, in conjunction with such oxygen-sensing, a device which produces electrical variations indicative of said relative proportion of inerts and oxygen.

Another object is to provide such apparatus which, at the same time, provides a suitable pilot flame for a gas burner.

Still another object is to provide a system for automatically cutting off the supply of gaseous fuel to the main gas burner located in an enclosure whenever the relative proportion of inerts in the air in said enclosure in the immediate vicinity of the main gas burner falls below a predetermined level.

It is a further object to provide such a system employing apparatus which serves both to detect the concentration of oxygen in the air in a combustion chamber and

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at the same time to provide a pilot flame for said main gas burner.

In accordance with the invention, these and other objects are achieved by the provision of apparatus comprising a gas conduit having gas inlet means and gas outlet means, first gas-transmissive flame-stabilizing screen means disposed inside and across the interior of said conduit intermediate said inlet means and said outlet means, and means for detecting the occurrence of gaseous combustion at the first screen means. Preferably there is also employed a second gas-transmissive flame-stabilizing screen means disposed across said outlet means. When gaseous fuel and air, or a gas containing oxygen, are supplied to the inlet means of the conduit, a gaseous mixture thereof flows successively through the first and second screen means and the gas outlet means to the exterior; and, when the gaseous fuel and the oxygen-containing gas are properly proportioned and constituted, a combustible gaseous mixture is formed at the outlet side of the second screen means so that after initial ignition a secondary flame is maintained at the exterior side of the second screen means. Furthermore, if the oxygen-containing gas is sufficiently rich in oxygen, at least partial combustion will also be supported at the outlet side of the first screen means once such combustion has been initiated; under these conditions a primary flame exists at the outlet side of the first screen means even while the secondary flame continues to burn at the outlet side of the second screen means. However, should the proportion of inerts in the oxygen-containing gas increase and the proportion of oxygen therein decrease correspondingly, a condition will be reached at which combustion is no longer supportable at the first screen means inside the gas conduit and the primary flame previously existing at that position will be extinguished. In the preferred embodiment using a second screen means, the flame previously existing at the first screen means leaves the outlet side of the first screen means and moves downstream to re-establish itself at the outlet side of the second screen means; the flame previously existing at the outlet side of the second screen will then continue to burn despite the change in position of the primary flame, even though the proportion of inerts is increased substantially further.

Accordingly, the presence or absence of flame at the first screen means provides an indication of the composition of the gaseous mixture passing through the first screen means. Thus, for example, using a known flow of the gaseous fuel into the conduit and a fixed physical size, shape and arrangement of the elements of the conduit and screens, the disappearance of flame at the first screen means will provide an indication that the proportion of oxygen has fallen below a predetermined level.

The presence or absence of flame at the first screen means is preferably detected and indicated electrically by means of a thermoelectric element, located in the gas conduit on the outlet side of the first screen means so as to be heated by the flame at the first screen means when said flame is present. Such heat will produce an increased electrical voltage from the thermoelectric generator, while the absence of said flame will produce a decrease in the thermoelectric generator output voltage. These changes in voltage in turn may be used to operate indicating equipment or for control purposes.

In the preferred form of the invention the conduit also contains an opening to the exterior which extends from a first position adjacent the first screen means to a second position adjacent the second screen means. In normal operation a flame exists along this opening which serves to re-ignite the flame at the first screen means, for example after it has been extinguished in response to a momentary rise in the proportion of inerts and the proportion of inerts has fallen again to a low level, or after both

the primary and secondary flames have been extinguished by external agencies and are to be re-ignited by a match or igniter for example.

As mentioned previously, we have found that the reduction in oxygen concentration to a predetermined level in the immediate vicinity of a burner in an enclosure is an adequate indication of incomplete combustion. Accordingly, the above-mentioned decrease in voltage from the thermoelectric device may be used to indicate the occurrence of conditions resulting in incomplete combustion. Furthermore, the output current of the thermoelectric generator is preferably connected to a safety shutoff device such as an electrically-operable gaseous fuel supply valve, to hold the valve open to supply gas to the main gas burner so long as the oxygen content relative to fuel gas and inerts is above a predetermined level, but to permit the valve to close and cut off supply of gas to the main gas burner when the ratio of oxygen to fuel gas and inerts is insufficient to maintain complete combustion. In this way the operation of the main gas burner may be automatically terminated whenever its further operation might result in the production of appreciable amounts of carbon monoxide.

In addition, in a particularly advantageous form of the invention the flame at the outlet side of the second screen means is positioned with respect to a main gas burner so as to serve as an ignition pilot therefor. By such an arrangement the device of the invention functions both as the pilot for the main gas burner and as an oxygen-sensing device for cutting off the main gas burner automatically when the oxygen concentration becomes undesirably low.

We have also found that it is especially advantageous to use for each of the first and second screen means a wire mesh, said first screen means preferably being composed of a mesh which is finer than that used for said second screen means. With this construction the desired stability of flame is obtained at both screen means, and the primary flame is caused to move abruptly and reliably between the two screen means with a snap action when the proportion of inerts rises above, and falls below, said predetermined level thereby enhancing the precision and reproducibility of the indications.

Other objects and features of the invention will be understood from a consideration of the following detailed description, taken in connection with the accompanying drawings, in which:

FIGURE 1 is a side elevational view, partly in section, showing an oven arrangement embodying a system in accordance with the invention;

FIGURE 2 is an enlarged elevational view, partly in section, of apparatus which is a part of the system of FIGURE 1 and which embodies the invention in one of its aspects, and illustrates a flame condition which occurs in one phase of operation of the apparatus;

FIGURE 3 is a view like that of FIGURE 2 but for a flame condition occurring during a different phase of operation of the device;

FIGURE 4 is a side elevational view, in full, of the apparatus of FIGURE 2; and

FIGURE 5 is a sectional view taken along lines 5—5 of FIGURE 3 illustrating a preferred form of screen structure for use in the device of the invention.

Referring now particularly to FIGURE 1, there is shown therein, by way of example only, one particular example of a system utilizing apparatus in accordance with the invention in connection with the broiler of a cooking range heated by gaseous fuel; it will be understood however that the system is also very useful in unattended gas appliances such as room heaters and water heaters. In the latter figure the oven 10 comprises a generally box-shaped frame 12 divided into an upper compartment 14 and a lower compartment 16 by a partition 18, the upper compartment 14 typically being used for baking and the lower compartment 16 being for broiling of foods. The usual doors 20 and 22 are hinged

mounted over the front openings 24 and 26 of the oven compartments 14 and 16. Ventilating passages for the oven are provided around the doors 20 and 22 and at the oven vent 28 located at the top of the oven.

The oven is heated by the main burner 30, which is supplied with a suitable gaseous fuel from a gas main 32 by way of manually-controlled gas valve V_M and a safety shutoff device, such as an electrically-controllable solenoid gas valve V_S . When the manually-controlled valve V_M is turned on by the operator, the main burner 30 is supplied with a suitable flow of gaseous fuel provided that the safety shutoff device V_S is simultaneously supplied with an electrical current for holding it open. It will be understood that the showing of the manual valve V_M is schematic only, and that it will generally be physically located at a convenient position for actuation by the operator.

A special pilot burner 40 which also serves as a sensor of the proportions of oxygen and inerts in the surrounding air is mounted beneath the main burner 30 in such a position that the pilot flame 42 of pilot burner 40 will ignite main burner 30 when main burner 30 is supplied with an appropriate flow of gaseous fuel as described above. In addition, pilot burner 40 provides an electrical control current by way of electrical cable 44 to the safety shutoff device V_S to hold the latter open so long as the proportions of oxygen and inerts in the atmosphere around the pilot burner are such as to insure complete secondary combustion at the main burner. However, should the composition of the atmosphere around the pilot burner be deficient in oxygen then the flame on the first screen means of pilot burner 40 will be extinguished and the current supplied to safety shutoff device V_S by way of electrical cable 44 reduced so that device V_S is shut, thereby cutting off the supply of gaseous fuel to the main burner 30 and preventing further incomplete combustion at the main burner. Using a thermoelectric generator to sense the flame at the first screen means which has an output sufficient to hold the safety shutoff device normally open but insufficient to reopen it once closed, the gas supply will remain off until appropriate repairs have been made and the safety shutoff device reset.

The pilot burner 40 is shown in more detail in FIGURES 2, 3 and 4. As shown for example in FIGURE 2, the pilot burner consists of a gas conduit 50, such as a cylindrical metal tube, divided into a lower mixing chamber 52 and an upper combustion chamber 54 by screen means disposed inside of, and across, the interior cross-sectional area of the conduit. At the upper end of the conduit there is a second screen means 58 positioned across the upper or outlet end of the conduit. The lower, or inlet end, of the conduit is provided with a pilot supply of gaseous fuel by way of the pilot supply tubing 60, connected to the gas main 32 as shown in FIGURE 1. Inlet means for air are also provided by a plurality of inlet air apertures 62, in this case four such apertures, spaced equiangularly about the wall of conduit 50 near the pilot supply nozzle 64. These four apertures permit the atmosphere of the oven to be drawn into the mixing chamber 52 when the gaseous fuel is injected into the same chamber through the gas jet orifice 65 in nozzle 64 in known manner, to provide a reasonably uniform mixture of air and gaseous fuel at screen 56.

A thermoelectric generator 70, such as a metal tube containing an ordinary thermocouple, extends through a snugly-fitting aperture in the side wall of the combustion chamber 54 in such a position that the sensitive end 72 of the thermoelectric generator is positioned slightly downstream from the first screen means 56, in which position it will be strongly heated when a flame is present at the outlet side of screen means 56, but will not be so heated and will cool when the flame at screen means 56 disappears.

As shown particularly clearly in FIGURE 4, there is also provided an opening 76 in the side wall of the com-

bustion chamber 54 extending from a position adjacent the first screen means 56 to a position adjacent the screen means 58. As shown, this opening comprises a port 78, which may be circular, and a slot 79 extending from port 78 to the upper end of combustion chamber 54 adjacent second screen means 58. Port 78 is aligned with the outlet side of first screen means 56, and preferably slot 79 is of smaller width than the port. The sizes of slot 79 and port 78 are small enough that they do not divert so much of the flow of the gaseous mixture that the desired flames 80 and 42 cannot be maintained at the outlet side of the second screen means, or that complete combustion is produced at the first screen means 56.

Each of the screen means 56 and 58 may comprise a mesh of high-temperature-resistant wire, the first screen means 56 being a finer mesh of smaller-diameter wires as compared with screen means 58 because the absence of secondary aeration makes stabilization of the flame on screen means 56 more difficult than on screen means 58; coarser mesh at screen means 58 is desirable to reduce the resistance to gas flow through the entire pilot. The general appearance of either of the screen means is represented in FIGURE 5.

As indicated in FIGURES 2 and 3, there are two main combustion phases which occur in the normal operation of the pilot burner. FIGURE 2 illustrates the combustion phase existing when the air outside of the pilot burner has substantially the proportions of oxygen and inerts contained in standard air. The rate of flow of gaseous fuel into the mixing chamber, the arrangement and size of the air inlet apertures 62 and the dimensions of the conduit 50 and of screen means 56 and 58 are such that, with air of standard proportions entering aperture 62, the mixture at first screen means 56 is rich enough in oxygen to permit what will be designated herein as limited primary burning at first screen means 56. The mixture is fuel rich so that combustion is only partial, and the mixture of hot combustion gases flowing to the exterior through second screen means 58 causes further combustion to occur at the outlet side of screen means 58 where additional oxygen is available from the surrounding air, the latter combustion being designated herein as secondary combustion. Part of the gaseous mixture escapes through the re-ignition opening 76, including port 78 and slot 79, and is kept burning by reason of the secondary air available on the outside. Thus, under the above-outlined conditions, once the pilot burner has been ignited in any conventional manner there will be produced a primary flame 80 stabilized at the outlet side of the first screen means 56, a secondary flame 42 stabilized at the outlet side of the second screen means 58, and a secondary flame 84 extending along and throughout the re-ignition opening 76. Primary flame 80 then serves to heat thermoelectric generator 70 to produce a current therefrom which, when supplied by way of electrical cable 44 as shown in FIGURE 1, is sufficient to hold open the solenoid-controlled gas valve V_s and thereby permit the supply of gaseous fuel to main burner 30 so long as manual valve V_m is turned on.

FIGURE 3 illustrates the flame conditions which occur when the proportion of oxygen to fuel falls below the complete combustion level, or the proportion of inerts in the atmosphere surrounding the pilot burner 40 increases above a predetermined level. As illustrated in FIGURE 3, the primary flame 80 is extinguished at screen means 56 because of insufficient oxygen in the mixture supplied to screen means 56, and moves downstream to a position at the outlet side of second screen means 58, where sufficient oxygen is available for additional burning. The normal secondary burning portion 42 of the flame also remains, as shown, at the outlet side of second screen means 58. Accordingly, the thermoelectric element 70 is no longer heated by the primary flame 80, and the current produced by the thermoelectric generator drops below the value necessary to hold open

safety shutoff device V_s , which device therefore closes and prevents further supply of gaseous fuel to the main burner 30. The fall in the oxygen content in the atmosphere surrounding the pilot burner 40 in oven 10 is correlated with a decrease in the completeness of combustion at the main burner, giving rise to carbon monoxide contamination. The above described operation serves to terminate or reduce operation of the main gas burner 30 in the event that such incomplete combustion occurs.

The two flame conditions shown in FIGURES 2 and 3 are reversible in the sense that, when the gaseous mixture supplied to first screen means 56 again contains proportions of oxygen greater than a predetermined level, primary burning can again be supported at the first screen means 56 and re-ignition of the primary flame 80 is provided automatically by the re-ignition flame 84 by way of port 78 thereof. This arrangement is particularly advantageous in providing for prompt automatic re-ignition of primary flame 80 in the event that momentary fortuitous variations in the proportions of inerts and oxygen at screen means 56 occur, which are not representative of a corresponding general increase in the proportion of inerts in the air surrounding the pilot burner. The re-ignition slot also permits easy ignition of the primary flame when starting the pilot, either initially or after a change flameout. The safety shutoff device may also be arranged to shut off the gas supply to the pilot burner as well as to the main burner automatically should flame 42 be accidentally extinguished.

The first and second screen means 56 and 58 serve as position-stabilizing elements for the flame, so that when the primary flame 80 moves from one screen means to the other in response to changes of the proportions of oxygen above the below said predetermined level it does so quickly, abruptly and affirmatively in a manner which may be described as a "snap action." This overcomes the tendency which otherwise exists for the primary flame to vacillate erratically back and forth from below to above the thermoelectric generator.

The mechanical construction of a suitable pilot burner for the above purposes may take any of many forms. In the particular example illustrated in the figures, the pilot burner may be made by starting with a relatively shorter piece of metal tubing of appropriate dimensions for the combustion chamber 54, and a separate, longer piece of metal tubing for the mixing chamber 52. The first circular-mesh screen means 56 may then be placed between the outlet end of the mixing chamber and inlet end of the combustion chamber and the screen and the two pieces of tubing brazed together. The second screen means 58 may be similarly brazed to the outlet end of the combustion chamber 54. The apertures 62 may be drilled in the side walls of the tubing constituting mixture chamber 52, and the threaded nozzle 64 screwed into internal threads in a central aperture in a washer 90 which has been brazed in position across the bottom of the mixing chamber tube to form a closed end therefor. The re-ignition slot 79 and port 78, as well as the circular opening 101 for receiving the thermoelectric element 70 may also be provided by conventional machining.

From a consideration of the foregoing it can be seen that the apparatus described embodies apparatus for sensing and providing indications, by the presence or absence of flame 80 at first screen means 56, of the relative proportions of oxygen, gaseous fuel and inerts supplied to first screen means 56. Thus if the supply of gaseous fuel is controlled by a fixed fuel orifice as is normally the case, the disappearance of the primary flame 80 from the first screen means constitutes an indication of oxygen deficiency in the atmosphere of the main burner which may be the result of reduced air intake or of an increase in the volume of inerts in the combustion chamber of the main burner. The sensitivity of the system to oxygen deficiency may be determined by a suitable selection or adjustment of the parameters of the system, in-

cluding physical dimensions of the pilot burner and its components and the rate of supply of gaseous fuel to it.

Thus the basic parameters in this system are the oxygen, fuel and inerts content of the atmosphere in the main burner combustion chamber, which is used as primary air to the pilot system, and the percent aeration by this atmosphere of the gaseous mixture passing through the first screen means 56. This percent aeration should be just sufficient to produce an ignitable gas mixture capable of flame stabilization on the outlet side of first screen means 56 when the atmosphere of the main burner combustion chamber is substantially free of inerts generated by the main gas burner due to venting inadequacies or failures. On the other hand, the percent aeration should not be greatly in excess of that required to stabilize combustion on first screen means 56 since this would prevent maintaining a proper pilot flame at the outlet side of the second screen means as is desired for pilot purposes. Furthermore, if as in the present embodiment of the invention it is desired that the pilot burner be as sensitive as possible to an abnormal oxygen deficiency, then the aeration of the pilot system should be only slightly above that required to maintain a flame at first screen means 56, so that even small decreases in the proportion of oxygen will cause the primary flame to disappear from first screen means 56.

For example, increasing the diameter of the conduit 50 increases the primary aeration by permitting increased air flow with increased linear velocity of the mixture. Use of finer mesh for either of the screen means decreases the aeration by introducing more resistance to air intake. Increasing the rate of fuel admission by increasing the size of the orifice 65 decreases the percent aeration. Increasing the number and size of the primary air inlet apertures 62 increases the primary aeration, and the nature of the gaseous fuel also effects the percent aeration in a manner which will be apparent to one skilled in the art.

The nature of the screen means employed also depends upon the requirements of the particular application, aside from the question of percentage aeration. The first screen means 56 is preferably sufficiently fine to stabilize the primary flame, and because it is generally more difficult to stabilize a flame with a fuel rich mixture where no secondary air is available the first screen means 56 is preferably of relatively fine mesh. The second screen means 58 should be capable of stabilizing the adjacent flame over a relatively wide range of conditions, since it should be effective for this purpose whether primary flame 80 is present or absent at this first screen means and when the presence of flame 80 raises the temperature, changes the composition, reduces the oxygen content and increases the volume and rate of flow of the gaseous mixture supplied to the second screen means 58. For this purpose we have found that a relatively coarse mesh is generally best suited for the second screen means 58.

The lengths of the mixture chamber 52 and combustion chamber 54 also effect to some extent the primary aeration of the pilot system, although in this respect the lengths are not highly critical. The mixing chamber 52, however, should be sufficiently long that a substantially homogeneous gaseous mixture is supplied to first screen means 56, and the combustion chamber 54 should have a length sufficient to accommodate the placement of the thermoelectric element 70 in a position in which the latter will be affected substantially only by the primary flame 80 at screen means 56 and not by flame 42 and will produce sufficient output current when heated by flame 80 to operate the control or indicating device which it supplies, in the present example the solenoid-controlled gas valve V_g .

Accordingly, with these various factors in mind one skilled in the art will be able to design a suitable form of pilot burner 40 for any given application. Without in any way thereby limiting the scope of the invention, the

following are some values of the various parameters which have been used successfully in one particular application of the invention in accordance with the embodiment illustrated in the figures. The total length of conduit 50 was about 2.25 inches, defining a mixing chamber 52 about one inch in length and a combustion chamber 54 about 1.25 inch in length. The interior diameter of both chambers, which were cylindrical in form, was about 0.6 inch. Primary air inlet apertures 62 were four in number, each about .23 inch in diameter and spaced equiangularly about the periphery of the mixing chamber substantially at the plane of the nozzle orifice 65. The nozzle provided a flow of natural gas at about 0.5 cubic foot per hour resulting in a gaseous mixture in mixing chamber 52 having about 70% aeration at first screen 56, when the inlet in apertures 62 was provided with standard air. First screen means 56 was 15-mesh screen of 0.014-inch diameter wire, while second screen means 58 was an 8-mesh screen of 0.020-inch diameter wire. The sensitive portion 72 of the thermoresponsive device 70 was a conventional automatic pilot-type thermocouple disposed about $\frac{1}{8}$ inch downstream of first screen means 56, and produced about 16 millivolts output when flame 80 was at the first screen means 56. This apparatus was effective to shut off the safety shutoff device V_s when the percentage of carbon dioxide present at first screen means 56 rose by about 1% from normal, corresponding to about a 10% rise in inerts present in the air in the oven surrounding the pilot burner and adjacent the primary air inlet aperture 62 and corresponding to an oxygen concentration of about 19%. In various other forms of the invention, operation was obtained when the inner diameter of the conduit 50 had various dimensions ranging from about $\frac{1}{2}$ to $\frac{3}{4}$ inch; when the length of the combustion chamber was varied from about $\frac{3}{4}$ to $1\frac{1}{2}$ inch and when the length of the mixing chamber 52 was varied from about $\frac{3}{4}$ to $1\frac{1}{2}$ inch. Typically, port 78 was $\frac{3}{16}$ inch in diameter and slot 79 was $\frac{1}{16}$ inch wide.

It will be understood that the example of a broiler in a kitchen gas range has been described by way of illustration. Water heaters, room heaters and any vented burner appliance, where interference with normal circulation in the combustion chamber is possible, are potential applications for the invention.

It will also be understood that the apparatus illustrated in the figures as a pilot burner may be employed, without its pilot burner function, solely as a sensor for the relative proportions of oxygen and combustible fuel. For example, it may be mounted outside of an oxygen storage tank, the air from the tank being supplied to the primary air inlet apertures 62 by way of appropriate tubing, either by the aspirating effect or by a small gas pump, to determine whether the oxygen content of the tank is sufficient for respiration. Thus it may be used to indicate the proportion of oxygen in any atmosphere or enclosure. Other means for sensing the presence or absence of flame 80, such as photoelectric means for example, could be used in place of the thermoelectric element, and the output of the sensing means may be used to operate indicating or alarm equipment in case of oxygen depletion due to fire. The sensor may operate a calibrated meter for example, rather than a gas valve, depending upon the purpose for which the invention is used. Furthermore, in some forms of the invention the means for detecting the occurrence of gaseous combustion at the first screen means may be simply a suitable high-temperature-resistant window through which the region adjacent the first screen means can be visually observed.

While the invention has been described with particular reference to specific embodiments thereof in the interest of complete definiteness, it will be understood that it can be embodied in any of a variety of diverse forms without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. Apparatus for sensing the proportion of a predetermined component in a gaseous mixture which contains oxygen, a fuel and inerts, comprising:

- a gas conduit having gas inlet means and gas outlet means;
- first gas-transmissive flame-stabilizing screen means disposed inside and across the interior of said conduit intermediate said inlet means and said outlet means;
- second gas-transmissive flame-stabilizing screen means disposed across said outlet means;
- means for permitting ignition of said gaseous mixture at said first screen means when the gaseous mixture supplied thereto is combustible; and
- means for detecting the occurrence of gaseous combustion at said first screen means.

2. Apparatus in accordance with claim 1, in which said conduit means contains an opening to the exterior extending from a first position adjacent said first screen means to a second position adjacent said second screen means.

3. Apparatus in accordance with claim 2, in which said opening comprises a port in said conduit adjacent said first screen means and a slot in said conduit of smaller width than said port extending from said port to said second position adjacent said second screen means.

4. Apparatus in accordance with claim 1, in which said first screen means has a higher resistance to flow of said gas than does said second screen means.

5. Apparatus in accordance with claim 4, in which said second screen means comprises a mesh and said first screen means comprises a mesh finer than that of said second screen means.

6. Apparatus for detecting the relative proportions of inerts and of oxygen in a fuel gas, comprising:

- a first chamber having gas inlet means for supplying a flow of said gas to said chamber, and having gas outlet means;
- means for supplying said gas inlet means with a flow of a gaseous fuel, whereby a flow of a gaseous mixture of said fuel and said gas is produced through said gas outlet means;
- a second chamber having gas inlet means communicating with said outlet means of said first chamber and supplied with a flow of said gaseous mixture from said first chamber;
- a first flame-stabilizing screen disposed between said first and second chambers in the path of said gaseous-mixture flow;
- a second flame-stabilizing screen in the path of said gaseous-mixture flow at said gas outlet means of said second chamber; and
- means for detecting the presence of a flame in said second chamber adjacent said first screen, said presence of said flame indicating that the proportion of inerts in said gaseous mixture in said first chamber is below a predetermined level.

7. Apparatus in accordance with claim 6 in which said second chamber contains an opening, extending between a position adjacent said second screen and a position adjacent said first screen, for providing a combustible gas mixture along said opening even when said proportion of said inerts is below said predetermined level, whereby a

flame at said opening provides re-ignition of flame at said first screen when the proportion of said inerts in said gas in said first chamber decreases from above to below said predetermined level.

8. Apparatus in accordance with claim 7, in which said opening is in the form of a port adjacent said first screen and a slot of lesser width than said port extending between said port and said position adjacent said second screen.

9. Apparatus in accordance with claim 6, in which said second screen is a mesh and said first screen is a mesh finer than that of said second screen.

10. Apparatus for providing electrical indications of the proportion of inerts in an oxygen-containing fuel gas, comprising:

- a gas-mixing tube having a plurality of inlet apertures and an outlet aperture;
- a combustion tube having an outlet aperture and having an inlet aperture communicating with said outlet aperture of said mixing tube;
- a first gas-transmissive flame-stabilizing screen disposed across said outlet aperture of said mixing tube and across said inlet aperture of said combustion tube;
- a second gas-transmissive flame-stabilizing screen disposed across said outlet aperture of said combustion tube;
- a source of gaseous fuel and means for providing a controlled rate of flow of said gaseous fuel to one of said inlet apertures of said mixing tube, thereby to establish a predetermined flow of said gaseous fuel through said mixing tube and said combustion tube;
- means for supplying another of said inlet apertures with a flow of said gas sufficient to maintain a combustible gaseous mixture at said second screen;
- a re-ignition slot in the side of said combustion tube extending from adjacent said first screen to adjacent said second screen for providing a flame at said opening adjacent said first screen upon the occurrence of a flame at said second screen; and
- a thermoelectric element in said combustion chamber against said first screen for producing an increase in electric current therefrom upon the occurrence of a flame in said combustion tube adjacent said first screen.

11. Apparatus for producing indications of the limits of combustibility of a mixture of fuel gas, oxygen and inerts when the relative amount of any one or more of its components is varied, comprising:

- a gas conduit having gas inlet means supplied with said mixture and having gas outlet means therefor;
- a gas-transmissive flame-stabilizing screen means disposed inside and across the interior of said conduit intermediate said inlet and outlet means;
- means for permitting ignition of said mixture at said screen means when said mixture has a composition rendering it combustible; and
- means for detecting the occurrence of combustion of said mixture at said screen means.

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FREDERICK KETTERER, *Primary Examiner.*