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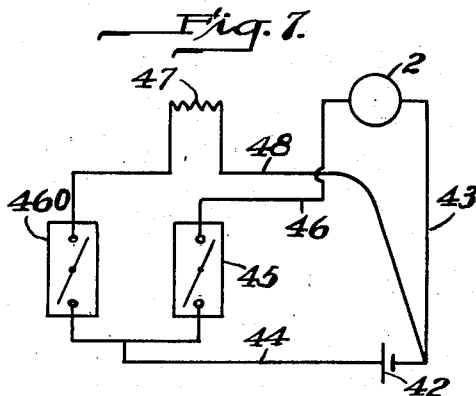
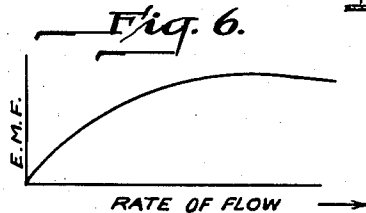
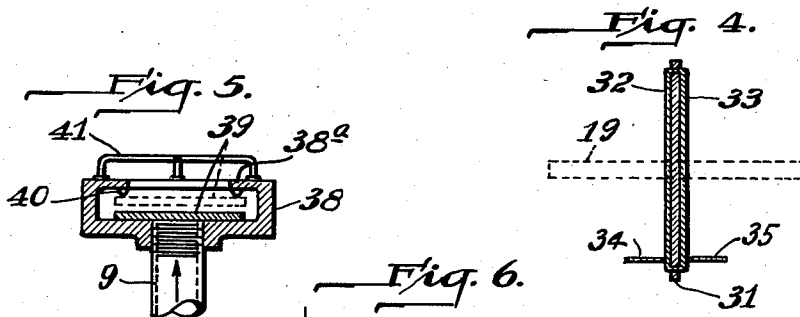
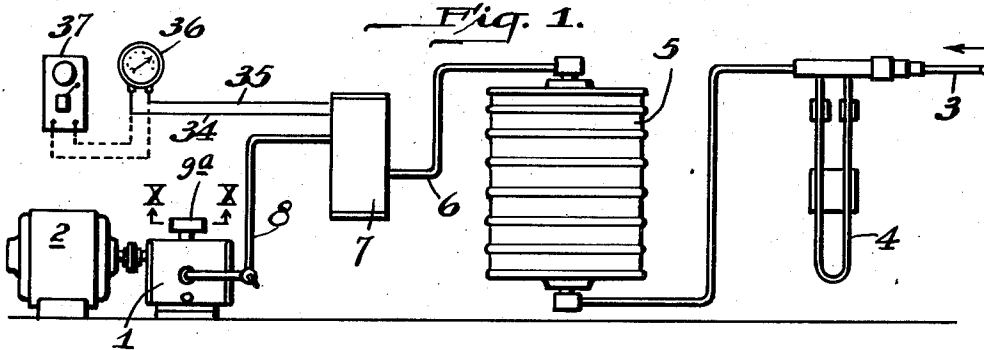
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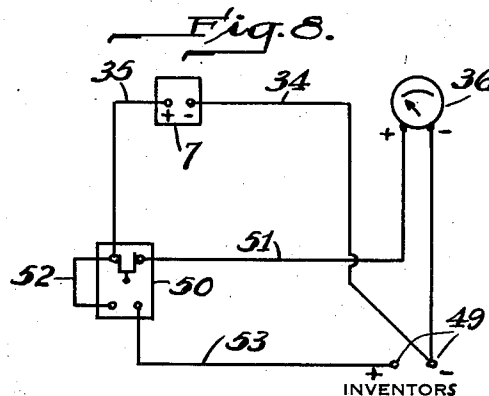
METHOD OF AND APPARATUS FOR QUANTITATIVE GAS ANALYSIS

Filed Sept. 14, 1931

2 Sheets-Sheet 1



WITNESSES
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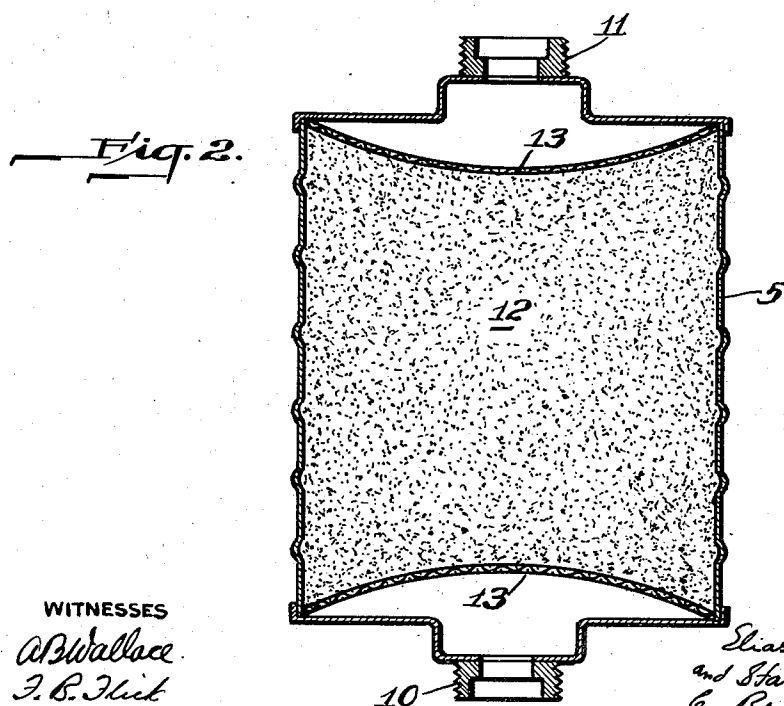
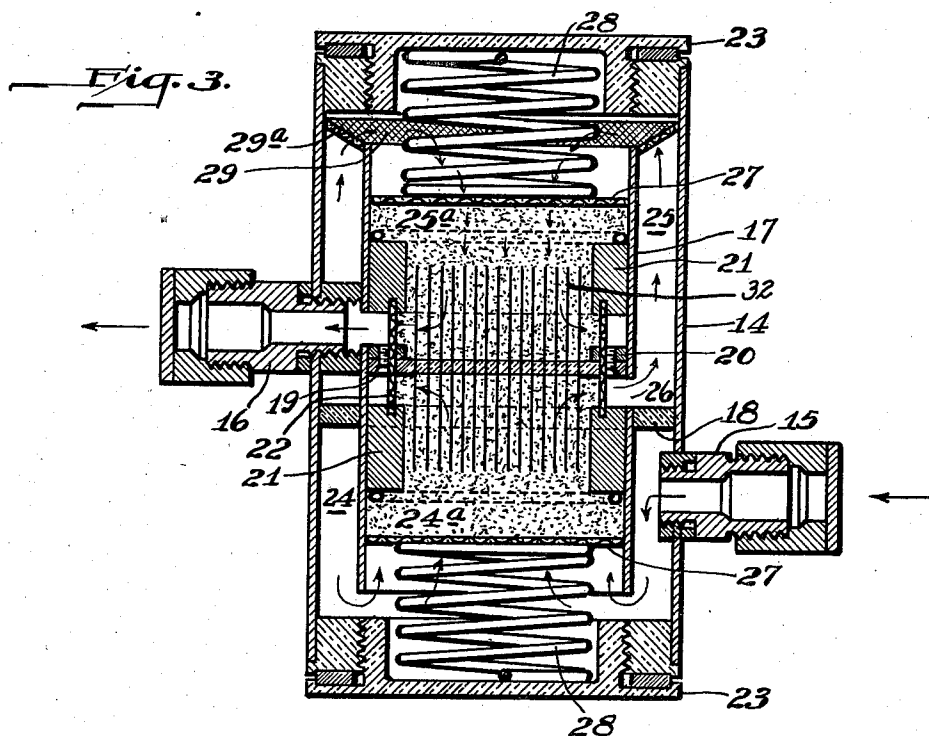
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WITNESSES

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UNITED STATES PATENT OFFICE

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METHOD OF AND APPARATUS FOR
QUANTITATIVE GAS ANALYSIS

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18 Claims. (Cl. 23—238)

This invention relates to the quantitative analysis of gases by means of catalysts, and especially to the determination of carbon monoxide in air, particularly of air vitiated by exhaust gases from internal combustion engines.

A particular application of apparatus for quantitative analysis of constituents of gases is in the determination of carbon monoxide in air. This is important, for instance, where air may be contaminated by exhaust gases from internal combustion engines, as in passenger busses, where the air may become vitiated by leakage of exhaust gas into the bus, especially in the case of bus compartments heated by exhaust from the engine. Also, persons carried by aircraft may be exposed to dangerous concentration of carbon monoxide resulting from the exhaust gases of their engines.

There have been available apparatus for quantitatively measuring carbon monoxide and other combustible constituents of gases, which make use of catalysts. The heat change due to catalytic action is used as a quantitative measure of the proportion of constituent, and it is measured by means of one or more thermocouples associated with the catalyst as a hot junction. The cold junction has been composed of any material which does not cause heat change when in contact with the gas, pumice being the material usually used. Apart from the limitation just mentioned, no attention has been paid to the cold junction material. In such apparatus the direction of gas flow has usually been straight through a body of pumice or the like (cold junction) in contact with the catalyst bed.

Apparatus of catalytic type available heretofore has been satisfactory for some purposes, but experience has shown that under some conditions it does not function properly. Thus it is not suitable for use in determining carbon monoxide in airplane cabins or cockpits, etc., where operation of the craft subjects it to rapid changes of temperature and atmospheric pressure as the craft changes altitude rapidly. Under these and other circumstances prior apparatus functions inaccurately, either indicating the presence of carbon monoxide when it is not actually present, or in amounts different from that actually present. Such inaccuracy may entail serious results. Nor has there been available a portable apparatus for determining such constituents with high accuracy over wide ranges of concentration, or under widely varying operating conditions.

It is among the objects of this invention to

provide an improved method of and apparatus for the quantitative determination of a combustible constituent of a gas by means of catalysts, which are simple, readily used, do not require complicated apparatus, are adapted for highly accurate determination of very small concentrations, as well as large amounts, of such constituents, and are adapted to provide accurate results irrespective of and under widely varying operating conditions.

A particular object is to provide a method and apparatus of the type described which are especially adapted for use in determining the presence and extent of carbon monoxide vitiation of air by internal combustion exhaust gases, especially for portable use in aircraft.

The invention is illustrated in the accompanying drawings, which represent its preferred embodiment, and in which Fig. 1 is a diagrammatic representation of the apparatus; Figs. 2 and 3 longitudinal sections through elements of the apparatus shown in Fig. 1; Fig. 4 a fragmentary section of a portion of the apparatus shown in Fig. 3, taken on line III—III; Fig. 5 a fragmentary section taken on line V—V, Fig. 1; Fig. 6 a graph representative of the relation between the potential developed in the apparatus and the rate of gas flow through it; and Figs. 7 and 8 wiring diagrams of the apparatus shown in Fig. 1.

The temperature rise due to the catalytic combustion of such constituents, especially when in air, is generally quite small; so that its inaccurate measurement may cause substantial inaccuracy in the result. We have discovered that the inability of these apparatus to function satisfactorily as previously constructed is due to the fact that the true temperature changes in the catalyst bed cannot always be measured exactly. For instance, they cannot accurately function under varying operating conditions, such as experienced by aircraft. We have found this to be due to the fact that the hot and cold junctions of the catalyst do not change in temperature at the same rate when the apparatus is exposed to a change in temperature. Thus, the catalyst, constituting the hot junction of the thermocouple, changes temperature at a rate different from that of the pumice or other material used as the cold junction. This difference in rate of heat transfer between the atmosphere on the one hand and the hot and cold junctions on the other as the apparatus is subjected to changing temperatures causes the thermocouple to indicate a false result, since the instrument has been calibrated for constant relative relation of the cold and hot

junctions. For instance, if an airplane equipped with such apparatus rises from the earth to a high altitude, and the cold junction material loses heat more rapidly than the catalyst material, the thermocouple will not indicate the true temperature in the catalyst, and quantitative measurement of carbon monoxide actually present is not possible.

This factor has not previously been recognized, any indifferent cold junction material being used on apparatus in which the gas passes directly through catalyst and cold junction beds a further source of inaccuracy has been due to transfer of heat from the catalyst to the cold junction material. The effect of this is, of course, to cool the former and heat the latter, rendering the thermocouple readings inaccurate. This is especially serious because of the low temperature gradient between the two junctions, which may not exceed 1° C. with some concentrations of CO.

We have discovered further, and it is upon this that our invention is predicated in part, that these disadvantages may be overcome, and highly accurate results assured under widely varying operating conditions, by providing hot and cold junctions of substantially the same thermal properties. In accordance with the invention, therefore, the hot and cold junctions change temperature at the same rate when the apparatus is exposed to changing temperature, and this maintains correct relationship between the two junctions. This provides for continuous accurate measurement of the temperature change caused by the action of the catalyst upon a combustible constituent in the gas passed through it, irrespective of changing external conditions.

We have discovered also that the sensitivity and accuracy of the apparatus may be further improved by minimizing heat transfer between the hot and cold junction materials. This is accomplished in accordance with this invention by arranging the hot and cold junction materials as separate elements, and preferably also by interrupting direct flow between the two beds, most suitably by passing the gas through the elements in opposite directions, in contrast to the straight through flow of prior apparatus.

Catalyst and cold junction beds having the same thermal properties may be provided in various ways, but the most satisfactory results are obtained by using as the cold junction a bed of the catalyst material in an inactive or spent condition. In this manner the hot and cold junctions of the thermocouple are embedded in the same material, the former being catalytically active, and the latter catalytically inactive, to the constituent to be determined. Thus they are of the same thermal conductivity, and by making the beds of substantially the same size, they have the same heat capacity.

The rate of heat transfer is governed in part by the conductivity of a material, so that this factor appears to be of importance here. However, the heat capacity appears to play a part also. In the absence of definite information as to which, if either, of these properties is controlling, the term "thermal properties" is used herein for brevity of reference.

The invention provides also an apparatus for the practice of the method just described, and in addition this apparatus embodies other features presently to be described, which constitute an improvement upon prior apparatus of this type. The method may be understood further, and the apparatus described, with reference to the accom-

panying drawings, which represent the preferred embodiment of the invention.

Having reference now to the drawings a pump 1 operated by a motor 2 draws gas to be tested into a sampling line 3, provided with a manometer 4 for use in measuring the rate of flow, and connected to a drier 5. The exhaust side of the drier is connected by a pipe 6 to the catalyst cell 7, from which it flows through a line 8 to pump 1 which exhausts the gas to the atmosphere through an exit line 9 and check valve 9a.

Drier 5 preferably comprises an ordinary gas mask canister, Fig. 2, preferably of relatively large capacity, having inlet and outlet couplings 10 and 11, and containing a granular drying agent 12, such as calcium chloride, or calcium chloride and activated alumina, held between wire screens 13 in the manner customary in such devices. Its purpose is to prevent poisoning of the catalyst by moisture.

In accordance with the invention the gas is passed through a catalyst cell which contains separate beds of catalyst and cold junction material of substantially the same thermal properties, and in which there are embedded respectively the hot and cold junctions of a thermocouple. The beds are separated to prevent heat transfer from the catalyst to the cold junction bed, most suitably by so constructing the cell as to cause the gas leaving the cold junction bed to change its direction of flow and pass through the catalyst bed in the opposite direction.

The embodiment of cell 7 shown comprises a tubular casing 14, Fig. 3, provided with inlet and outlet coupling members 15 and 16 connected respectively to lines 6 and 8. Disposed within casing 14 is a tube 17 spaced from the shell by a ring 18 of any suitable material. Tube 17 is divided transversely into two compartments by means of a disk 19, preferably of heat insulating character, held in position by screws fastened to a shoulder 20 interiorly of the tube. On opposite sides of disk 19 there are connected to the tube rings 21 which hold a tubular screen member 22 in fixed position spaced from the interior wall of the tube. The ends of the casing are closed by caps 23 threaded into the casing, as shown.

In this construction the cell contains annular passages 24 and 25 between the casing and tube, which are separated by ring 18. Passage 24 opens into inlet coupling 15, and into the adjacent chamber 24a of the tube. Opposite screen 22 at the base of chamber 24a is a perforation in the wall of the tube, connecting the chamber with passage 25, and this latter opens into the chamber 25a formed in tube 17 by disc 19. Exhaust coupling 16 is connected to chamber 25a, as shown.

A deep bed of inactive, or spent, catalyst is disposed in chamber 24a, to act as cold junction material, and chamber 25a is filled with the same material in a catalytically active condition. The beds contain approximately the same amount of material, so as to be of like thermal properties. The catalyst preferably comprises hopcalite where CO is to be determined, and for the cold junction spent hopcalite may be used, or the activity of hopcalite may be destroyed for this purpose.

The beds of catalyst and cold junction material are maintained in position by means of screens 27 urged inwardly by springs 28 acting between the screens and caps 23. Dust, oil and the like may be removed from the gas before it

reaches the catalyst by a filter 29 of gauze held in place by a screen 29a, as shown.

In order to determine the temperature change caused by the action of the catalyst upon a combustible constituent of the gas, such as CO, a thermocouple is mounted in the cell with its cold junction in the inactive material in chamber 24a, and its hot junction in the catalyst. Dependent upon the accuracy required, one or more thermocouples may be used, the sensitivity being increased by the use of a thermocouple unit of a plurality of couples connected in series. Such an arrangement is shown in Figs. 3 and 4, in which a plate 31, of mica or the like sealed in disc 19, through which it passes, acts as a support for a plurality of thermocouples connected in series and having their opposite ends embedded as described.

In the preferred embodiment, the thermocouples comprise Chromel wires 32 and Constantan wires 33, Fig. 4. By the use of a thermocouple of this type comprising fifty-five such couples in series, and using hopcalite as the catalyst, the apparatus is capable of determining up to about 0.15 percent of CO with an accuracy of 0.01 percent of CO. By appropriately increasing or decreasing the number of thermocouples, the sensitivity and range of the apparatus may be changed according to need.

The construction shown and described provides for flow of gas through the cold junction and thence to the catalyst in a counterdirection, as indicated by the arrows in Fig. 3. As there shown, dried gas from drier 5 enters through coupling 15 into annular space 24, and flows through the inactive bed 24a, whence it passes out through screen 22 and opening 26 into annular space 25 on the opposite side of ring 18. The gas then flows through catalyst bed 25a, where the CO is oxidized, and it leaves through outlet coupling 16.

For use as a portable instrument, or in a permanent installation, such as in a vehicular tunnel, or on an aircraft, the ends of the thermocouples are connected to leads 34 and 35 connected to a galvanometer 36 having its scale graduated to read directly in percentage of CO. If desired, the thermocouple may be connected to a signalling device, such as a bell 37, or to a graphic recorder, of which several types are available.

Drier 5 prevents access of moisture to the catalyst from the inlet end of the apparatus, and for the same purpose pump 1 is provided with an automatic check valve which closes the exhaust line when the apparatus is not in use. One form of valve is shown in Fig. 5. It comprises a hollow housing 38 connected to exhaust pipe 9, and within the housing there is a light weight disc 39. When the pump is operating, disc 39 is forced upwardly against studs 40 formed on inwardly extending flanges 38a, permitting the gas to be exhausted to the atmosphere. When the pump ceases to operate the disc falls and closes the exhaust line. Guard members 41 prevent external injury to disc 39.

The accuracy and sensitivity of the determinations are also dependent upon the rate of flow of gas through the apparatus, and this may be influenced by variation in atmospheric pressure. An instance of this is in the testing of air in an aircraft cabin, cockpit or the like space, where the craft changes altitude rapidly, with consequent sudden change in pressure and gas flow. We have found that by regulating the rate of flow within certain limits the effect of such changes in pressure may be minimized or elimi-

nated. Having reference to Fig. 6, the variation of thermocouple E. M. F. with the rate of flow of gas through the catalyst was plotted for a given concentration of CO in air. With low rates of flow the E. M. F. increases rapidly as the rate of flow increases. Under such conditions changes in altitude would seriously affect the results. However, our tests demonstrated, as Fig. 6 shows, that within certain ranges of flow rate its variation does not exert any substantial change in potential recorded by the thermocouple. We have found that, in general, rates of flow from about 3.5 to 5 liters per minute satisfactorily overcome the difficulty referred to, a rate of 4½ liters per minute being preferred.

In order to insure constancy of flow rate under varying conditions pump 1 preferably comprises a rotary positive pressure blower type. For this use the blower duty is not heavy, so that it may be operated by means of a motor run from an ordinary six volt storage cell, thus making it possible to provide a portable type apparatus, since most automotive vehicles and aircraft use such batteries. Being used as an exhaust pump, the inlet of the blower is connected to the outlet of cell 7. Regulation of the flow rate within the limits given, to maintain substantial constancy of flow, is provided for by means of the manometer 4, its scale being graduated appropriately.

In the use of this apparatus at high altitudes, i. e., at low temperatures, it has been found that the blower starts sluggishly, owing to chilling of the grease. This may be overcome by providing the blower with a heating element. The wiring diagram for the motor and heating element are shown in Fig. 7. Current is supplied to motor 2 from a current source 42 by means of a lead 43, and a lead 44 connected to one pole of a double-throw single-pole switch 45, the other pole being connected by a lead 46 to the other side of the motor. In order to control the heating circuit, lead 44 is also connected to one pole of another switch 46 which controls a heating element 47 arranged to heat the grease in pump 1, this circuit returning to the current source by a lead 48.

The indicating circuit is shown in Fig. 8, in which thermocouple lead 34 from cell 7 is connected to galvanometer 36 through one terminal of jack 49. The other lead, 35, is connected to one side of a double-pole double-throw switch 50 connected by a lead 51 to the other side of the galvanometer. A shunt 52 connects lead 35 also to one pole on the opposite side of the switch, the other pole being connected by a lead 53 to the other terminal of the jack.

Where the apparatus is embodied in a portable instrument galvanometer 36 forms a permanent part thereof. Jack 49, however, provides for connecting the cell to a recorder, alarm signal, or the like, according to need.

In the use of the apparatus gas to be analyzed is drawn continuously into sampling line 3, and passes through drier 5 to cell 7, where the combustible constituent which is to be determined is burned by the catalyst. The rate of flow is regulated readily by observation of manometer 4 and regulation of the pump operation accordingly. Changes in the operating conditions, such as sudden variations in temperature, are without effect upon the results obtained, because upon the occurrence of a change in temperature both the hot and cold junctions absorb or give off heat, as the case may be, at substantially the same rate, so that their relative condition remains constant and the accuracy of the reading is not affected.

Also, the elimination of direct flow through and separation of the junction beds insures the retention of heat of combustion in the hot junction bed, providing for accurate results.

Moreover, because the potential reading is independent of change in rate of flow within the optimum range, this factor does not affect the results. Thus, the invention renders it possible to obtain highly accurate determinations of a constituent under widely varying and rapidly changing operating conditions.

The invention has particular value in connection with carbon monoxide control in aircraft, although it may be used equally with automotive vehicles, vehicular tunnels, and in other locations. Because the apparatus is simple, and portable, it may be used readily with airplanes to determine the presence of CO, in its cabin, etc., as a basis for designing, or redesigning, such craft to avoid CO contamination of the air which reaches its passengers. Likewise, in passenger busses, large passenger airplanes, dirigibles, or the like, it may be mounted in fixed position and operated continuously, the occurrence in the air of a fixed minimum percentage of CO actuating alarm signal 37.

According to the provisions of the patent statutes, we have explained the principle and mode of operation of our invention and have illustrated and described what we now consider to represent its best embodiment. However, we desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.

We claim:

1. In a method of quantitatively determining a combustible constituent of a gas, the steps comprising passing said gas successively through separate bodies of material thermally insulated from each other and having substantially the same thermal properties, one of said bodies being catalytically inactive and the other catalytically active to said constituent, and measuring the temperature change due to catalytic action by thermocouple having its hot and cold junction associated respectively in said active and inactive bodies.

2. In a method of quantitatively determining a combustible constituent of a gas, the steps comprising passing said gas through a body of material catalytically inactive to said constituent, and then passing it through a body of oxidizing catalyst separate and thermally insulated from said inactive material, said bodies having substantially the same thermal properties, and measuring the temperature change by a thermocouple having its hot junction in contact with said catalyst material, and its cold junction in contact with said inactive material.

3. A continuous method of determining a constituent of a gas, comprising drying the gas and passing it continuously through a body of material catalytically inactive to said constituent, and then passing it in countercurrent direction through a separate bed of the same material in a condition to catalytically cause a change of said constituent, said beds being of substantially the same thermal properties and being thermally insulated from each other, and measuring the temperature change in the catalytically active bed by a plurality of thermocouples connected in series and having their hot and cold junctions embedded respectively in the catalytically active and inactive beds.

4. A method of quantitatively determining a

combustible constituent in a gas, comprising passing the gas successively through separate beds of an oxidizing catalyst respectively in catalytically inactive and catalytically active condition with respect to said combustible constituent, said beds being thermally insulated from each other and of substantially the same thermal properties, measuring the temperature change in said active material by a thermocouple having its hot and cold junctions embedded respectively in said active and inactive material, and regulating the rate of flow to render the temperature effect in the active bed independent of changes in the pressure of the gas.

5. A method of quantitatively determining a combustible constituent of a gas, comprising passing said gas successively through separate bodies of an oxidizing catalyst respectively in catalytically inactive and catalytically active condition, said bodies being thermally insulated from each other and having substantially the same thermal properties, measuring the temperature change in said active body by a plurality of thermocouples having their hot and cold junctions associated respectively in said active and inactive bodies, and regulating the rate of flow within the range in which the temperature effect in said active body is independent of changes in pressure of the gas.

6. Apparatus for quantitatively determining a constituent of a gas comprising a container provided with a gas inlet and a gas outlet, separate bodies of the same material in catalytically inactive and catalytically active condition with respect to said constituent arranged in the path of the gas in the container adjacent said gas inlet and outlet respectively for successive passage of the gas therethrough, said bodies being of substantially like thermal properties, a partition between said bodies separating and heat insulating them from each other, means for passing the gas from the inactive to the active body, and means for measuring the temperature in said active bed including a plurality of thermocouples in series having their hot and cold junctions embedded respectively in said active and inactive material.

7. Apparatus for quantitatively determining a constituent of a gas comprising a container provided with a gas inlet and a gas outlet, a catalytically inactive material arranged in the path of gas adjacent said inlet, a separate body of catalyst active with respect to said constituent arranged in the path of the gas adjacent said outlet, a partition between said bodies separating and heat insulating them from each other, means for passing gas from said inactive material through said catalyst in countercurrent direction, and means for measuring the temperature in the catalyst bed including a thermocouple having its hot and cold junctions embedded respectively in said catalyst and inactive material, said bodies being of substantially like thermal properties.

8. Apparatus for quantitatively determining a constituent of a gas comprising a container provided with a gas inlet and a gas outlet, a body of inactive catalytic material arranged in the path of gas adjacent said inlet, a separate body of the same material in catalytically active condition with respect to said constituent arranged in the path of the gas adjacent said outlet, said bodies being of substantially like thermal properties, a partition separating and heat insulating said inactive and active catalyst bodies from each other, means for passing gas from said inactive material through said active material in countercurrent direction, and means for measuring the

temperature in the catalyst bed including a plurality of thermocouples in series having their hot and cold junctions embedded respectively in said active catalyst and inactive material.

9. Apparatus for continuously and quantitatively determining a constituent of a gas, comprising a container provided with a gas inlet and a gas outlet, means for drying gas passed to said container, a body of inactive catalyst in the path of gas adjacent said inlet, a body of the same material in catalytically active condition with respect to said constituent in the path of gas adjacent said inlet, said bodies being of substantially the same thermal properties, a partition separating and heat insulating said bodies from each other, means for passing the gas in counter-current directions through said bodies, means for measuring the temperature in said catalyst body comprising a thermocouple having its hot and cold junctions embedded respectively in said active and inactive material, and a positive pressure blower associated with said outlet to draw gas through the container at a substantially uniform rate of flow.

10. In a method of quantitatively determining a combustible constituent of a gas, the steps comprising passing a sample of said gas successively through separate bodies of (1) material catalytically inactive with respect to said combustible constituent and (2) an oxidizing catalyst, said bodies being thermally insulated from each other and having substantially the same thermal capacity, and measuring the temperature change in said active body due to its catalytic action on said constituent by a plurality of thermocouples connected in series and having their hot and cold junctions associated respectively with said active and inactive bodies.

11. Apparatus for quantitatively determining a constituent of a gas comprising a container provided with a gas inlet and a gas outlet, separate beds of material respectively in catalytically inactive and catalytically active condition with respect to said constituent and of substantially identical thermal properties arranged in the path of the gas in the container adjacent said gas inlet and outlet respectively for successive passage of the gas therethrough, a partition separating and heat insulating said beds from each other, means for passing the gas from said inactive to said active body, and means for measuring the temperature in the active bed including a thermocouple having its hot and cold junctions embedded respectively in said active and inactive beds.

12. Apparatus for quantitatively determining a constituent of a gas comprising a container through which said gas is passed, separate beds of material catalytically inactive and catalytically active with respect to said constituent and of substantially identical thermal properties arranged respectively in the path of gas through the container for successive passage of the gas therethrough, partition means separating and heat insulating said beds from each other, means for measuring the temperature change in the active bed including a thermocouple having its hot and cold junctions embedded respectively in said active and inactive beds, and a rotary positive blower connected to said container to draw said gas therethrough at a substantially uniform rate.

13. In a method of quantitatively determining a combustible constituent of a gas, the steps comprising passing said gas through a body of material catalytically inactive to said constituent,

then passing the gas in the opposite direction through a separate body of active oxidizing catalyst thermally insulated from said inactive material, said bodies being of substantially the same thermal properties, and measuring the temperature change in the catalytically active body by a thermocouple having its cold and hot junctions embedded respectively in said inactive and catalyst bodies.

14. In a method of quantitatively determining a combustible constituent of a gas, the steps comprising passing said gas first through a body of oxidizing catalyst in inactive condition, then passing the gas in the opposite direction through a separate catalytically active body of the catalyst thermally insulated from said inactive material, said bodies being of substantially the same thermal properties, and measuring the temperature change in the catalytically active body by a plurality of thermocouples having their cold and hot junctions embedded respectively in said inactive and active catalyst bodies.

15. In a method of quantitatively determining carbon monoxide in air, the steps comprising passing the air through a bed of inactive oxidizing catalyst, then passing the same air in the opposite direction through a separate body of said catalyst in active condition and thermally insulated from said inactive material, said bodies being of substantially the same thermal properties, and measuring the temperature change in the catalytically active body by a plurality of thermocouples having their cold and hot junctions embedded respectively in said inactive and catalyst bodies.

16. A continuous method of quantitatively determining a constituent of a gas, the steps comprising continuously passing said gas through a body of material catalytically inactive to said constituent, then passing the same gas in the opposite direction through a separate body of the same material in a condition to catalytically cause a change of said constituent, said bodies being thermally insulated from each other and being of substantially the same thermal properties, and measuring the temperature change in the catalytically active body by a thermocouple having its cold and hot junctions embedded respectively in said inactive and catalyst bodies.

17. A method of quantitatively determining a combustible constituent in mixture with air, comprising passing the air through a body of oxidizing catalyst in inactive condition, then passing the same air in the opposite direction through a separate body of the same material in catalytically active condition with respect to said combustible constituent, said bodies being thermally insulated from each other and having substantially the same thermal properties, measuring the temperature change due to catalytic action by a plurality of thermocouples connected in series and having their hot and cold junctions associated respectively with said active and inactive bodies, and regulating the rate of flow within the range in which the temperature effect in said active body is independent of changes in atmospheric pressure.

18. A method of quantitatively determining carbon monoxide in air, comprising drying the air and passing it through a body of oxidizing catalyst in inactive condition, then passing the same air in the opposite direction through a separate body of said catalyst in catalytically active condition with respect to carbon monoxide, said

bodies being thermally insulated from each other and having substantially the same thermal properties, measuring the temperature change due to catalytic action by a plurality of thermocouples connected in series and having their hot and cold junctions associated respectively with said

active and inactive bodies, and regulating the rate of flow within the range in which the temperature change in said active body is independent of changes in atmospheric pressure.

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