

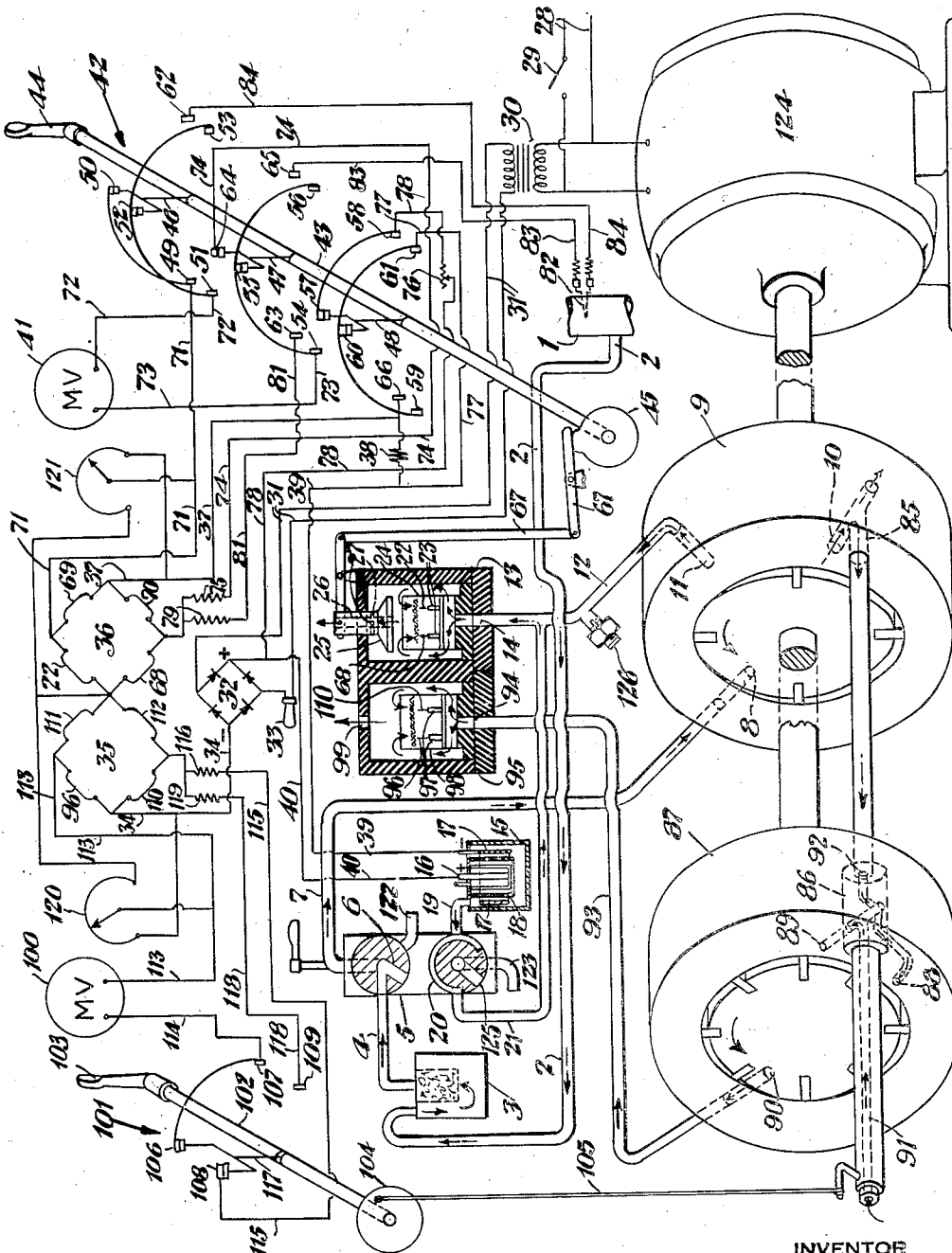
July 30, 1946.

A. P. SULLIVAN

2,404,993

GAS ANALYZER

Filed Jan. 22, 1940



INVENTOR
ALAN P. SULLIVAN
BY *Edmund R. Rodea*
ATTORNEY

UNITED STATES PATENT OFFICE

2,404,993

GAS ANALYZER

Alan P. Sullivan, Elizabeth, N. J., assignor to
Cities Service Oil Company, New York, N. Y., a
corporation of Pennsylvania

Application January 22, 1940, Serial No. 314,899

3 Claims. (Cl. 23—255)

1

This invention relates to gas analyzers, and more particularly to an apparatus adapted to give accurate and sensitive measurements of the oxygen and combustible content of a gas in either low percentages or relatively high percentages of oxygen and combustibles.

The invention is particularly adapted for the analyses of exhaust gases, such as domestic and industrial furnace exhaust gases, Diesel and gasoline engine exhaust gases; and for other types of gases, such as mine gases and atmospheres in which the percentage of the combustibles and oxygen is not very large.

The apparatus of this invention is an improvement on and a continuation in part of the apparatus described in the Patent No. 2,273,981, issued February 24, 1942, to John D. Morgan and Alan P. Sullivan.

In the apparatus of the above patent, the gas to be analyzed is ignited in a combustion chamber by means of a platinum or platinum-alloy catalyst wire, which forms one leg of a Wheatstone bridge. The heat of combustion of the gas raises the temperature of the catalytic leg of the Wheatstone bridge, thus increasing its resistance proportionally to the amount of combustibles or oxygen in the gas. This change in the amount of resistance is indicated on a galvanometer connected across the Wheatstone bridge circuit.

The most efficient operating temperature range for the catalyst wire in a gas analyzer of this type has been found to be from 1400° to 1600° F.

If a platinum or platinum-alloy catalyst wire is operated below 1400° F. for the ignition of exhaust gases, such as exhaust gases from an internal combustion engine which contain partial oxidation products of hydrocarbons, the catalyst will lose its activity in a very short time due to poisoning. In other types of gases burned below 1400° F. the ignition is irregular and not dependable, due to incomplete combustion and formation of partial oxidation products.

The loss of activity of the catalyst wire due to poisoning above 1400° F. has been eliminated by the manner of assemblage and treatment of the catalyst as described in Patent 2,273,981.

When a platinum or platinum-alloy catalyst wire is operated above 1600° F., its life is considerably shortened due to the vaporization of the wire.

Such an apparatus, as described in the Patent No. 2,273,981, has been found to give accurate and sensitive analyses of a gas in the range of the percentage of oxygen and combustibles for which it was designed; but it is not suitably adapted to

2

give sensitive analyses of gases whose oxygen and combustible content varies over a wider percentage range. This lack of sensitivity of a single range apparatus for analyses in wide percentage ranges results from the necessity of the operation of the catalyst wire in a temperature range of 1400° to 1600° F. in order to insure long life, accuracy, and sensitivity to the catalyst wire.

The primary object of the invention is to provide a simple, accurate, and sensitive gas analyzer which can be used for measuring the oxygen and combustible content of gases in either a range of high or low percentages of oxygen and combustibles; and yet maintaining the temperature of the catalyst wire in the most efficient operating temperature range of 1400° to 1600° F.

Another object of the invention is to provide a gas analyzing apparatus which is adapted to be used as an indicating means for adjusting domestic furnaces, industrial furnaces, Diesel engines, and gasoline engines to the highest degree of operating efficiency.

The present invention is particularly adapted for analyses of gases exhausted from steam boiler furnaces, metallurgical furnaces, and internal combustion engines, particularly gasoline engines and Diesel engines. The exhaust gases from a gasoline engine rarely have free oxygen content, but all the other gases from the different types of furnaces and engines usually have both oxygen as well as combustible constituents. The apparatus is therefore well adapted for analyzing gases having both oxygen and combustible content, as the sample taken into the apparatus is divided and each part analyzed simultaneously.

The apparatus is so designed that a very short lag exists between the time that the sample is taken into the apparatus and the time that the analyses are determined. Therefore, this apparatus may be used for accurately controlling combustion in all types of furnaces and internal combustion engines.

Fundamentally, the apparatus of this invention provides for the simultaneous measurements of the combustible content, the oxygen content, and the temperature of the gas to be analyzed; keeping the catalyst wire temperature in the range of 1400° to 1600° F. and nevertheless obtaining sensitive measurements regardless of the amount of oxygen and combustibles in the gas.

In the operation of the gas analyzer, the gas sample is divided into two parts. Hydrogen is added to one part, and the mixture of hydrogen and sample gas is conveyed to the oxygen analyzing chamber to be analyzed to determine its

oxygen content. Air is added to the other part, and the mixture of air and sample gas is conveyed to the combustible analyzing chamber to be analyzed to determine its combustible content. An electrically heated catalytic combustion wire, suspended in each of the analyzing chambers, ignites the gaseous mixture passing through the chamber; and the resulting heat of combustion increases the resistance of the catalyst wire proportionally to the amount of oxygen or combustibles in the gaseous mixture. The catalyst wire in each analyzer forms a leg of a Wheatstone bridge circuit, and the increased resistance of each catalyst wire is measured directly in percentage of oxygen or combustibles on a millivoltmeter connected across each Wheatstone bridge circuit.

In analyzing a gas for its oxygen content, the apparatus may be designed to operate in any of two percentage ranges. The ranges selected for the preferred form are: 0% to 4% oxygen—low range, and 0% to 20% oxygen—high range. To operate the analyzer in the low range, the apparatus is adjusted in such a way that the volume of hydrogen added to the gas is decreased to approximately one-fifth the volume added when operating in the high range; and the amount of the mixture of gas and hydrogen burned by the catalyst wire is approximately five times that amount burned when operating in the high range. These adjustments are accomplished by the operation of a multipole switch, which is electrically connected to an electrolytic hydrogen generator, and mechanically connected to a baffle located in the combustion chamber. By turning the switch to the low range position, a resistance is connected into the electrolytic hydrogen generator circuit in order to decrease the generation of hydrogen, and the baffle in the combustion chamber is moved out of the path of flow of the gas mixture to the catalyst wire, such that more gas mixture will be ignited by the catalyst wire. By these adjustments, the catalyst wire will operate in the same temperature range for both the high and low percentage ranges.

In analyzing a gas for its combustible content, the apparatus may be designed to operate in any of two percentage ranges. The ranges selected for the preferred form are, 0% to 4% combustibles—low range, and 0% to 20% combustibles—high range. When operating the analyzer in the low range, the apparatus is adjusted such that a mixture of five parts sample gas and one part air is ignited by the catalyst wire. When operating in the high range, the apparatus is adjusted such that a mixture of one part sample gas and five parts air is ignited by the catalyst wire. The adjustment of the mixture ratio is performed by use of a switch which is mechanically connected to a movable valve in the proportioning pump. The proportioning pump has two suction ports, one of which draws in five volumes of gas while the other port draws in one volume of gas. When the switch is turned to the low range position, the movable valve is adjusted to connect the five volume suction port to the sample gas inlet, and the one volume suction port to the air inlet. In the high range position, the five volume suction port is connected to the air inlet and the single volume suction port is connected to the sample gas inlet. The catalyst wire will operate in the same temperature range for both the high range and low range analysis positions.

The invention which has been broadly explained will now be specifically described in con-

nection with the accompanying drawing, which illustrates a flow and wiring diagram of the preferred form of the invention.

Referring to the drawing, a continuous sample of the gas to be analyzed is withdrawn from pipe 1, which pipe may be the stack of a furnace or the exhaust pipe of a combustion engine. This sample is conveyed through conduit 2 to a gas filter 3, where suspended liquid and solid material, such as water and dust, are removed from the gas by a cotton filter contained therein.

This cleaned and dried gas sample is conducted through conduit 4 to a valve 5. With valve 5 in the position illustrated, the gas passes through passage 6 into conduit 7, through which it passes to suction port 8 of the rotary sliding vane pump 9.

The pump 9 rotates at a constant speed in a counterclockwise direction, having one suction port 8, and two discharge ports 10 and 11. The function of pump 9 is to discharge a constant flow of gas at port 11 regardless of variation in the pressure of the gas entering the pump.

This is accomplished by the use of the atmospheric discharge port 10, which is located a little more than 45° in the direction of rotation past the point of maximum clearance between the rotor and the inner peripheral surface of the pump housing. As the gas passes this atmospheric discharge port 10 at varying pressure, it is brought to atmospheric pressure, and any gas in excess passes out through the passage of port 10. The gas is compressed between the atmospheric discharge port 10 and the sample discharge port 11, such that a constant uniform flow of gas is exhausted from the pump into conduit 12, regardless of any variation in the pressure of the gas entering the pump 9 at suction port 8.

The sample gas pumped into conduit 12 is conveyed therein to aperture 14 of oxygen analyzing chamber 13. The sample gas is analyzed in chamber 13 for its oxygen content by igniting a mixture of sample gas with hydrogen. The amount of hydrogen added to the sample gas is in slight excess of the amount of hydrogen required to react with the oxygen of a gas sample.

The hydrogen for the oxygen analysis is generated at a constant rate by an electrolytic hydrogen generator 15, which generator has an anode 16 separated from a cathode 17 by an asbestos diaphragm 18; all of said parts being immersed in an electrolytic solution, such as a solution of sodium hydroxide. The hydrogen generated at cathode 17 passes through conduit 19 to valve 5, through which it flows by means of a peripheral groove 20 into a conduit 21. The hydrogen flowing through conduit 21 enters conduit 12, mixes with the sample gas flowing therein, and the mixture enters aperture 14 of the oxygen analyzing chamber 13.

In the oxygen analyzing chamber 13 a catalytic ignition wire 22 is supported on one of the posts 23, which posts are surrounded by an impervious metallic cylindrical shield 24. A movable baffle 25 is supported over the shield 24, said baffle 25 having a central bore 26, and four openings 27 leading to the bore 26 from the side of the baffle.

The mixture of sample gas and hydrogen entering the oxygen analyzing chamber 13 by the aperture 14, passes upwardly around the outside of the impervious shield 24. With the baffle 25 in the position illustrated, part of the mixture of sample gas and hydrogen passes into the shield 24 by diffusion and convection currents to be ignited by the catalyst wire 22 contained therein.

5

The remainder of the gas-hydrogen mixture along with the products of combustion pass upwardly out of the oxygen analyzing chamber 13 by way of the bore 26 of the baffle 25.

If the baffle 25 is lowered to rest on the top of the shield 24, the air-hydrogen mixture after entering the oxygen analyzing chamber 13 passes through the side openings 27 into the baffle 25 and down through the bore 26 into the shield 24. Much less gas mixture enters shield 24 to be ignited by catalyst wire 22 when baffle 25 is lowered on shield 24. The area of accessibility of the gas to enter shield 24 by way of the bore 26 is much less than the area of accessibility of the gas to enter the shield unobstructed by baffle 25.

The mixture of hydrogen and sample gas is burned on the surface of the catalyst wire 22 which is electrically heated. The combustion of the mixture will generate more or less heat in accordance with the amount of oxygen present in the gas sample. This heat varies the resistance of the catalyst wire 22, and a measure of this resistance is used for determining quantitatively the amount of oxygen in the sample. The catalyst wire 22 forms one leg of a Wheatstone bridge, which bridge is used for measuring the resistance of the catalyst wire 22. A direct current is used in the Wheatstone bridge, and in the electrolytic hydrogen generator 15. All of the electrical current used in the apparatus is derived from a single source.

An electric current is introduced into the wires 28 from a power source, the current being controlled by a switch 29. The current is conducted by wires 28 to transformer 30, where the voltage is reduced to approximately twelve volts. The secondary transformer current is conducted by wires 31 to full wave rectifier 32, which has a ballast lamp 33, such as an amperite, in series with the circuit.

A rectified D. C. current, leaving rectifier 32 at approximately 8 volts is conducted by line 34 to a Wheatstone bridge 35, then through the bridge 35 to a Wheatstone bridge 36. The current leaves bridge 36 through line 37, passing through a 0.2 ohm resistance 38, and thence through line 39 to the cathode 17 of hydrogen generator 15. The current passing through the electrolytic solution of the hydrogen generator 15 leaves the generator at anode 16, and is conducted by line 40 back to rectifier 32.

The Wheatstone bridge 36 is employed in determining the oxygen content of the gas. One of its legs is the catalytic wire 22, which ignites the mixture of sample gas and hydrogen in the combustion chamber 13. When the gas burns, it heats the catalyst wire, increasing its resistance, and thus unbalancing the bridge. A millivoltmeter 41 is connected across the bridge 36, and any unbalancing of the bridge 36 causes a current to flow to the millivoltmeter 41, through the multipole switch 42. The multipole switch 42 is used in connection with the analyzer for the purpose of selecting the range of operation of the analyzer. There are two percentage ranges: 0 to 4% oxygen or low range, and 0 to 20% oxygen or high range.

The switch 42 is a triple-pole, triple-throw switch, having a movable shaft 43 with an adjusting lever 44 at one end and a cam 45 at the other end. Three contact blades 46, 47 and 48 are fixed on the shaft 43, and arranged for each blade to connect two contact points at each position of the switch. Several of the contact points are internally connected together; thus contact

6

point 49 is connected to contact point 50, contact points 51, 52 and 53 are connected together; contact points 54, 55 and 56 are connected together; contact point 57 is connected to contact point 58; and contact points 59, 60 and 61 are connected together. The cam 45 connected to the switch shaft 43, when turned, raises and lowers the baffle 25 in the oxygen analyzing chamber 13 by means of linkage 67.

The Wheatstone bridge 36 shown in the illustration is composed of an active catalytic platinum-alloy wire 22, a wire 69 of the same material and having substantially the same resistance, and two gold plated platinum-alloy inactive wires 68 and 70, each of which has the same resistance. The catalyst wire 22 and one of the gold plated wires 68 are mounted upon the posts 23 in the oxygen analyzing chamber 13, and when air alone is passed through chamber 13, the bridge 36 should be balanced with no current flowing through the millivoltmeter 41 connected across the bridge 36.

When a gas sample mixed with hydrogen is passed through combustion chamber 13, it will be ignited by catalyst wire 22, whose resistance will be increased due to the temperature rise. The increase in resistance will unbalance the bridge 36 and a current will flow to the millivoltmeter 41. With the multipole switch 42 in the low-range position, as illustrated, the meter current flows through line 71 to contact point 49, thence through the internal connections and switch blade 46 of the switch 42, and out of the switch at contact point 51, to flow through line 72 to the meter 41. The current leaves the meter 41 to flow through the line 73 to contact point 54, then through the connections and switch blade 47 of switch 42, leaving at contact point 64 through line 74 to Wheatstone bridge 35. A resistance 75 is placed in the line 74 for the purpose of calibrating the meter 41 to give direct readings on its scale in percentage oxygen of the gas being analyzed.

Since the amount of hydrogen added to the sample gas is decreased during the operation of the analyzer in the low-range, a resistance 76 is placed in parallel with the hydrogen generator 15. The circuit of the hydrogen generator, the rectifier, and the bridges for low-range operation may be described as follows: rectified D. C. current leaves rectifier 32 by line 34, passes through bridge 35, through bridge 36, leaving by line 37, then through the 0.2 ohm resistance 38. One part of the current goes to hydrogen generator 15 by line 39, then to the rectifier 32 by line 40; the other part of the current goes by line 77 to contact point 61, then through the internal connections and switch blade 48 of switch 42, out at contact point 58, and thence through line 78, through the 1.3 ohm adjusted resistance 76 to the rectifier 32.

When analyzing a gas having more than 4% oxygen, the switch 42 is turned 90° counterclockwise, from the position of the switch illustrated. By turning the switch 42 to this high-range position, the flow of hydrogen from the generator 15 is increased, and the flow of sample gas and hydrogen mixture to the catalyst wire 22 is decreased.

By thus turning the switch 42, 90° counterclockwise, the cam 45 lowers the baffle 25 down upon the shield 24, and as a result, the gas and hydrogen mixture will have to enter the baffle 25 through side holes 27, and go down through bore 26 to be burned by catalyst wire 22. The

central bore 26 is designed to permit approximately only one-fifth as much gas and hydrogen mixture to reach the catalyst wire 22 when the baffle is lowered, as will reach the wire when the baffle is raised.

The circuit for the rectifier, the bridges and the hydrogen cell for the high range position of the switch may be outlined as follows: the current leaves rectifier 32 by line 34, goes through bridge 35, through bridge 36, through line 37, to contact point 66. The current goes through switch blade 48 and the internal connections of the switch 42, out of the switch at point 61, through line 77, through line 39, thus cutting out both the 0.2 ohm resistance 38, and the 1.3 ohm resistance 76. The current then flows through line 39, goes through the hydrogen cell 15 out through line 40 back to the rectifier 32. By cutting out resistance 38 and 76 the generation of hydrogen will be increased approximately five times.

If a gas is passed through the analyzer when switch 42 is in the high-range position, the meter current flow from the bridge 36 to the millivoltmeter 41, due to unbalancing of the bridge, will go through line 71 to contact point 49. This current flows through the switch blade 46 to contact point 51, and out through line 72 to the millivoltmeter 41. The current leaves the millivoltmeter 41 by line 73, going to contact point 54, through blade 47 to contact point 63. The current leaves the contact point 63 through line 81 to return to bridge 36. The current passes through high-range calibrating resistance 79, in the line 81. The calibrating resistance 79 is used in order that a direct reading of the percentage of oxygen in the gas to be analyzed can be read directly on a meter scale of the millivoltmeter 41.

By turning the switch 90° clockwise from the position illustrated the apparatus will be adjusted to give temperature readings on the millivoltmeter 41 of the temperature of the gas withdrawn from the pipe 1. The temperature of the sample gas is important when the apparatus is used in conjunction with adjusting furnaces for their maximum operating efficiency. A thermocouple 82 is inserted in pipe 1 near the opening of conduit 2. A lead 83 is connected to contact point 65, and a lead 84 is connected to contact point 62.

When the switch 42 is in position for measuring the gas temperature, the current of the thermocouple goes through line 83 to contact point 65, through switch blade 47 and the switch connections, and out through contact point 54 through line 73 to the millivoltmeter 41. The current leaves the millivoltmeter 41 through line 72 going to contact point 51, then through switch blade 46 and the switch connections and out through contact point 62, through lead 84 to thermocouple 82.

The millivoltmeter 41 has three scales upon its face; a high-range percentage oxygen scale; a low-range percentage oxygen scale; and a temperature scale.

Part of the sample gas is mixed with air, ignited by a catalyst wire of a Wheatstone bridge, and the percentage of combustibles in the gas is directly indicated on a millivoltmeter connected across the Wheatstone bridge. The source of the sample gas is from the atmospheric discharge port 10 of the sample pump 9. The sample gas discharged at port 10 is at atmospheric pressure, and part is drawn through the pump passage 85

of the sample pump 9 to a range changing valve 86 located in pump 87.

The pump 87 is a proportional mixing pump which has two suction ports 88 and 89, and one discharge port 90. The suction ports are so located with respect to the periphery of the housing, that suction port 88 draws in five volumes of a gas while suction port 89 draws in only one volume of gas. The ports have passages leading to the seat of the movable valve 86, and the openings in the valve seat are 90° apart on the periphery.

The range changing valve 86 has two axial passageways leading from the ends of the valve, one of which, passage 91, is open to the air and the other, passage 92, opens into passage 85 of pump 9. With the valve 86 in the valve seat of the pump 97 in the position illustrated, sample gas from passage 85 will be drawn through valve passage 92 to port 88 by way of the port passage. Air will be drawn through valve passage 91 to port 89 through the port passage. The mixture discharged at port 90 will consist of five parts sample gas and one part air.

If the valve 86 is turned 90° clockwise from the position illustrated, then the sample gas from passage 85 is drawn through valve passage 91 into port 89, and air is drawn through valve passage 91 to port 88, such that the mixture discharged through port 90 is one part sample gas and five parts air.

The mixture of air and sample gas discharged at a constant rate at port 90, passes through conduit 93 to the aperture 54 of a combustible analyzing chamber 95. The combustible analyzing chamber 95 is constructed similarly to the oxygen analyzing chamber 13 except it has no baffle. A catalyst wire 96 is mounted on one of the posts 97 which are enclosed in an impervious cylindrical shield 98. The gas mixture entering the aperture 54 passes upwardly around the outside of the shield 98, part of which passes down into the shield 98 by diffusion and convection currents to be ignited by the catalyst wire 96. The remainder of the gas mixture, along with the products of combustion of the part of gas mixture ignited, pass out of analyzing chamber 95 by means of a hole 99 in the top of said chamber.

The catalyst wire 96 forms one leg of the Wheatstone bridge 35, through which passes the rectified D. C. current from rectifier 32 as previously described. When gas is passed through the analyzing chamber 95, and ignited by the catalyst wire 96, the temperature of the wire is raised, thus increasing its resistance. The change in resistance of one leg of bridge 35 unbalances the bridge causing a current to flow through switch 101 to millivoltmeter 100 connected across the bridge 35.

The apparatus is designed to analyze gases in two different percentages of combustible ranges: 0 to 4% combustibles or low range, and 0 to 20% combustibles or high range. The switch 101 is used for selecting the range of operation of the analyzer.

The switch 101 is a single-pole, double-throw switch having a shaft 102 with an adjusting lever 103 at one end and a disk 104 at the other end. The movable valve 86 is connected to disk 104 by the linkage 105, such that the valve 86 will move in the same direction as the lever 103. There are four contact points on the switch 101, of which contact points 106 and 107 are connected together by connections in the

switch. A contact blade 117 is attached to the shaft 102, which blade connects contact point 106 to contact point 108 when the blade is in a vertical position, and connects contact point 107 to contact point 109 when the blade is in a horizontal position.

The Wheatstone bridge 35 is composed of the platinum alloy catalyst wire 96, a wire of similar material 111 and of approximately the same resistance, and two nickel plated platinum-alloy wires 110 and 112, of equal resistance. The catalyst wire 96, along with the nickel plated wire 110 is mounted on posts 97 in the combustible analyzing chamber 95.

When the bridge 35 is in an unbalanced condition and the switch 101 is in the low-range position, as illustrated, meter current leaves the bridge 35 by the line 113, and flows to the millivoltmeter 100. This current leaves the meter 100 by line 114, going to contact point 107, passing through the switch 101, out at contact point 108 through line 115 to the bridge 35. The low-range calibrating resistance 116 is placed in the line 115 in order that direct readings of the percentage combustibles of the gas analyzed are indicated on a scale of millivoltmeter 100.

With the switch 101 in the low-range position, the disk 104 holds the movable valve 86 in the position illustrated, such that five volumes of sample gas enter port 88 of the pump 87, and one volume of air enters the port 89.

To operate the apparatus in the high-range, the switch 101 is turned 90° clockwise from the position illustrated, and meter current will flow from the bridge 35, due to its unbalanced condition, through line 113 to millivoltmeter 100. The current leaves millivoltmeter 100 through line 114, going to contact point 107, passing through switch blade 117 to contact point 109, and returning to bridge 35 by line 118. The high-range calibrating resistance 119 is placed in the line 118 in order that direct readings of the percentage combustibles may be read from a scale of meter 100.

When the switch 101 is turned to the high-range position, the movable valve 86 is also turned 90° clockwise from the position illustrated. In this position of the valve 86, one volume of sample gas is drawn into port 89 and five volumes of air are drawn into port 88 of pump 87, such that the air-gas mixture entering the analyzing chamber 95 in the high-range position will be in the ratio of five parts air to one part gas.

The millivoltmeter 100 has two scales upon its face: a high-range percentage combustible scale and a low-range percentage combustible scale.

A motor 124 for operating the pumps is connected directly across the power intake leads 28. This motor is a constant speed motor, and drives the interconnected pumps 9 and 87 at a constant rate so that the pumps operate to deliver a predetermined quantity of gas mixture for analysis at a uniform flow.

In order to obtain accurate analyses, the apparatus should be periodically checked to balance Wheatstone bridges 35 and 36, and to set the flow of hydrogen delivered by the hydrogen generator 15 to the oxygen analyzer. The valve 5 is adapted to be used in conjunction with other controls for making these adjustments, as the valve 5 controls the type of gas going to the sample pump 9 and connects the flow of hydrogen to the oxygen analyzing chamber 13.

The valve 5 can be turned to four different positions. The position illustrated being the "read" or "sample gas analysis" position; by

turning the valve 60° counterclockwise, it is in the "check ratio of hydrogen to sample gas" position; by turning the valve 120° counterclockwise, it is in the "check balance of Wheatstone bridges" position; and by turning the valve 180° counterclockwise, it is in the "off" position.

The valve is turned to the "off" position when the apparatus is not in use. The upper section of the valve 5 shuts off any sample gas flow to the pump, and the lower section of the valve 5 connects the hydrogen generator 15 to the oxygen analyzing chamber 13.

When the valve 5 is turned to the "check balance of Wheatstone bridges" position, air alone is pumped through both analyzing chambers in order that the bridges can be electrically balanced by potentiometers 120 and 121. When an electrical balance is reached, the millivoltmeters connected across the bridges should have a zero reading. In this position the upper section of valve 5 connects air inlet 122 through valve passage 6 to the tube 7 leading to sample pump 9. The lower section of the valve 5 shuts off the flow of hydrogen to the oxygen analyzing chamber 13 and vents the hydrogen through slot 125 of the valve 5 to a valve vent 123. A potentiometer 120 connected across Wheatstone bridge 35 is adjusted to balance the bridge 35, and a potentiometer 121 connected across the Wheatstone bridge 36 is adjusted to balance the bridge 36.

When valve 5 is in the "check ratio of hydrogen to sample gas" position, air is pumped to both analyzers and hydrogen is supplied to oxygen analyzing chamber 13. In this position of valve 5, its upper section connects the air inlet 122 to the conduit 7 by valve passage 6, thus introducing air into the suction of the pump 9. The lower section of valve 5 connects hydrogen generator 15 to oxygen analyzing chamber 13. The ratio of hydrogen to sample gas in the gas mixture entering the oxygen analyzing chamber should be such that there is a slight excess of hydrogen over the amount needed to react with the maximum amount of oxygen encountered in either the high range or the low range. When the switch 42 is in the high-range position with the sample gas being air, the correct ratio of hydrogen to sample gas is obtained by adjusting the vent 126 until a maximum reading is indicated on the high-range scale of millivoltmeter 41 connected across bridge 36. When the switch 42 is in the low-range position and the sample gas pumped to the analyzer is air, the correct ratio of hydrogen to sample gas is obtained by adjusting the variable resistor 76 until a reading slightly in excess of 4% is obtained on the low-range scale of millivoltmeter 41 connected across bridge 36.

When the valve 5 is in the "read" position as illustrated, the sample gas is analyzed for its oxygen content in the oxygen analyzing chamber and its combustible content in the combustible analyzing chamber. The upper section of valve 5 connects the gas passage conduit 4 to the pump suction passage conduit 7 by the groove 6, and the lower section of valve 5 continues to introduce hydrogen from the hydrogen generator 15 to the oxygen analyzer 13.

The preferred form of the invention having been thus described, what is claimed as new is:

1. A gas analyzer for quantitatively measuring the oxygen content of a gas, comprising a combustion chamber, means for passing a continuous stream of gas to be analyzed at a uniform rate through the chamber, a metal shield mounted centrally within the chamber having imperforate

11

base and side walls positioned in baffling relation to the stream of gas flowing through said chamber, a Wheatstone bridge electric circuit embodying a catalyst wire leg mounted within said shield and a galvanometer for measuring variations in electric conductivity of the catalyst, an apertured movably mounted closure for the top of the metal shield, and a switching mechanism controlling the galvanometer circuit for adjusting the sensitivity of the galvanometer, said switching mechanism and closure moving means being interconnected and arranged for simultaneous adjustment of the position of said closure and the sensitivity of said galvanometer.

2. In a multi-range gas analyzer adapted for analyzing gas quantitatively for a constituent of a gaseous mixture, a combustion chamber, means for positively delivering a continuous flowing stream of gas to be analyzed through a conduit to said chamber, means comprising a Wheatstone Bridge electric circuit including a catalyst wire leg mounted in said chamber for setting up combustion therein and a galvanometer for measuring any increase in temperature thereby developed, means connected with said conduit for supplying to the gas stream a continuous flowing stream of gas which is combustively reactant with said constituent of the gas, means connected with the supplying means for changing the relative volumes of gas and reactant gas in the mixture, and an electrical switching mechanism control-

12

ling the galvanometer circuit for adjusting the sensitivity of the galvanometer, said volume changing means and switching mechanism being connected together and so arranged that adjustment of the switching mechanism to actuate said sensitivity adjusting mechanism will simultaneously operate said volume changing means.

3. In a multi-range gas analyzer adapted for analyzing products of combustion quantitatively for oxygen content, a combustion chamber, means for delivering to said chamber a continuous flowing stream of the gas to be analyzed, a Wheatstone bridge electric circuit including a catalyst wire leg mounted in said chamber for setting up combustion therein, a galvanometer for measuring any increase in temperature thereby developed, an electrolytic hydrogen cell and connections arranged for adding to the gas stream flowing to the combustion chamber a continuously flowing stream of hydrogen, and means in the bridge circuit including electrical switches and calibrated resistances whereby to adjust the sensitivity of the galvanometer and the rate of supply of hydrogen by the hydrogen cell, said switches and the circuits of said resistances being interconnected and arranged for simultaneously actuating said sensitivity adjusting means and said hydrogen proportioning means for making analyses in different ranges.

ALAN P. SULLIVAN.