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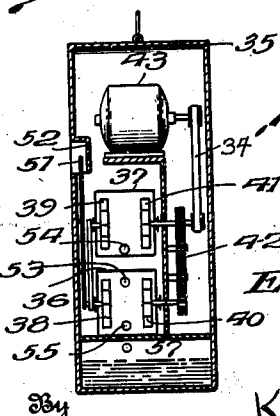
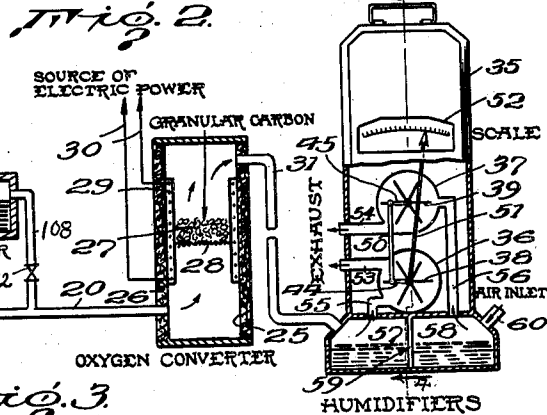
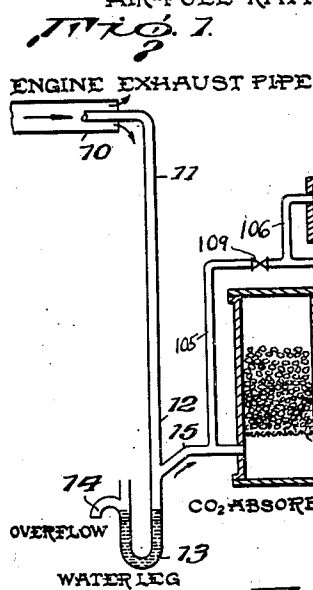
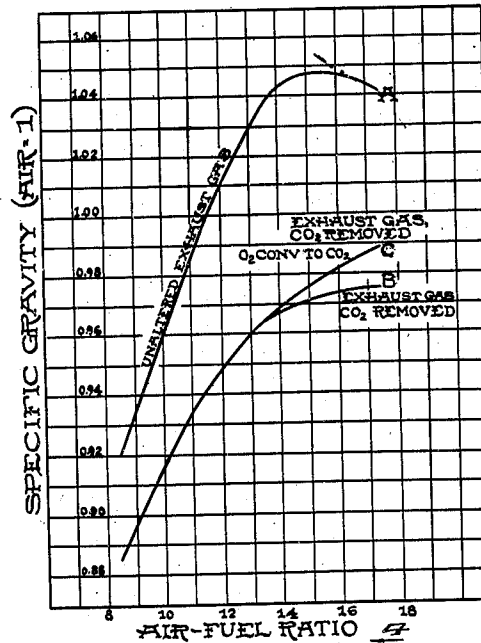
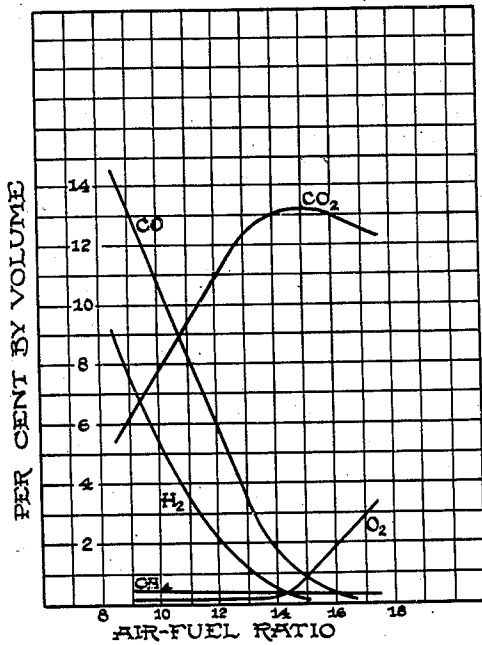
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2,168,236

DETERMINING AIR-FUEL RATIOS IN COMBUSTION

Filed Nov. 24, 1936

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 7.

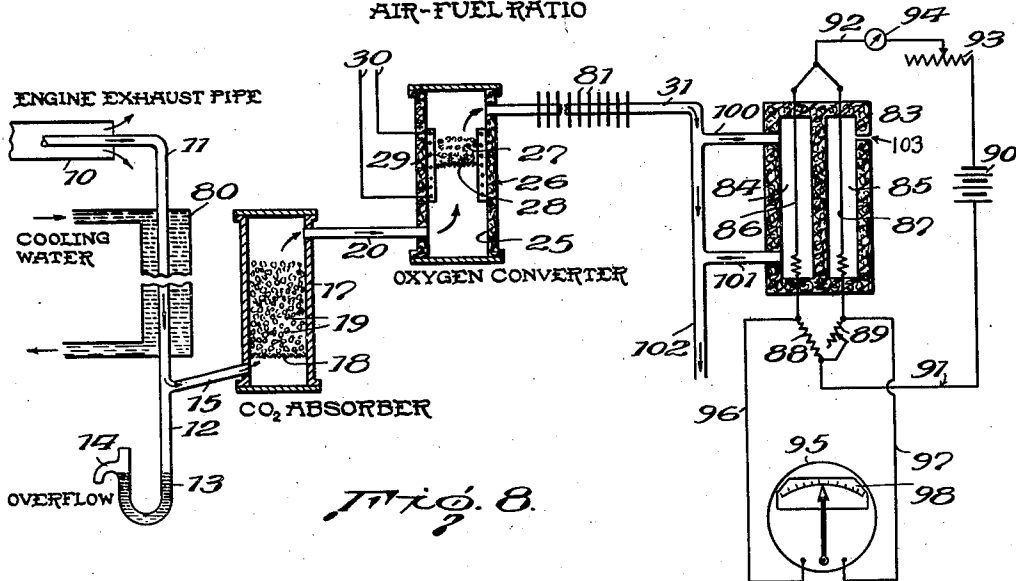
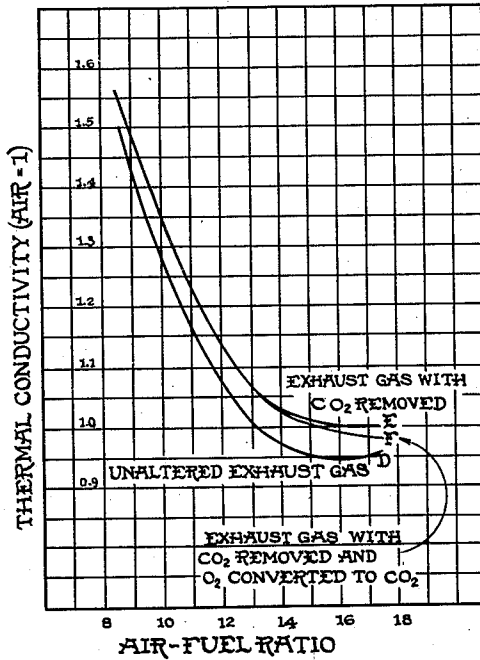


Fig. 8.

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UNITED STATES PATENT OFFICE

2,168,236

DETERMINING AIR-FUEL RATIOS IN COMBUSTION

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Application November 24, 1936, Serial No. 112,598

9 Claims. (Cl. 23—232)

This invention relates to determining air-fuel ratios in combustion and apparatus therefor; and it comprises a method of determining air-fuel ratio for internal combustion engines and the like, said method including the steps of freeing a sample of exhaust gas from the engine, of CO₂, standardizing the moisture content of the gas, and then determining the density or other characteristic property of the gas relative to air, the gas sometimes being also subjected to treatment for conversion of O₂ into a denser gas prior to measurement; and it further comprises apparatus for carrying out such method, including means for removing CO₂ from the gas, means for standardizing the water content of the gas and means for determining density or other physical property of the thus treated gas, means for converting O₂ into a heavier gas advantageously being also provided; all as more fully hereinafter set forth and as claimed.

In studying, adjusting and operating internal combustion engines it is a desideratum to know the air-fuel ratio of the original charge as supplied to the cylinders by the carburetor or other charge-forming device. With such information, adjustments of the charge-forming device can be readily made to secure maximum economy or power under the desired range of working conditions; adjustments that are more accurate and reliable than those made by ordinary trial and error.

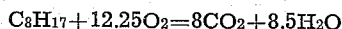
Air-fuel ratios may be defined as the ratios, by weight, of air to the amount of gaseous, vaporized or misted fuel in the charge.

The theoretical air-fuel ratios for complete combustion are well known for a large number of engine fuels:—gasolines, Diesel oils, various gases, alcohols, etc. For example, the theoretical ratio in the case of most gasolines is about 15:1 or 14.5:1. Also, in the case of engines the optimum air-fuel ratios are known for idling, accelerating and various load conditions; such air-fuel ratios being usually somewhat different from theoretical.

It has been established that the proper air-fuel ratios for gasoline automobile engines operating under various working conditions (idling, maximum load, etc.) are substantially the same for a wide range of engine types; engines having all sorts of compression ratios, combustion chamber designs, etc. For example, the best air-fuel ratio for idling is about 12:1 or 12.5:1 for all gasoline engines.

The hydrogen-carbon ratio of average gasoline in use today varies somewhat from the conven-

tional C_nH_{2n} formulation, being empirically about C₈H₁₇. Combustion of a gasoline of this composition theoretically takes place under conditions expressed by the following equation:



This corresponds to a theoretical air-fuel ratio of 15:1 (the proportion of oxygen in air being 21 per cent) and represents ideal combustion, unattainable in practice. Actually, the products of combustion from an engine at this air-fuel ratio contain, in addition to the N₂, CO₂ and H₂O, small amounts of free oxygen, and of unburned fuel in the form of CO, H₂ and CH₄ and other hydrocarbons. With richer mixtures the proportion of CO and H₂ increases substantially while that of CO₂ decreases and the O₂ content drops to a very low figure. With leaner mixtures the proportion of O₂ increases, while that of CO₂ decreases and the combustible content approaches zero.

Determination of air-fuel ratio can be accomplished by quantitative analysis of either the gaseous intake or the exhaust gas. It has been established that measurements of the components of the exhaust gas accurately correspond to air-fuel ratios in the unburned charge. Indeed, measurements on the exhaust are usually more reliable and more convenient than those on the intake, because the intake charge, at locations suitable for withdrawing a sample, is frequently not mixed to complete uniformity, and moreover its pressure is below atmospheric so that pumping is necessary to obtain a sample. Air-fuel ratio determination by conventional gas analyzing procedures is accurate, with skilled operators, but it is a complicated and time-consuming process. It is not only costly but also results in a considerable lag between the time the sample is taken and the time the air-fuel ratio is finally known. Conventional gas analysis procedures are quite impracticable for ordinary routine testing and service station needs.

Attempts have been made to provide simpler and more direct methods and means for determining air-fuel ratio; systems better adapted for use in garages, etc., by unskilled operators. Most of the prior proposals involve determination of the content of combustibles in the exhaust gas, such content being taken as a measure of the air-fuel ratio of the original charge. The combustibles are burnt and the heating effect measured. Such schemes require complicated apparatus, as usually a definite proportion of extra air must be added to the exhaust gas sample to make the

combustibles burn. Moreover, these methods fall down when the original charge is on the lean side of theoretical (excess air) since then the combustible content of the exhaust gas drops substantially to zero.

According to the present invention, I provide methods and means for determining air-fuel ratios which are simple, quick and reliable and are capable of utilization by unskilled operators. Moreover, the systems under the invention work equally well for determining air-fuel ratios on the lean side of the theoretical and on the rich side.

In the principal embodiment of the invention I make use of a gas tester of the type disclosed in König U. S. Patent 1,664,752 (April 3, 1928) which depends on the principle that the amount of energy which a gas, upon being put into motion, can transmit to a movable vane or impulse wheel, depends directly on the density of the gas. In the König apparatus two enclosed chambers are provided, one containing gas to be tested and the other containing a standard gas, usually air. Each chamber contains a rotary impeller, both driven by a single motor, and a similar impulse wheel, spaced from the impeller and not connected to the motor. The two impulse wheels are linked together. Upon rotation of the motor-driven impellers torque is imparted to the two impulse wheels so that they tend to rotate. The impulse wheel in the denser gas (flue gas) receives more torque than that in the less dense gas, and the linkage is such that the differential torque is caused to move a pointer over a scale.

In flue gas measurement, the density of the flue gas is always higher than that of air, and moreover always increases with increasing CO₂ content. Hence the scale of the instrument can be calibrated directly in terms of percentages of CO₂. However, upon applying the instrument to engine exhaust gases, the difficulty arises that the density of the exhaust gases has a maximum value (at the exhaust gas composition about corresponding to the theoretical air-fuel ratio) and falls off with either richer or leaner values. Thus mere measurements of the density of the exhaust gas, by the König apparatus or any other gas density measuring device may not tell whether the mixture is on the lean or the rich side.

According to the invention I utilize the König principle, but I modify the exhaust gas prior to density measurement, in such manner as to have the density of the modified sample increase continuously with increasing air-fuel ratio, thus having a different density corresponding to each different value of the air-fuel ratio. By this expedient, the scale of the indicator can be calibrated directly in terms of air-fuel ratio.

In the method of the present invention, a sample of exhaust gas is collected in a known way and is freed of as much of its water content as can be condensed by cooling the sample to room temperature. The gas is then freed of CO₂, as by passing it over alkali, usually solid caustic potash, etc. This step is sufficient to make the density of the sample a continually increasing quantity, and I can measure its density and thereby determine the air-fuel ratio. However, it is better to add a further step; to convert the oxygen into a heavier gas, which makes the density of the thus modified sample increase more sharply in the leaner region. Accordingly, the sample is passed over a bed of hot carbon under such conditions that the oxygen is converted largely or entirely into CO₂. The density of CO₂ is about

1.5 (air=1), and increases the net density of the sample by conversion of any oxygen therein, into CO₂. The same result can be secured by converting the oxygen into some other denser gas, e. g., SO₂, but conversion to CO₂ is usually more practical.

In the accompanying drawings there are shown, more or less diagrammatically, examples of specific embodiments of the method and apparatus.

Fig. 1 is a chart showing the proportions of components of exhaust gas from a gasoline engine, at various air-fuel ratios,

Fig. 2 is a chart showing the variation of density with air-fuel ratio, for unaltered exhaust gas, and for exhaust gas with certain components removed therefrom,

Fig. 3 is a diagrammatic showing of one form of apparatus organization within the purview of the invention, utilizing a gas density measuring apparatus,

Fig. 4 is a view, partly in elevation and partly in vertical section, of the working parts of the gas density measuring apparatus of Fig. 3,

Figs. 5 and 6 are views of two forms of scales for the measuring apparatus,

Fig. 7 is a chart similar to Fig. 2 but showing variation of thermal conductivity with air-fuel ratio, and

Fig. 8 is a diagrammatic showing of an apparatus organization utilizing a thermal conductivity measuring apparatus.

In the drawings, in which like reference characters indicate like parts, Fig. 1 is a graph showing the proportions of the various components of exhaust gas from gasoline engines, over a range of air-fuel ratios in the intake charge. This graph is taken from data given by D'Alleva & Lovell in the S. A. E. Journal, vol. 38, No. 3, pages 90 to 96 (March 1936). The graph represents average values obtained on several different engines; the values for the several engines, however, not differing much from each other. At about the theoretical air-fuel ratio (15:1) the exhaust gas substantially consists of N₂ and CO₂ with small amounts of CO and O₂. On the lean side the proportion of CO₂ drops, while that of O₂ increases. On the rich side the proportion of CO₂ also drops, while O₂ drops substantially to zero and increasing amounts of CO and free hydrogen (H₂) occur. At all ratios there is a negligible trace of unburned hydrocarbon.

In one embodiment of the invention I make use of density measurements on a sample of exhaust gas. Fig. 2 shows, at A, the variation in specific gravity of exhaust gas, at various air-fuel ratios. The specific gravity rises to a somewhat ill-defined maximum at about the theoretical air-fuel ratio; this being because the proportion of the densest component, CO₂, is highest at this point (see Fig. 1). Specific gravity is less on the lean side and on the rich side of theoretical. Specific gravity measurements of the exhaust gas have the disadvantage of low sensitivity or precision in their relation to air-fuel ratio in the region around the theoretical ratio, which is a region of practical importance; and moreover, specific gravity measurement may be ambiguous, since in general a given specific gravity value corresponds to two air-fuel ratios; one above and one below theoretical. Thus a specific gravity of 1.04 corresponds to two air-fuel ratios; 13.8:1 and 17.5:1 (Fig. 2).

I find that by taking out the CO₂ from the exhaust gas, the specific gravity of the remaining

gas always increases with increasing air-fuel ratio; having no maximum; and that this permits direct specific gravity measurements to be made of the modified sample, which measurements correspond unambiguously to air-fuel ratio. Fig. 2, at B, shows the way in which specific gravity changes with air-fuel ratio, when CO₂ is removed from the exhaust gas. A still further improvement results if the oxygen in the exhaust gas is converted into a heavier gas, such as CO₂. Fig. 2, at C, shows the change of specific gravity with air-fuel ratio, in a sample from which CO₂ has been removed and O₂ converted into CO₂. The function gives a fairly rapid change of specific gravity with air-fuel ratio over the entire working range.

One good way of practicing the invention will be apparent from Fig. 3, which shows one form of apparatus organization adapted for carrying out the invention. As shown, a sample of exhaust gas is taken from an engine exhaust manifold or pipe 10 as by a sampling tube 11, and such moisture as will condense out at room temperature condenses in the lower part 12 of the tube as in a trap 13. Accumulated water overflows at 14. The gas sample is passed from the sampling tube by a tube 15 into a CO₂ absorber. The CO₂ absorber conveniently comprises a container 17 having a screen bottom 18 in which is placed a mass of flaked caustic potash as at 19. The caustic potash takes up CO₂ and in the course of time becomes spent, whereupon it is replaced. The sample, freed of CO₂, is now passed through a tube 20 to means for converting any oxygen in the sample, into CO₂. (If desired the sample can be freed of CO at this point in a CO absorber 16, as described post.) The oxygen converter is shown as comprising a closed container 25, heat insulated as indicated at 26, containing a body of granular carbon 27 supported on a screen 28 and heated by an electrical resistance heating element 29 supplied with current through wires 30. The carbon body is kept shallow, as shown, and under such conditions oxygen in the sample is converted into CO₂. The gas now passes through a tube 31 into the density measuring apparatus.

The measuring apparatus (Figs. 3 to 6) comprises a casing 35, in which are mounted two stationary cylindrical chambers 36 and 37, each containing a vaned impulse wheel 38 and 39, and each containing a vaned impeller 40 and 41. The two impellers are geared together as indicated at 42 and are driven at the same rate but in opposite directions, by a belt 34 and a motor 43. The two impulse wheels are linked together by cranks 44 and 45 and link 50, and the lower wheel has fixed thereto a radial pointer arm 51 moving over a scale 52. The two chambers have gas outlets at 53 and 54 and inlets at 55 and 56.

The base of the instrument is formed as to define two closed compartments 57 and 58, separated from each other by a partition 59 and holding water as shown. The exhaust gas passes into chamber 57 through pipe 31 and there becomes cooled and saturated with moisture. The gas now enters the lower cylindrical chamber 36, and leaves through the outlet 53 therefrom. Air is drawn into the other base chamber 58 from the atmosphere through an inlet 60 and becomes saturated with moisture. It enters the upper cylindrical chamber 37 through the inlet 56 and leaves through exhaust 54. The partition between the two base chambers is made of thin metal so that the air and the gas are in good heat exchange relationship and come to the same temperature.

Upon rotation of the impellers by the motor, the gas in each cylindrical chamber is put in motion and transmits to the impulse wheels a torque dependent upon the density of the gas. The opposed torques produce a differential torque, registered on the scale by the pointer, and proportional to the difference in density between the gas and air. For a more detailed description of this form of gas density measuring device, the acknowledged König patent may be consulted.

In operation, exhaust gas is continuously withdrawn from the engine and passed through the units described. There shows on the scale the air-fuel ratio of the engine. Fig. 5 shows the scale 52, when the oxygen converter is used. Fig. 6 shows the scale 52' when the oxygen converter is not used.

Other means for measuring the density of the gas can be used besides the König instrument shown. The means shown for removing CO₂ and converting oxygen to CO₂ exemplify useful types of such apparatus.

It is sometimes desirable, though not strictly necessary, to remove CO from the exhaust sample. Means for doing this is shown in Fig. 3, as comprising a container 16 holding a body of cuprous chloride solution or other CO absorbent as indicated at 21. Conduit connections 105, 106, 107 and 108, and valves 109, 110, 111 and 112 are provided as shown. Ordinarily the connections are made so as to pass the sample first through the CO₂ absorber, to avoid unduly rapid exhaustion of the cuprous chloride, but it is possible to use the cuprous chloride for absorbing both CO₂ and CO, in which case valves 110 and 111 are closed and valves 109 and 112 are opened. When the CO is removed from the gas sample the scales shown in Figs. 5 and 6 must be somewhat modified but their general character remains the same.

Instead of measuring the density of the gas I can measure other characteristic physical property, for example, thermal conductivity. Here measurements of the thermal conductivity of unaltered exhaust gas suffer from the same disadvantage as described in connection with density measurements. Fig. 7 shows, at D, the variation of thermal conductivity with exhaust gas at different air-fuel ratios. The conductivity reaches a diffuse minimum at a ratio around 16:1 and then increases on either side. By removing CO₂ from the exhaust gas the variation no longer has a minimum; it drops to a substantially constant value as indicated, at E, in Fig. 7. When CO₂ is removed and also oxygen is converted into CO₂ further improvement results. The thermal conductivity has a fairly sharp change with air-fuel ratio over the entire range, as indicated at F in Fig. 7.

Fig. 8 shows apparatus useful for carrying out this embodiment of the invention. The sample is taken from the exhaust pipe, CO₂ is absorbed and oxygen converted to CO₂, in a manner similar to that described in connection with Fig. 3. In this embodiment I sometimes condense out of the exhaust gas more moisture than condenses at room temperature. This is accomplished by circulating cooled water around sampling pipe 11, through a jacket 80 as shown in Fig. 8. In this embodiment it is also advantageous to cool the gas leaving the O₂ converter prior to measurement. This is conveniently done by providing radiation ribs 81 on pipe 31.

The thermal conductivity measuring apparatus comprises a closed casing 83, defining chambers 84 and 85. Chamber 84 contains a platinum wire 86 and chamber 85 a platinum wire 87. These wires

form two sides of a Wheatstone bridge, the other two sides of which are formed by resistances 88 and 89. Current is applied across 86, 87, 88 and 89 by a battery 90 and wires 91 and 92. A variable resistance 93 and milli-ammeter 94 are located in wire 92. A galvanometer type measuring instrument 95 is connected across the bridge in the usual position by wires 96 and 97. This galvanometer carries an air-fuel ratio scale 98.

Exhaust gas enters chamber 84 through inlet 100 and leaves through outlet 101. Excess gas passes to waste through pipe 102. Chamber 85 is vented as at 103.

The operation of the first part of the system is similar to that of the system of Fig. 3. The thermal conductivity gage is given a zero setting, prior to making a test, by allow both chambers (84 and 85) to be filled with air and adjusting one of the resistances 88 or 89 if necessary to make the needle of meter 95 point to an air-fuel ratio on the scale, corresponding to unit thermal conductivity (i e., to 15:1—Fig. 7—if the CO₂ absorber and oxygen converter are in use). When the bridge is thus balanced the exhaust gas sample taken through the pipe 31 and inlet 100 surrounds wire 86. The thermal conductivity of the gas being different from that of air (higher at most ratios) leakage of heat from wire 86 differs from that from wire 87 and the resistance of the two wires becomes unequal, unbalancing the bridge. The meter 95 registers the change. The rate of passage of exhaust gas through chamber 84 is made small to avoid errors due to convection.

A CO absorber can be introduced into the system of Fig. 8 if desired, in a way analogous to the arrangement in Fig. 3.

While the invention has been described in reference to determining air-fuel ratio in a gasoline engine, it can be applied, with simple modification, to engines using other fuels, and to combustion processes generally.

What I claim is:

1. In a method of determining air-fuel ratio in combustion processes in internal combustion engines which give rise to gaseous combustion products containing CO₂ and other, lighter gases, the proportion of CO₂ being greatest at some one air-fuel ratio value and lower at air-fuel ratios above and below said one value, removing the CO₂ from the combustion products to produce a gas mixture in which any given value of the properties of density and thermal conductivity thereof corresponds to only one particular air-fuel ratio, then, without oxidizing any constituent of the remaining gas mixture, measuring one of said properties by comparison with a standard gas having a substantially fixed value of said property, and determining the air-fuel ratio directly from said measurement.

2. A method of determining air-fuel ratio as defined by claim 1, wherein the physical property measured is density.

3. A method of determining air fuel ratio as defined by claim 1, wherein the physical property measured is thermal conductivity.

4. In a method of determining air-fuel ratio in combustion processes in internal combustion engines which gives rise to gaseous combustion products containing CO₂ and other, lighter gases, the proportion of CO₂ being greatest at some one air-fuel ratio value and lower at air-fuel ratios above and below said one value, removing the CO₂ from the combustion products to produce a gas mixture such that any given value of the properties of density and thermal conductivity thereof corresponds to only one particular air-fuel ratio, combining with oxygen present in said resultant gaseous mixture an added substance to produce a compound which increases the rate of change of values of one of said properties with respect to change of air-fuel ratio throughout a given range of air-fuel ratio values, and then measuring one of said properties of the gaseous mixture by comparison with a standard gas having a substantially fixed value of said property.

5. A method of determining air-fuel ratio as defined by claim 4, wherein the property measured is density.

6. A method of determining air-fuel ratio as defined by claim 4, wherein the property measured is thermal conductivity.

7. A method of determining air-fuel ratio as defined by claim 4, wherein the substance combined with oxygen is carbon.

8. A method of determining air-fuel ratio as defined by claim 4, wherein the substance combined with oxygen is sulphur.

9. In a method of determining air-fuel ratio in combustion processes in internal combustion engines which give rise to gaseous combustion products containing CO₂ and other, lighter gases, the proportion of CO₂ being greatest at some one air-fuel ratio value and lower at air-fuel ratios above and below said one value, removing the CO₂ from the combustion products to produce a gas mixture in which any given value of the properties of density and thermal conductivity thereof corresponds to only one particular air-fuel ratio, and then, without oxidizing any constituent of the remaining gas mixture and through comparison with a standard gas having a substantially fixed value of one of said properties, causing movement of an indicator element in response to changes in said physical property to indicate on a scale calibrated in terms of air-fuel ratio.

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