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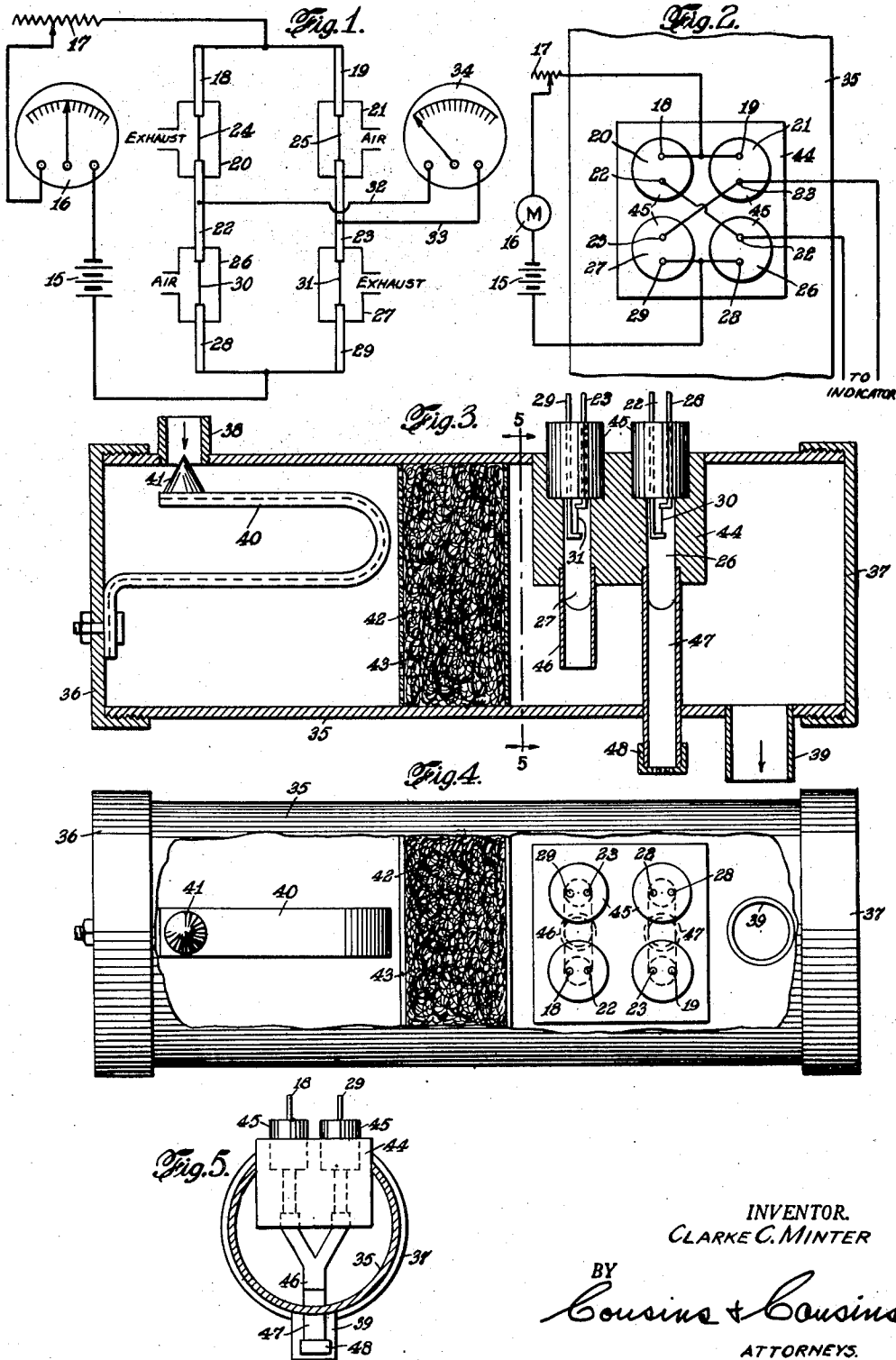
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EXHAUST GAS ANALYZER

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Fig. 6.

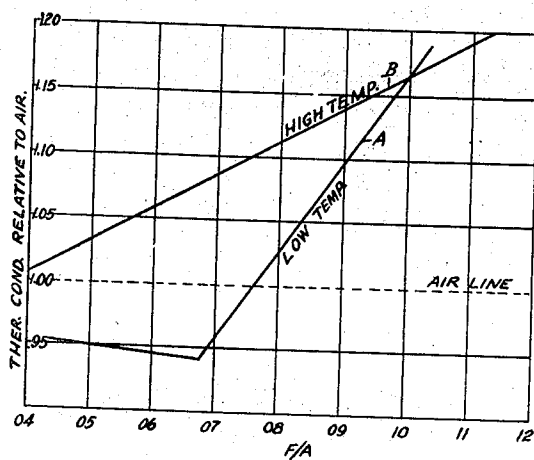


Fig. 7.

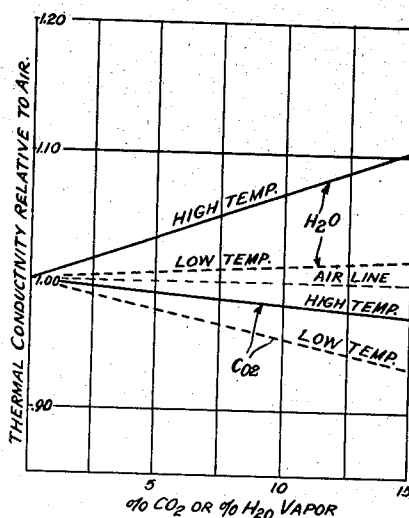


Fig. 8.

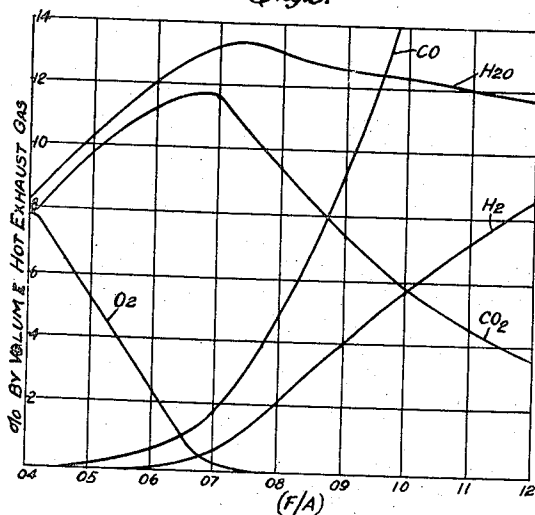


Fig. 9.

FUEL-AIR Ratio (%)	% CO ₂	% CO	% H ₂	% H ₂ O	% O ₂
.125	3.0	16.4	9.00	11.6	
.100	5.8	14.8	5.6	12.25	
.0833	8.6	6.4	2.9	12.85	
.0714	11.2	2.2	.79	13.3	
.0625	11.4	.66	.26	12.4	2.4
.0555	10.4	.26	.10	11.25	4.0
.050	9.7	0	0	10.25	5.3
.0416	8.1	0	0	8.6	7.7

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EXHAUST GAS ANALYZER

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8 Claims. (Cl. 73-27)

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This invention relates to an improved apparatus, of the type shown in U. S. Patents Nos. 2,025,121 and 2,251,751, for analyzing the exhaust gas from internal combustion engines.

With the apparatus disclosed in said patents, and until quite recently, lean gaseous mixtures were not used in gasoline engines to any appreciable extent, but recently an increase in the volatility of gasolines, plus the improved mixing of fuel and air in the carburetor, and the induction system now used, such use has been made possible.

For instance, it is pointed out in Patent 2,025,121, dated December 24, 1935, that the apparatus described therein was limited in usefulness, in that it could be used with confidence only for mixtures in which the gasoline content was in excess of the air.

Therefore, the disclosure, in this and earlier patents, is not helpful to indicate the most suitable ratios of gas and air for the lean mixtures in present use, particularly with reference to aircraft engines and those of the Diesel type.

It is, by reason of this condition, an object of the present invention to provide an improved exhaust analyzer, in which mixtures containing an excess of air can be determined with the same degree of accuracy as the mixture-ratios which contain an excess of fuel.

A further feature is in the provision of means for raising the operative temperature of the exhaust analyzing apparatus to a point wherein the water vapor of combustion does not condense but passes through the apparatus, acting as a constituent of the exhaust gas, influencing its thermal conductivity and its variation with the mixture-ratio, such transalency being mainly accomplished by the inherent heat of the exhaust.

These and other purposes, which will later become apparent, are attained by the novel construction, combination and arrangement of parts, hereinafter described and illustrated in the annexed drawings, constituting a graphical component of this disclosure, and in which:

Figure 1 is a diagram showing the air, exhaust and electrical connections relating to the present invention.

Figure 2 is a schematic view of the wiring.

Figure 3 is a longitudinal sectional view taken through the center of an embodiment of the invention, showing its connections.

Figure 4 is a plan view, partially broken away to show the interior construction.

Figure 5 is a transverse sectional view, looking on line 5-5 of Figure 3, drawn to a smaller scale.

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Figure 6 is a chart showing the thermal conductivity of exhaust gas relative to air.

Figure 7 is a similar chart showing the thermal conductivity relative to mixtures of CO₂ in air.

Figure 8 is a graph indicative of the volume percentages of the constituents of exhaust gas for a definite fuel charge.

Figure 9 is a charted list of the elements and percentages indicated in Figure 8.

Exhaust gas contains CO, CO₂, O₂, N₂, H₂ and H₂O, the percentage varying with the mixture ratio.

As the invention is based on physical properties not clearly obvious, it is considered desirable to explain them in some detail in order that they be understood.

In Figure 8 it is shown graphically how the percentages of the various constituents of exhaust gas vary with the mixture-ratio.

The data is for a fuel containing 85% carbon and 15% hydrogen, the analysis being made at a temperature sufficiently high to prevent the condensation of water-vapor.

It can be seen that the H₂-% and the CO-% diminish, as the mixture is made leaner, finally disappearing altogether at a point slightly beyond the theoretical point of complete combustion, approximately .068.

The CO₂-% goes through a maximum in a mixture slightly richer than complete combustion, while H₂O goes through a maximum approximately at the mixture giving maximum power.

O₂ does not appear in any appreciable quantity until the theoretical, complete combustion point has been passed.

The curves in Figure 6 show the thermal conductivity of exhaust gas relative to air for various ratios.

Curve A, in Figure 6, shows the variation of the relative thermal conductivity of exhaust gas, as obtained in analyzers which operate at a low temperature with condensation of the water of combustion.

Curve B shows the relative thermal conductivity of the exhaust gas as obtained in the present analyzer, which operates at such a high temperature that the water of combustion does not condense, but passes through the apparatus as a vapor, contributing to the thermal conductivity of the exhaust gas.

In curve A it can be seen that the thermal conductivity of the exhaust gas from mixture-ratios leaner than .077 is less than that of the air for low temperature analyzers, actually going

through a minimum at a ratio of about .065 and increasing so slowly beyond that point as to be of no practical value as a means of measuring very lean mixtures.

In curve B it can be seen that, at the higher operative temperatures of the present apparatus, the water vapor operates in such manner that the thermal conductivity of the exhaust gas, from the leanest mixture which could be employed to operate an engine, is actually greater than that of air.

This condition, of intensifying the thermal conductivity of the exhaust gas, increases as the mixture strength is increased, as indicated by the chart, and constitutes the basis of this invention.

To further clarify the physical principles of the invention, there is shown in Figure 7 how an increase in operating temperature affects the thermal conductivity relative to air, of two of the constituents of exhaust gas which determinately operate in producing sufficiently great variations in the thermal conductivity of exhaust gas from mixtures containing an excess of air.

The broken lines in Figure 7 show how the thermal conductivity of water-vapor, and of CO₂, vary with concentration in N₂, or air, at the low temperature employed in old type exhaust gas analyzers.

The broken lines in this graph show that, while the thermal conductivity of mixtures containing water-vapor are greater than air, the net conductivity of mixtures containing both CO₂ and water-vapor is less than air, because the difference between air and the CO₂ mixtures is greater than the difference between the water-vapor and air mixtures.

By operating the present analyzer at higher temperatures, the result shown in the continuous curves of Figure 7 is obtained. At the higher temperature the thermal conductivity of the water-vapor mixtures increases relative to air, and coincidentally the thermal conductivity of the CO₂ mixtures increases relative to air.

The result is that the thermal conductivity of mixtures containing both water vapor and CO₂, in the proportions they would have in exhaust gas, produced by combustion of a mixture in which the fuel-air ratio is as low as .04, will have a thermal conductivity greater than that of air, and which will increase progressively as the mixture is made richer.

In the present invention there is a concentration of water-vapor and its variation with mixture ratio to be considered, so that the net conductivity of exhaust gas from mixtures containing an excess of fuel will be greater at the higher temperature of operation, but its rate of variation with fuel-air ratio will not be so great as at low temperature operation.

In mixtures containing an excess of air there is the effect of CO₂ and water-vapor alone to consider, as hydrogen is not present in appreciable quantities.

The effect of variations in the concentration of oxygen in the exhaust in such cases is appreciable, but the controlling influence is the net result of the opposing influences of the CO₂, and the water-vapor.

The novel result obtained by operating an exhaust gas analyzer at higher temperatures is attributable to the much greater temperature co-efficients of the thermal conductivity of water-vapor and CO₂ compared with air.

At 100° centigrade, according to the best available measurements, the temperature co-efficient

of thermal conductivity of air (used as a comparison gas), is given as 0.00260 per degree C.; that of nitrogen, carbon monoxide and hydrogen being approximately the same as for air.

The temperature co-efficient of thermal conductivity for water-vapor, at the same temperature, is given as 0.00456 per degree C., while that for CO₂, under the same conditions, is 0.00565.

From the foregoing it will be seen that as the operating temperature is increased, the thermal conductivities of CO₂ and water-vapor increase much more rapidly than the conductivity of air.

Having enumerated the physical principles of the present invention, its novel features will now be given.

Use is made of the fact that the exhaust gases are available at the engine in a condition of high temperatures; instead of cooling the exhaust to the ambient temperature, with consequent condensation of most of the water-vapor, the exhaust gases are only partially cooled.

This prevents the condensation of the water-vapor in the exhaust, it being delivered to the apparatus at a temperature sufficiently high to obtain the result shown in Figure 6.

Referring now more particularly to the apparatus, in Figure 1 a source of electrical current is designated by the numeral 15, one of its connections passing through a meter 16 to a rheostat 17, thence divided between a pair of heavy metallic conductors 18 and 19 respectively, entering cells 20 and 21.

The cell 20 is open to the engine exhaust, while the cell 21 is open to atmospheric air. A second pair of heavy metallic conductors 22 and 23 enter the cells 20 and 21 and are connected to the conductors 18 and 19 by filaments 24 and 25, constituting two of the elements of a Wheatstone bridge, and are open to the effects of the exhaust and air, respectively.

The heavy conductors 22 and 23 extend respectively into another pair of cells 26 and 27, 26 being open to the air and 27 open to the exhaust, into which also extend heavy conductors 28 and 29, connected within the cells by filaments 30 and 31, forming the other elements of a Wheatstone bridge.

The conductors 28 and 29 are connected at their outer ends to convey return current to its source 15. Leads 32 from the heavy conductor 22, and 33 from conductor 23 are connected to a millivoltmeter indicator 34, provided with a hand and dial for reading the fuel air ratio of the exhaust.

The complete apparatus, as shown best in Figure 3, is composed of a casing 35, preferably tubular, having detachable heads 36 and 37, an inlet 38 directly connected with the engine exhaust, preferably through a long copper tube, and an outlet 39 leading to the atmosphere.

The inlet pipe delivers a portion of the exhaust gas to the inlet 38 of the analyzer at a temperature of 250 to 300 degrees C., and the pipe is sufficiently long that the heat radiation from it lowers the temperature of the exhaust gas, as it leaves the engine, to such degree.

Adjustably secured to the inner side of the casing head 36 is one leg of a U-shaped bimetallic strip 40, its free leg carrying a conical plug 41 adapted to automatically control the passage through the inlet 38 according to the temperature of the strip 40, which is so designed and arranged as to partially close the passage through the exhaust gas inlet 38, should the tempera-

ture of the exhaust exceed a predetermined degree.

Adjacently beyond the bend of the strip is a filter, composed of a body of metallic wool 42, held in to completely fill the central portion of the casing by perforated support plates 43.

Set in the casing, adjacent the opposite side of the filter, is a metallic block 44 extending deeply therein. This block contains the four straight-through circular cells (20, 21, and 26, 27), counterbored at their outer ends to receive insulators 45 in which the leads 18, 22 and 19, 23 are set, and which are connected by the filaments 24, 25 and 30, 31.

The cells 20, 27, adjacent the filter, are connected by short lengths of tubes joined at 46 and open to the interior of the casing 35, to receive the filtered exhaust and conduct it directly to the filaments 24, 31, which are also subjected to heat from the block 44, immersed in the exhaust.

The more remote cells 21, 26 have tubes 47 connected at their bottoms, these tubes being extended through the wall of the casing 35 to the atmosphere, where they are provided with a perforated cap 48.

All the gases, both exhaust and air, which diffuse up the tubes 46 and 47 respectively, are heated by the exhaust before reaching the cells. Thus a uniformly high temperature is obtained in the gases in the cell.

The relatively small current flowing through the several filaments may raise the temperature of the gases in the cells to a certain extent, but such increase is unimportant and not necessary to the result obtained.

It has been found that the mean temperature of the gases in the cells must be in excess of 200° C., in order to obtain satisfactory results in analyzing very lean fuel mixtures. If lower temperatures are employed in the cells, lean mixtures can be analyzed, but not with the same degree of accuracy.

The indicator 34 has a dial having a scale, the numerals of which are to be read at fuel-air ratio or some multiple thereof. The mechanical zero of the pointer is at the extreme left of the scale and can be set by an adjusting button in the usual manner.

Having thus described the invention in considerable detail, so as to be clearly understood by those familiar with the art, what is claimed as new and sought to be secured by Letters Patent of the United States is:

1. An internal combustion engine exhaust gas analyzer, comprising a two part chamber through which the exhaust gas passes, a filter intermediate the parts of said chamber, means in one part operative upon the rise of the temperature beyond a definite degree to control the passage of exhaust gas, a body in the other part of said chamber having a plurality of cells, a Wheatstone bridge element in each of said cells, half of said cells being open to the exhaust gas and the other half open to air at the temperature of the exhaust, and an indicator calibrated in terms of fuel-air ratio actuated by said bridge elements.

2. Apparatus for analyzing internal combustion engine exhaust gas comprising in combination, a source of electric current, a casing through which a portion of the exhaust gas passes, means responsive to the temperature in said casing to automatically regulate the flow of gas therein, a heat conductive body in said casing, a plurality of cells in said body, a Wheatstone bridge ele-

ment connected with the electric current source disposed in each cell, half of said elements being exposed to the hot exhaust gas and the other half to atmospheric air heated to substantially the same temperature as the gas, and an indicator calibrated to show fuel-air ratio controlled by said bridge.

3. Apparatus for analyzing internal combustion engine exhaust gas comprising in combination, a source of electric current, a casing through which a portion of the exhaust gas passes, means responsive to the temperature in said casing for automatically regulating the amount of exhaust gas entering said casing in such manner as to maintain a substantially uniform temperature therein, a filter in said casing, a metallic block in said casing opposite the filter, at least two spaced cells in said block, a Wheatstone bridge filament in each cell connected to the electric current source, half of said filaments being exposed to the hot exhaust gas and the other half to atmospheric air heated to the same temperature as the gas, and an indicator calibrated to show fuel-air ratio controlled by said Wheatstone bridge.

4. An exhaust gas analyzer comprising, in combination, a Wheatstone bridge, a cylindrical chamber having an inlet and an outlet through which gases are passed, a metal block in said chamber having four cells and a sensitive element of the Wheatstone bridge in each cell, two of the cells being in open communication with said chamber and two open to atmosphere, and a bimetallic valve in said chamber adapted to vary the area of the exhaust inlet in accordance with the temperature of the incoming exhaust gases.

5. The method of analyzing internal combustion engine exhaust gas which comprises the steps of leading the hot gas together with its entire water-vapor of combustion at a temperature above 100° C. to a first resistor portion of an electrically energized resistor network, heating atmospheric air to a substantially equal temperature, leading the heated air to a second resistor portion of said network and measuring the resulting variation in voltage across selected points of said first and second resistor portions.

6. The method of analyzing internal combustion engine exhaust gas resulting from a lean fuel-air mixture which comprises the steps of leading the hot gas together with its entire water-vapor of combustion at a temperature of at least 200° C. to a first resistor portion of an electrically energized resistor network, heating atmospheric air by means of the hot exhaust gas to a substantially equal temperature, leading the heated air to a second resistor portion of said network and measuring the resulting variation in voltage across selected points of said first and second resistor portions.

7. An engine exhaust gas analyzer comprising, in combination, a casing having inlet and outlet openings, an electrical resistor network having a plurality of resistors disposed in said casing, means for indicating voltage variations across selected points of said network resulting from the passage of current therein and thermally responsive means disposed in said casing arranged to automatically decrease the rate of flow of exhaust gas into said inlet opening upon an increase in temperature of the exhaust gas.

8. An analyzer as claimed in claim 7 in which a conduit of substantial heat-radiating capacity is provided to lead the exhaust gas into said inlet opening, the heat radiation from said conduit

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serving to substantially lower the temperature of the exhaust gas entering said inlet opening at the decreased flow.

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