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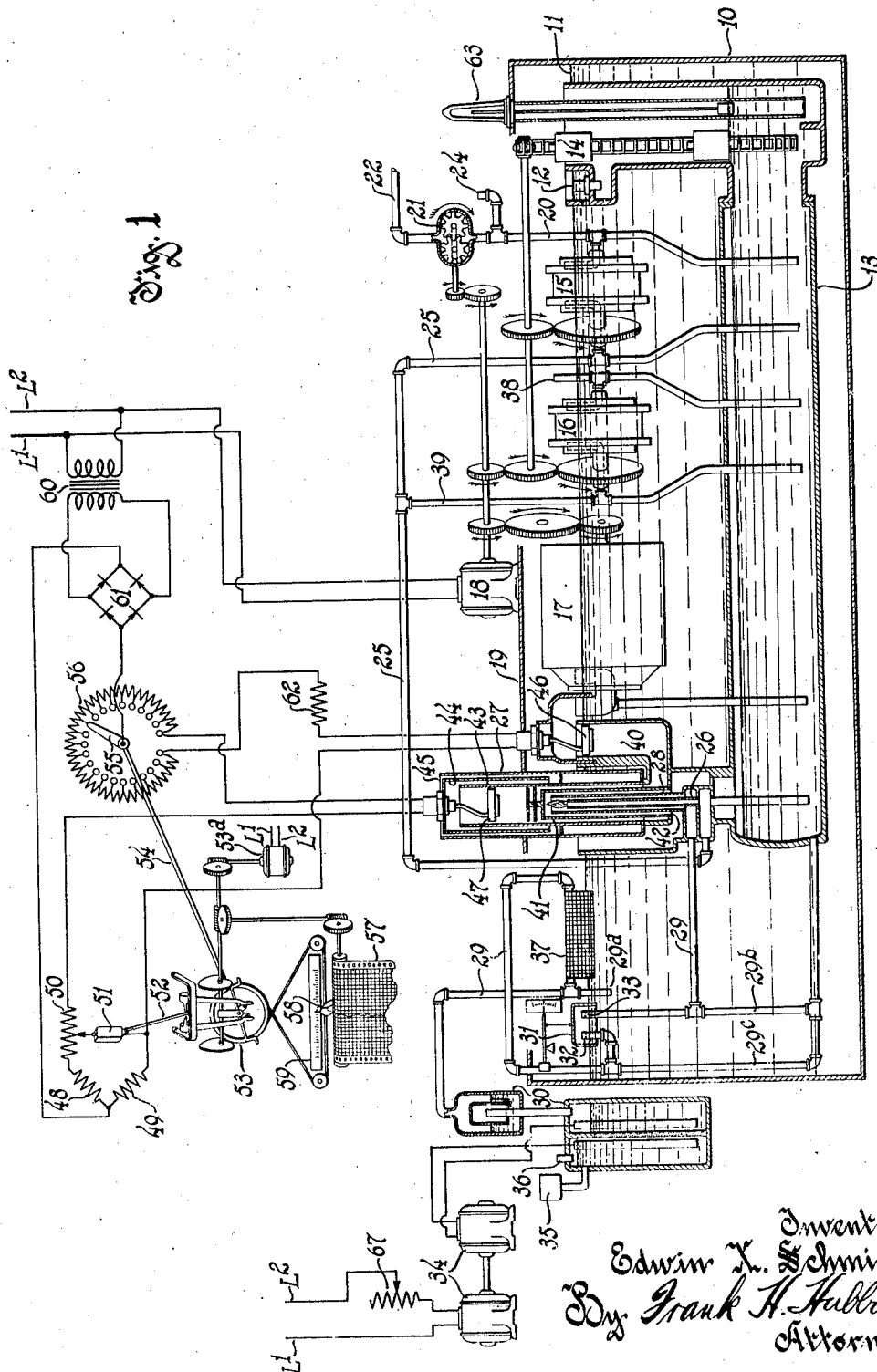
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METHOD OF AND APPARATUS FOR ASCERTAINING THE PROPORTIONAL
VALUE OF A COMBUSTIBLE CONSTITUENT OF A FLOWING FLUID

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2 Sheets-Sheet 1



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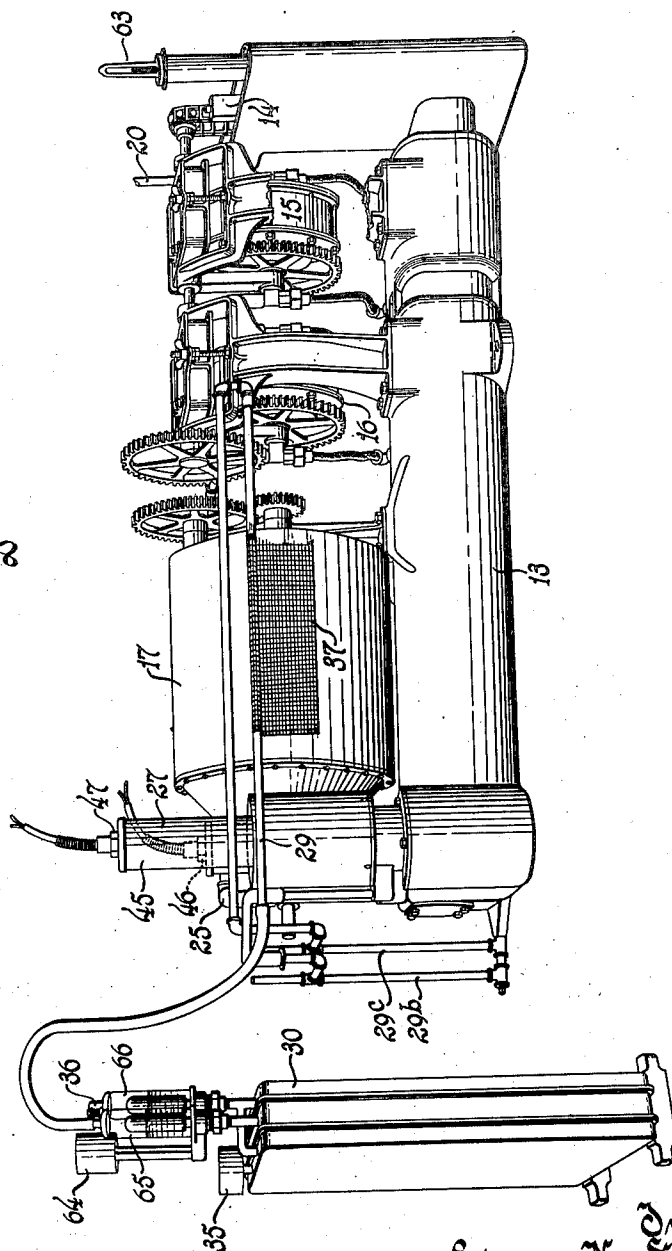
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Fig. 2



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UNITED STATES PATENT OFFICE

2,001,114

METHOD OF AND APPARATUS FOR ASCERTAINING THE PROPORTIONAL VALUE OF A COMBUSTIBLE CONSTITUENT OF A FLOWING FLUID

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13 Claims. (Cl. 73—184)

This invention relates to improvements in methods of and apparatus for ascertaining the proportional value of a combustible constituent of a flowing fluid, and the invention relates more particularly to methods of and apparatus for determining and recording the percentage content of oxygen in flue gases.

As is well understood by those familiar with the art of fuel combustion in industrial furnaces and the like it is of great importance to know exactly the percentage or proportional value of free oxygen in the flue gases, since it is known that such percentage affords an accurate indication of the relative perfection of the combustion being carried on, and such indication will enable the attendant to intelligently control combustion of the fuel to obtain the best results.

An object of the invention is to provide for accurate determination in a simple and efficient manner of the percentage content of a constituent of a flowing fluid.

Another object is to provide for such determination by methods and means which compensate for variations in temperature, pressure or saturation conditions of the flowing fluid.

Another object is to provide novel calorimetric methods of and means for continuously ascertaining the required value.

Another and more specific object is to provide for attainment of the desired results by burning a continuous sample of flue gases or similar fluid in the presence of a continuously flowing excess stream of hydrogen.

A further object is to insure continuous combustion irrespective of the percentage content of oxygen in the flue gases.

Other objects and advantages of the invention will hereinafter appear.

The accompanying drawings illustrate an embodiment of the invention which will now be described, it being understood that the embodiment illustrated is susceptible of modification without departing from the scope of the appended claims.

In the drawings, Figure 1 is a diagrammatic and schematic view of calorimetric means of the precision type arranged to provide for continuous determination and recordation of the percentage content of a constituent of a flowing fluid per standard cubic foot of the latter, and

Fig. 2 is a perspective view illustrating the mechanical form of the device,—certain of the parts being omitted for clarity of illustration.

The calorimetric device herein disclosed is in general of the type described and claimed in

the patents of Horace N. Packard No. 1,625,277, dated April 19, 1927, No. 1,662,802, dated March 13, 1928, and No. 1,774,723, dated September 2, 1930. In the calorimetric devices disclosed in the aforementioned Packard patents it is contemplated that a continuous sample of the test fluid shall be burned in an excess of air, whereas in the present invention the arrangement is such that a continuous sample of flue gases or other fluid is burned in excess of hydrogen, simple means being provided to ascertain and directly indicate and/or record the percentage content of oxygen per standard cubic foot of said flue gases.

Referring to Fig. 1, the numeral 10 designates a tank adapted to contain a liquid, such as water, the level of which is maintained at the line 11, as by means of the weir 12 which discharges into the reserve liquid chamber 13,—from which the liquid is withdrawn as by means of the continuously operable chain and bucket pump or conveyor 14 to replenish the body of liquid in tank 10.

Located within tank 10 and submerged to the required degree with respect to the liquid level 11 are a plurality of wet displacement meters or pumps 15, 16 and 17. The pumps 15, 16 and 17 are driven at definitely proportional speeds by a single motor, such as the electric motor 18, through the medium of suitable gearing, as shown. The pumps 15 and 16 are preferably of equal capacities and the same are geared to be driven at like speeds, whereby the flows produced by these pumps are equal in volume. Means of the character disclosed in Packard Patent No. 1,774,723 are preferably provided to permit testing and adjustment of the relative capacities of pumps 15, 16 and 17, and description thereof herein is deemed unnecessary.

Tank 10 is preferably provided with sectional cover elements, illustrated diagrammatically at 19, but such cover elements are arranged to suitably vent the tank to provide for attainment of atmospheric pressure therewithin.

The inlet of pump 15 is connected by pipe 20 with the outlet end of a pump 21, which is adapted through pipe 22 to withdraw a continuous sample of gases from the furnace flue or the like (not shown). The pipe connection between pumps 15 and 21 is provided with a vent 24 to atmosphere whereby supply of a sample of the flue gases to pump 15 at substantially atmospheric pressure is insured. The continuous sample of flue gases is delivered by pump 15 through piping 25 to the tube 26 of a burner designated in gen-

eral by the numeral 27. Surrounding tube 26 is a tube 28 through which flows a quantity of hydrogen in excess of that required for combustion of the test gas. The stream of hydrogen is supplied to the burner through piping 29 from a suitable source, such as the electrolytic hydrogen generator designated in general by the numeral 30,—a prover bell 31 of well known form and flow restricting orifices 32 and 33 being interposed in the line of piping 29 to maintain the flow of hydrogen at substantially atmospheric pressure and to eliminate fluctuations in the rate of supply thereof to the burner.

The hydrogen generator may be of well known form including the required number of cells of a given capacity,—a suitable motor generator set 34 being employed to produce the required constant voltage by which the quantitative rate of hydrogen generation is maintained approximately constant. A filling cup for replenishing the electrolyte of the cells is shown at 35, and 36 designates the outlet for the oxygen generated in the cells,—such oxygen being discharged to the atmosphere as indicated, or the same may be salvaged in any suitable manner if desired. The flow of hydrogen in piping 29 is preferably cooled to provide for condensation of any water vapor contained therein. Such cooling may be effected in a simple manner,—as by surrounding a portion of piping 29 with a strip of textile fabric such as gauze 37, the lower end of which is submerged in the body of liquid in tank 10 to provide for continuous moistening of the strip by capillary action,—the cooling effect incident to evaporation of the moisture carried by the strip being well understood. Piping 29 is preferably provided with drip tubes 29^a, 29^b and 29^c to prevent clogging thereof by condensed moisture therewithin.

As aforesaid the test gas is burned in the presence of an excess of hydrogen. Hydrogen is preferred mainly because of its high velocity of flame propagation; because of the fact that no carbon can be formed from hydrogen to clog the combustion chamber, and also because of the fact that the combustion heat of oxygen in hydrogen is almost exactly the same as that of oxygen in carbon monoxide. This latter fact may be of considerable importance since flue gases, for testing of which the present device is especially suitable, may possibly contain carbon monoxide.

Due to the fact that the device herein disclosed is intended for testing of a continuous sample of fluid which may have a very low percentage of oxygen, it is necessary to supply some form of energy to support combustion, that is, to insure against extinguishment of the burner flame under all conditions. I therefore prefer to supply a metered amount of oxygen in the form of air which is mixed with the sample from pump 15. As aforeindicated, the pump 16 is provided for this purpose,—atmospheric air being withdrawn from the interior of tank 10 through inlet 38 and conveyed through piping 39, 25 to the burner,—the volumetric rate of flow of air from pump 16 being preferably equal to the volumetric rate of flow of the test sample from pump 15. Thus if the sample of flue gases being tested contains no oxygen, the mixture of the volumetrically equal flows of flue gases and air which are burned in the presence of the excess of hydrogen will have one-half as high a percentage of oxygen as would be contained in a flow of air equal in volume to that of the mixture. The temperature rise in the calorimeter, with zero percentage of

oxygen in the sample, would therefore be one-half as high as it would be if the sample being tested consisted of air.

The principal reason for employment of equal volumetric rates of flow of air and flue gases is that by this arrangement the pumps 15 and 16 may be made exactly alike and may be driven at the same speed by connecting the same to a common drive shaft. Moreover, this arrangement simplifies the manner in which the pumps 15 and 16 may have their delivery rates set or adjusted relatively to the rate of delivery of the heat absorbing air by pump 17. The rate of supply of hydrogen should preferably be such that an excess of hydrogen will be present over that required for combustion of the maximum amount of oxygen which can be delivered in the fluids from pumps 15 and 16. In this manner provision is made for insuring a reliable state of combustion in the burner throughout all possible variations in the percentage content of oxygen in the sample.

Pump 17 withdraws the cooling air at atmospheric pressure from within tank 10 above the level 11 of the sealing liquid and supplies the same by conduit 40 to the burner structure 27, such cooling air being caused to flow in heat exchanging relation to, but out of direct contact with, the products of combustion in the burner. Thus the products of combustion are caused to flow downwardly between the exterior of tube 28 and the interior of an inverted cylinder or cup-shaped member 41 to be discharged at the point 42 for escape to the atmosphere, and cooling air flows upwardly in an annular stream between the exterior of member 41 and the interior of a tube 43 which is open at its upper end. Surrounding tube 43 and having its closed end positioned thereabove is an inverted cylinder or cup-shaped member 44, between the interior of which and the exterior of tube 43 the cooling air flows in a reflexed path to the lower end of member 44, and thence upwardly between the exterior of the latter and the interior of a tube 45 to atmosphere.

Located within the stream of cooling air at a point preceding the heat exchanging area is a temperature resistance thermometer 46 of the character described, for instance, in the aforementioned Packard Patent No. 1,662,802, the purpose of which thermometer is to ascertain the temperature of the cooling fluid prior to the heat exchange. Also located within the stream of cooling fluid at the desired point is a second thermometer resistance 47, the purpose of which is to ascertain the temperature of the cooling fluid subsequent to the heat exchange.

The thermometer resistances 46 and 47 are electrically connected to respectively form the major portions of two arms of the well known Wheatstone bridge circuit described in the aforementioned Packard patents; suitable fixed resistances 48 and 49 being adapted to form the other arms of said bridge. The Wheatstone bridge circuit may be initially balanced by means of a suitable variable resistance 50,—a galvanometer coil 51 being connected across the bridge circuit and the needle 52 associated therewith being utilized in conjunction with a well known form of control mechanism to automatically effect rebalancing of the bridge circuit.

Such control mechanism is indicated in general at 53, and is of the character disclosed in Patent No. 1,125,699, dated January 19, 1915, to Leeds. Thus the coil 51 effects deflection of the needle 52 whose sense and extent of deflection control the

sense and extent of rotation of the shaft or movable structure 54,—one end of which carries a contactor 55 slidable over the contacts of a resistance 56 to equalize the resistance values of the arms containing the respective thermometer resistances 46 and 47 whereby the bridge circuit is balanced automatically during testing of the flue gases or like fluid.

In other words, the deflecting system of the galvanometer controls a disengageable mechanical connection between the electric motor 53^a and the shaft 54 whose direction and extent of movement depend upon the extent and sense of deflection of the needle 52. The recording paper or sheet 57 is advanced at a constant rate by the motor 53^a past the marker or pen 58 which is moved transversely of the record sheet by a flexible connection between the same and shaft 54.

The pen 58 is adapted to co-act with a stationary scale 59 to indicate directly the instantaneous percentage content of the constituent (oxygen) in the sample (flue gases).

Lines L¹ and L² in each instance may represent a common source of supply of direct or alternating current, but where an alternating current source is utilized the Wheatstone bridge circuit is supplied therefrom through a suitable step-down transformer 60 and a rectifier system 61 of the well-known crystal type may be employed.

Included in circuit in series with the thermometer resistance 46 is a fixed resistance 62 the resistance value of which is equal to that of resistance 56. The purpose of this resistance 62 is to bring the Wheatstone bridge circuit into balance when contactor 55 is at that end (the left-hand end) of resistance 56 which corresponds with the left-hand end of scale 59; or, in other words, when no heat is being imparted to the flow of cooling fluid between thermometer resistances 46 and 47.

Each of the pumps 15, 16 and 17 and the tube 26 of burner 27 is provided with a drip passage

suitable change speed gearing and with a prover bell floating on the line connecting the outlet of pump 17 with the inlet of the pump 15 or 16 being tested, suitable adjustments of the latter pumps individually may be effected to insure the desired ratio of the rates of delivery thereof with respect to the rate of delivery of pump 17. Such adjustments of pumps 15 and 16 may of course be effected by changing the gear ratios in the change speed gearing and/or by changing the degree of immersion of said pumps 15 and 16 within the sealing fluid in tank 10.

I prefer to provide for a maximum temperature rise in the device herein disclosed of approximately 40 degrees F., with the sealing liquid in tank 10 at a temperature of approximately 60 degrees F. Air, which contains 20.95 per cent oxygen, has a heating value with hydrogen of 134.4 B. t. u's. per cubic foot. I prefer to use the ratio of 190.09 to 1 in change speed gears. A gas with a heating value of 100 B. t. u's. per cubic foot will, with a gear ratio of 126.733 to 1, give a temperature rise of 42.652 degrees F. As aforesaid the heating value of air in hydrogen is 134.4 B. t. u's. per cubic foot, and therefore requires a change speed gear ratio of approximately 188.8 to 1. Since two meters 15 and 16 of equal capacities are employed the desired gear ratio for each of the two meters is 377.6 to 1. During the ratio test 40—20 gears will preferably be used. Therefore the use of 32—28 gears will give a ratio of 360.13 to 1 per meter or a total ratio for both meters 15 and 16 of 180.65 which when air (20.95 per cent oxygen) is supplied by both meters will give a maximum temperature rise of 43.653 degrees F. When there is no oxygen (or zero percentage of oxygen) in the sample of flue gases supplied by pump 16, the temperature rise between thermometer resistances 46 and 47 will be 21.826 degrees F., and for other percentages of oxygen in the flue gases supplied by pump 46 the temperature rise will follow the equation:—

$$\text{Temperature rise} = 21.826 \text{ plus } \left(\frac{\% \text{ oxygen}}{20.95} \right) \text{ times } 21.826.$$

leading to the storage chamber 13 in the manner indicated. Chamber 13 is preferably provided with a float gauge 63 of well known form to indicate the level of liquid therewithin.

The mechanical form of the device is illustrated in Fig. 2, but several of the parts of the device are omitted for clarity of illustration,—the corresponding parts of Fig. 2 having been given like numerals of reference. The cup 64 in Fig. 2 is provided for filling to a suitable level with liquid the cups 65 and 66 through which the generated hydrogen and oxygen are respectively adapted to pass.

A suitable rheostat 67 is preferably employed to adjust or control the speed of the motor of the set 34 whereby the rate of current supply from the generator to the electrolytic cell or cells 30 may be regulated to control the rate of supply of hydrogen to burner 27. It will of course be understood that the hydrogen might alternatively be supplied from a tank or other suitable source as by means of a meter or pump having a capacity and rate of speed which will deliver the necessary excess of hydrogen.

The capacities of the pumps 15 and 16, respectively, relative to the capacity of the cooling air pump 17 may be adjusted individually in the manner disclosed in the aforementioned Packard Patent No. 1,774,723. Thus by employment of

I prefer to calibrate the scale 59 as follows:—Left end—cold balance zero (no heat in burner). Approximate center—zero percentage of oxygen in flue gases. Full scale, right end—air supplied by both meters 15 and 16 (20.95% oxygen). The upper half of scale 59 is preferably graduated in equal divisions of one-half of one per cent each to show the percentage of oxygen in the sample.

The capacity of pump 15 may be checked or determined in another manner, if desired. Thus by effecting volumetric test of the capacity of pump 16 relatively to pump 17 in the manner aforescribed, and by properly adjusting pump 16 to provide the proper capacity ratio thereof with respect to pump 17, pump 15 may be adjusted by thermal methods. For instance, with the burner in operation pump 16 delivering air to the burner gives half-scale reading on scale 59. Pump 15 may then be adjusted to give the same reading with the burner operating on air from pump 15, with pump 16 disconnected.

Alternatively with the burner in operation on air delivered by both pumps 15 and 16 full scale reading is obtained on scale 59 if the pumps 15 and 16 have the correct capacities,—thereby providing a simple check upon the delivery rates of said pumps jointly. Then if desired each pump individually may be checked and/or adjusted to

give half-scale reading upon scale 59, with said pumps supplying air to the burner.

What I claim as new and desire to secure by Letters Patent is:

1. The method of continuously ascertaining the instantaneous proportional value of a constituent of a gaseous fluid, which comprises the steps of supplying to a burner a continuous metered flow of said fluid, supplying to said burner a continuous flow of another fluid, mixing said fluids and igniting the mixture whereby said constituent of the first-mentioned fluid combines chemically with at least a portion of said second-mentioned fluid to generate heat, continuously ascertaining the value of the total heat generated per standard cubic foot of said first-mentioned fluid, and utilizing said value as a direct indication of the proportional value of said constituent.
2. The method of continuously ascertaining the instantaneous percentage content of a combustible constituent in a gaseous fluid, which comprises effecting a continuous metered flow of said fluid to a burner, effecting a continuous flow to said burner of a second gaseous fluid which will combine chemically with said constituent with resultant liberation of heat, said second mentioned fluid being supplied at a rate in excess of that required to fully combine with said constituent, continuously ascertaining the total value of the liberated heat per standard cubic foot of said first mentioned fluid, and utilizing said value to indicate directly the percentage content of said constituent in the first-mentioned fluid.
3. The method of continuously ascertaining the instantaneous percentage content of a combustible constituent in a gaseous fluid, which comprises effecting a continuous metered flow of said fluid to a burner, effecting a continuous flow to said burner of a second gaseous fluid which will combine chemically with said constituent with resultant liberation of heat, said second mentioned fluid being supplied at a rate in excess of that required to fully combine with said constituent, continuously ascertaining the total value of the liberated heat per standard cubic foot of said first mentioned fluid, and utilizing said value to effect direct indication and recordation of the percentage content of said constituent in said first-mentioned fluid.
4. The method of ascertaining the volumetric proportionality of a combustible constituent of a flowing gaseous fluid, which consists in supplying to a calorimeter burner a continuous metered sample of said fluid and a continuous flow of a second fluid, mixing said fluids and igniting the mixture whereby said combustible constituent is chemically combined with at least a portion of said second-mentioned fluid to generate heat in accordance with the proportional value of said constituent, supplying a continuous metered quantity of a third fluid for cooperation with said second fluid to insure against extinguishment of the burner flame, continuously ascertaining the total heating effect of the combustion, and utilizing the value of the total heating effect so ascertained as a measure of the proportional value of said constituent.
5. The method which comprises mixing streams of flue gases and air, which are definitely proportioned relatively to each other volumetrically, effecting combustion of the mixture in the presence of an excess of flowing hydrogen, continuously ascertaining the total heating value of the products of combustion with reference to the

number of standard cubic feet of flue gases supplied per unit of time, and utilizing the value so ascertained for effecting direct indication and recordation of the percentage content of oxygen in said flue gases.

6. The method which comprises mixing streams of flue gases and air of equal volume, effecting combustion of the mixture in the presence of an excess of flowing hydrogen, continuously ascertaining the total heating value of the products of combustion with reference to the number of standard cubic feet of flue gases supplied per unit of time, and utilizing the value so ascertained for effecting direct indication and recordation of the percentage content of oxygen in said flue gases.

7. The method which comprises mixing streams of flue gases and air of equal volume, effecting combustion of the mixture in the presence of an excess of flowing hydrogen, effecting a separate metered flow of cooling fluid in heat exchanging relation to the products of combustion, ascertaining the difference in temperatures of said last mentioned fluid before and after the heat exchange, and utilizing the value of the difference so ascertained as a measure of the percentage content of oxygen in said flue gases.

8. Apparatus for continuously ascertaining the instantaneous proportional value of a combustible constituent of a gaseous fluid, comprising a burner, means for supplying to said burner a continuous, constant metered flow of said fluid, means for supplying to said burner a continuous flow of another combustible fluid in excess of that required to effect complete combustion of said constituent, means for ascertaining the total heating effect of the combustion per standard cubic foot of said first mentioned fluid, and means controlled by said last mentioned means to indicate directly the proportional value of said constituent.

9. A calorimeter for continuously determining the instantaneous percentage content of oxygen in flue gases, which comprises means for measuring the temperature rise of a fluid subjected to the heat of combustion of a continuously flowing sample of said flue gases in the presence of an excess of hydrogen, means for subjecting the fluid, the flue gases and the hydrogen to like temperature, pressure and saturation conditions, associated means for supplying said fluid and said flue gases in continuous streams having a definite volumetric ratio, and means for utilizing said measurement of the temperature rise as a direct measure of the percentage content of oxygen in said flue gases.

10. A calorimeter for continuously determining the instantaneous percentage content of oxygen in flue gases, which comprises means for measuring the temperature rise of a cooling fluid subjected to the heat of combustion of a continuously flowing stream of volumetrically proportioned quantities of said flue gases and air in the presence of an excess flow of hydrogen, said means including means for subjecting the cooling fluid, the flue gases, the air and the hydrogen to like temperature, pressure and saturation conditions, associated means for supplying said cooling fluid in a continuous stream having a definite volumetric ratio to said stream of flue gases and air, and means for utilizing said measurement of the temperature rise as a direct measure of the percentage content of oxygen in said flue gases.

11. Apparatus for determining the percentage

content of oxygen in flue gases, comprising a burner, means for supplying under substantially like conditions of temperature, pressure and saturation hydrogen, air and flue gases to be supplied to said burner and a cooling fluid to be supplied in proximity to said burner in heat exchanging relation to the products of combustion of said hydrogen, air and flue gases, said means supplying continuous streams of air, flue gases and cooling fluid whose volumes are in definite ratio, means for measuring the temperature rise of the cooling fluid subjected to the heat given off by combustion of said streams of air and flue gases in the presence of said hydrogen, and means for utilizing such measurements to indicate and record directly the percentage content of oxygen in said flue gases.

12. Apparatus for determining the percentage content of oxygen in flue gases, comprising a burner, means for supplying streams of hydrogen, air and flue gases for combustion in the burner and a stream of cooling fluid in proximity to the burner but separated from the products of combustion, said means insuring a definite quantity ratio of the air, flue gases and cooling fluid supplied thereby, a Wheatstone bridge circuit including resistance thermometers in the path of the stream of cooling fluid to measure the tem-

perature rise of the latter caused by the heat given off by the combustion, and continuously operable means controlled by said Wheatstone bridge circuit, said last mentioned means being calibrated to indicate and record the percentage content of oxygen in said flue gases.

13. Apparatus for continuously ascertaining the instantaneous percentage content of oxygen in flue gases comprising, in combination, means to effect combustion of a continuous sample flow of said flue gases in the presence of a continuous excess flow of hydrogen, means for causing the combustion products to flow in a given direction and in heat exchanging relation to the gases prior to combustion thereof, means for causing an opposite flow of cooling fluid in heat exchanging relation to said combustion products, means for causing a return flow of said cooling fluid to impart heat to its own flow during said last mentioned heat exchange, for substantially equalizing the temperatures of said cooling fluid and said combustion products, and continuously operable means for ascertaining the temperature rise of said cooling fluid, said last mentioned means being calibrated to indicate directly the percentage content of oxygen in said flue gases.

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