Dec. 31, 1935. R. W. KEITH 2,026,180

FUEL CALORIMETER

Filed Nov. 29, 1933 2 Sheets-Sheet 1

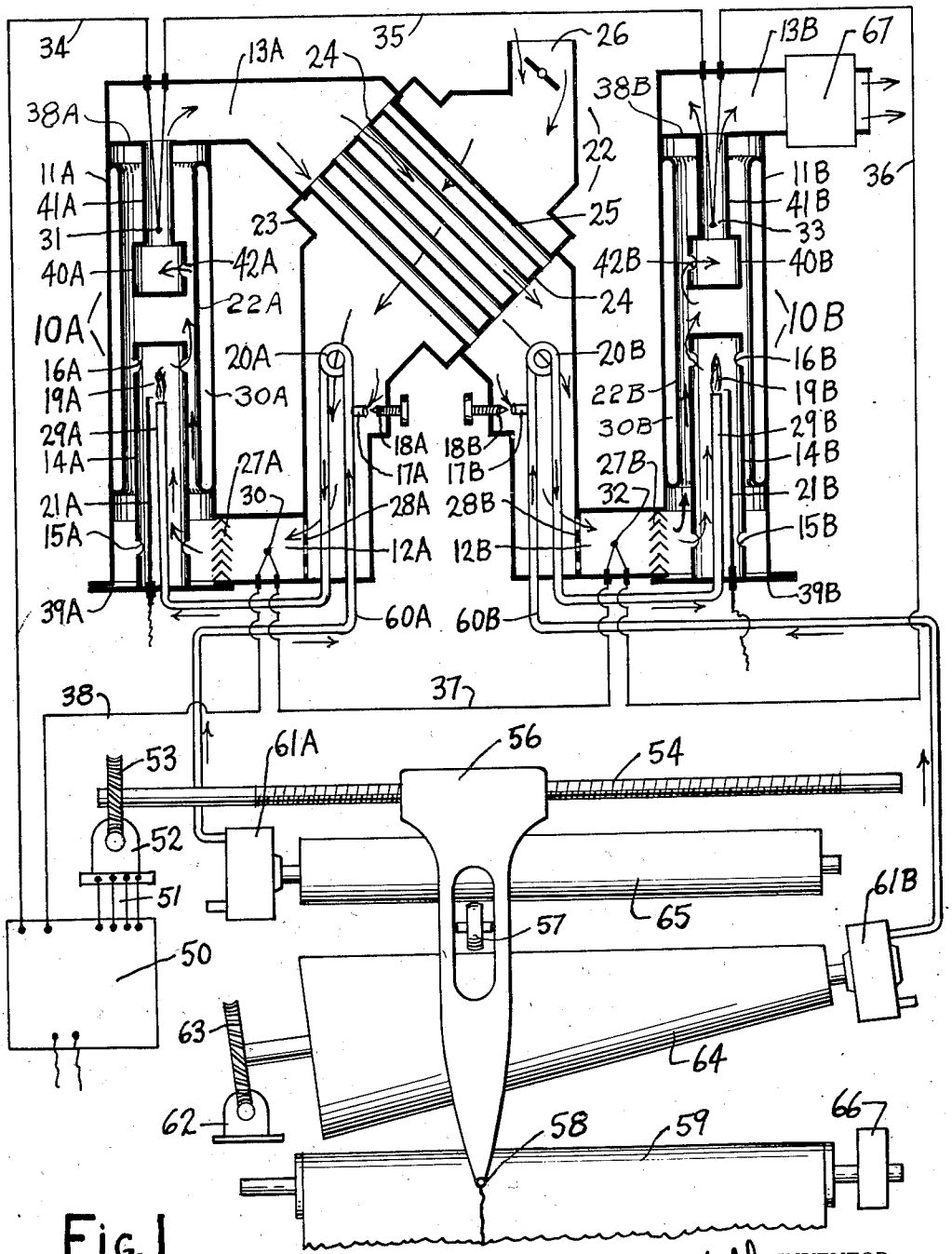


Fig. 1

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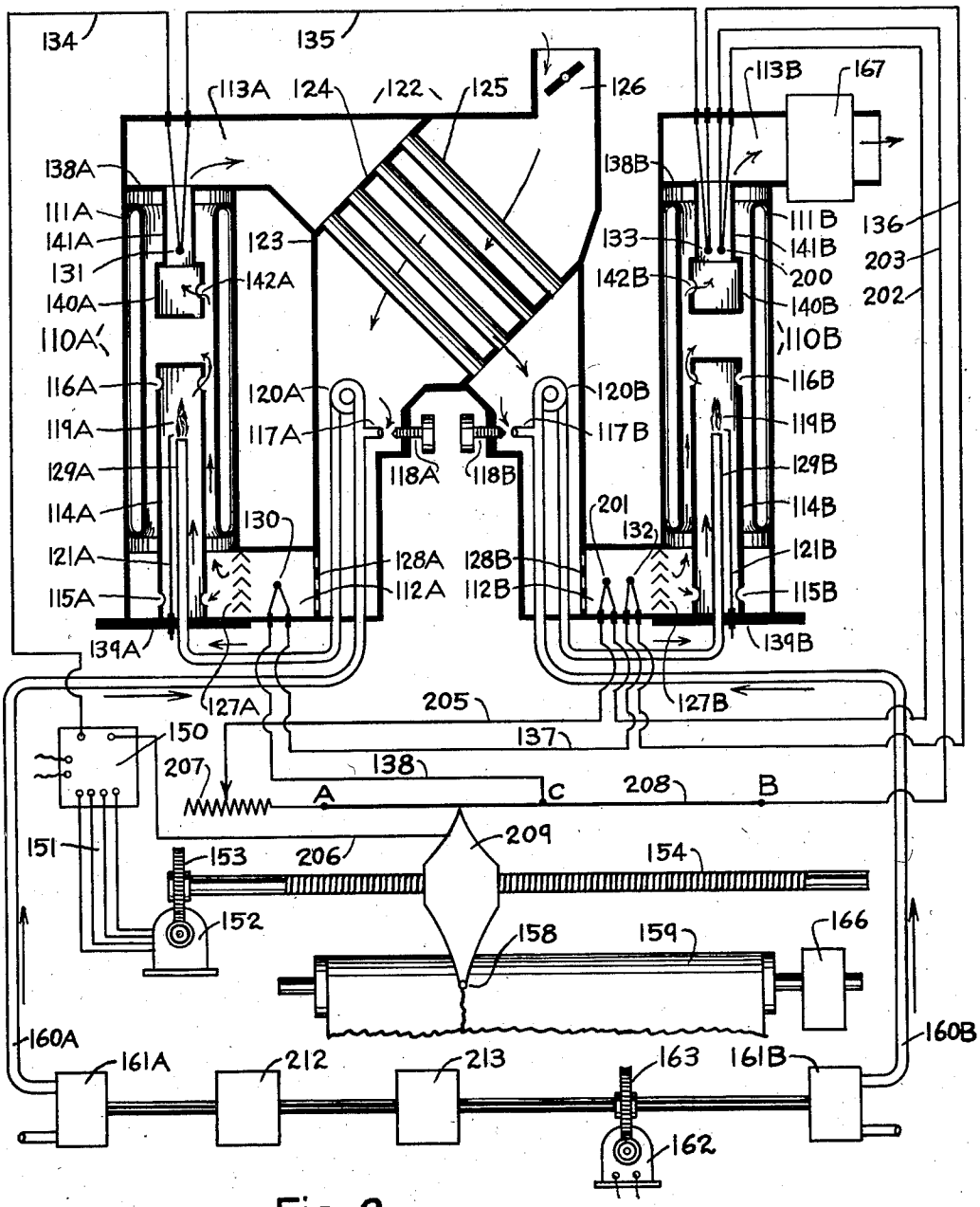


FIG. 2

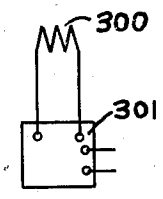


FIG. 3

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Patented Dec. 31, 1935 2,026,180

UNITED STATES PATENT OFFICE

2,026,180

FUEL CALORIMETER

Rafael W. Keith, Caroline, N. Y.

Application November 29, 1933, Serial No. 700,339

25 Claims. (Cl. 73—184)

My invention pertains to a simple, novel calorimeter of the multiple chamber type for continuously determining the calorific value of a combustible, and more particularly relates to structural means for effectively measuring and automatically recording the heating value of a combustible without the need of any liquid as an intermediary cooling agency.

The method of operation that underlies my improved apparatus is primarily based upon an offset or thermal balance principle in which a gaseous heat absorbing agency containing free oxygen is successively heated in two separate steps at commensurable input rates. One such step brings about a definite temperature rise by burning an unknown combustible in such working fluid to impart a relatively small surplusage of sensible heat thereto; while the complementary or counterbalancing step may be instigated by means of any adjustable heating medium whose rate of thermal output is definitely known and made capable of selectively inciting a temperature rise that closely corresponds to that of the first named step. When the temperature rise occurring in each such step is maintained at substantially equal value, a comparative measure is afforded for directly evaluating the rate of heat supplied by the unknown combustible in terms of an equivalent known heating effect. The described order of these successive heating steps may be reversed and still produce an identical result. As a further refinement, my working fluid may also be alternately utilized as a heat absorbing agency and as a cooling medium.

The present instrumentalities are of the continuous flow calorimeter type, comprising a pair of cooperating primary and secondary combustion chambers which may be kept substantially identical as far as their respective structural and thermal characteristics are concerned and may collectively be termed "complementary chambers". One point of structural novelty resides in interconnecting the top of a tubular primary chamber in series with the bottom of a similar secondary chamber by conduit means and conducting a stream of gaseous working fluid therethrough whose major constituent is atmospheric air. Such conduit means preferably, but not necessarily, includes an interposed compartmental heat exchanger or the like intercooler device.

Broadly considered, a localized body portion of flowing working fluid may be successively heated in any suitable manner while passing through the respective complementary chambers. In my preferred embodiment, each of these multiple combustion chambers may be equipt with a separate test burner, of which one such may be supplied from a source of standardized combustible of known heating value while the other burner is fed with sample gas of unknown heating value, the rates of fuel supply to the respective burners being made relatively adjustable and quantitatively determinable by appropriate control means. Prior to reaching the primary chamber, a stream of fresh working fluid may initially be passed through one compartment of my heat exchanger in order to preheat such incoming air stream to a limited extent and thereby obviate moisture condensation during the subsequent cooling thereof. No correction is then needed to take account of such condensation, my calorimeter being preferably arranged to register the net or lower heating value of the sample gas.

A relatively large volume or stream of preheated working fluid is made to flow steadily into the primary combustion chamber that shelters the test flame whose gas heating value is to be determined. Since a comparatively small volume of sample gas is intended to be burned in the presence of a large excess of preheated air, the rate of sensible heat input is inherently limited, which in turn correspondingly restricts the resulting temperature rise. Such flame heated working fluid may then be cooled by conveying the same from the primary combustion chamber through a different intercooler compartment and placing the conveyed fluid in heat exchanging relationship with the current of fresh air that is simultaneously fed through the first cited intercooler compartment. After leaving the primary chamber, said fluid stream may be reduced to the same temperature that prevails in the preheated air being entered into the primary combustion chamber. Thereupon the working fluid may be delivered into the secondary combustion chamber and reheated therein at a measurable rate of input by the use of a small standardized reference flame or an equivalent supplemental heating means. The respective rates of gas flow to the test flame and to the reference flame may be manually adjusted or automatically manipulated so that the temperature rise in both combustion chambers is maintained in a substantially equal relationship. It is pointed out that in my improved calorimeter, one and the same working fluid is successively and cooperatively passed through both complementary combustion chambers and reheated in one such chamber.

Sensitive temperature responsive devices may be arranged in both the primary and secondary

combustion chambers in order to determine when the desired temperature conditions have been achieved. By starting the cited reheating operation in the secondary chamber from the same temperature level that initially prevailed prior to entering the primary chamber, a similarity of temperature condition is realized, with the result that the mean specific heat of the working fluid as well as the calorimeter heat losses become substantially equalized. My calorimeter is however capable of rendering reasonably exact determinations without resort to any intercooler and still provide for an instrument whose inherent inaccuracy remains negligible in meeting the more practical requirements.

Instead of adjustably altering the proportionate supply of combustible gases delivered to their respective flames, the gas of unknown heating value and the standard reference gas may as an alternative, be supplied to their respective test burners in a volumetric fixed ratio, whereupon the resulting successive temperature rises that occur in the respective combustion chambers, may likewise be used as a comparative measure of relative heating values when a definite rate of fluid flow is maintained therethrough.

My copending prior application, Serial No. 477,888 as filed August 26, 1930, is descriptive of a method and apparatus that in certain respects is analogous in its teachings to the foregoing, the instant disclosure being a continuation in part thereof.

The object of the present invention is to provide for certain refinements in method and structural aspects over said original application and to otherwise improve the performance thereof, by working with calorimeter means possessing the previously described characteristics and capable of accurately determining the thermal value of a combustible without need of computing allowances for heat losses, room temperature or humidity of the air supply.

A further object is to equip said apparatus with certain control appurtenances and adapt the same to function cooperatively with differential recording devices designed to automatically regulate the gas supply to my multiple calorimeter; also to provide facilities for at times, checking the readings obtained and to permit of making adjustments that will insure a high standard of performance on the part of said instrument. Other features of improvement will hereinafter be more explicitly pointed out.

Reference is had to the accompanying two sheets of drawings which are illustrative of certain preferred structural arrangements of my invention, and in which drawings:

Fig. 1 cross-sectionally represents a schematic elevational view through the principal parts of a fuel calorimeter assembly embodying my invention as equipt with automatic control devices.

Fig. 2 is a view similar to Fig. 1 but discloses certain modifications of the recording mechanism and mode of manipulation.

Fig. 3 diagrammatically depicts certain alternative details pertaining to a substitute reheating coil.

Referring more specifically to the drawings, attention will first be directed to the Fig. 1 style of instrument. In this upright calorimeter embodiment, there are provided two laterally spaced primary and secondary combustion chambers respectively designated in their entirety as 10A and 10B, which may respectively be heat insulated in a suitable manner to minimize heat losses. The structure of each such component chamber is intended to be substantially alike and to possess other similar inherent characteristics. The reference numerals indicating the various housing parts will be followed by the letter A to designate primary chamber members and by the letter B when referring to the secondary chamber.

The tubular insulated jackets 11A and 11B of these complementary combustion chambers may at their bottom regions, respectively be provided with a laterally disposed intake port or passageway 12A and 12B, while each upper region thereof respectively communicates with the discharge port or passageway 13A and 13B.

The open bottom of each such jacket may be closed by a removable cover plate 39A or 39B. Separately mounted thereon are the upstanding jet burners 29A and 29B that respectively terminate in the small test flames 19A and 19B. These flames may be ignited by electric pilot means 21A and 21B or the like. Said gas burners are preferably of the premixing type and respectively housed within the tubular draft casings 14A and 14B which protect the flame against direct radiation and extinction. The uppermost end of the respective burner casings is capped and a plurality of delivery or crown ports 16A and 16B are disposed therebeneath through the casing. A similar series of intake or draft ports 15A and 15B are located at the lowermost region of the respective casings.

The respective topmost regions of the tubular jackets 11A and 11B are substantially closed by the annular crown plates 38A and 38B. The innermost perimeter of each such plate respectively carries the depending outlet tube 41A or 41B serving to support the cylindrical mixing boxes 40A and 40B in elevated relation to the aforesaid crown ports. Said boxes may each be provided with a series of radially opposed mixing apertures 42A and 42B. These apertures are arranged to project the incoming working fluid inwardly into impinging relationship and thence upwardly through a single discharge outlet so as to promote turbulence which thus brings about a substantially equalized temperature throughout the respective flowing fluid bodies prior to leaving their mixing boxes through the contracted tubes thereof.

For heat insulating purposes, each jack wall such as 11A and 11B, may respectively be equipt with an interiorly spaced lining tube 22A or 22B to constitute therebetween a hermetically sealed vacuum chamber such as 30A or 30B. The effectiveness thereof may be augmented by interiorly applying a silvered coating to the respective chamber walls.

As a further precautionary measure against heat loss, the delivery end of the intake passageways 12A and 12B may respectively be commanded by the antiradiation shields 27A and 27B, which each preferably comprises a plurality of cross-sectionally channel shaped metal slats or baffles that are stacked in superimposed gratelike relation and adapted to divert the gaseous flow therethrough in zigzag fashion. Spacedly located ahead of each such shield, is a perforated grid 28A or 28B intended to effect a well distributed flow into and through their respective intake passageways.

The various channels leading through my combustion chambers are so interconnected that a major portion or main current of working fluid entering the passageways 12A and 12B, will flow upwardly around their respective burner casings

14A and 14B while a minor portion feeds through the draft ports 15A or 15B and out of the crown ports 16A or 16B. After being combined, each such stream of working fluid is thereupon fed upwardly within the confines of the lining tube and thence into a mixing box for delivery into the respective discharge passageways such as 13A or 13B, said course being represented by arrows.

A crossfeed conduit unrestrictedly interconnects the discharge passageway 13A with the intake passageway 12B. Inbuilt around such connective conduit is shown a compartmental heat exchanger 22 comprising the tubular shell 23 of which the respective ends may be enclosed by a header 24; between these headers there extends a bank of intercooler tubes 25 of which the interior defines one compartment of my intercooler and the surrounding space constitutes another compartment thereof. The intercooler shell is further shown equipt with a controllable air feed duct 26 arranged to supply atmospheric or room air around the exterior of the tubes 28. Said fresh air may be delivered downwardly through the primary feed passageway 12A. Similarly, the down coming working fluid after leaving the intrcooler tubes, may be directed into the secondary intake passageway 12B, which then becomes a component of the chamber interconnecting conduit 25.

As will be understood, independent banks of tubes may also serve for intercooler purposes and these banks may be immersed in a common water bath. In addition, the outlet end 13B of the secondary chamber may be equipt with suitable forced circulating means such as a positively driven draft producing appliance designated as 67, it being preferred to keep both combustion chambers under a slight vacuum by the use of a suction blower or the like. The total volume of induced air flow to test flame requirements may be varied within rather wide limits, since the function of my calorimeter is not dependent upon any fixed ratio therebetween.

The separate fuel supplies required for the burners 2A and 29B are delivered to their respective flames by the gas feed pipes 60A and 60B. The preheater loop sections thereof, namely 20A and 20B, may respectively be incorporated within the confines of a different heat exchanger compartment as shown in order that each such combustible may initially be made to closely approach the temperature of the working fluid stream in which it is to be burned.

The respective loop sections may be provided with a bypass valve 17A or 17B as controlled by the needle valve screws 18A and 18B to admit and respectively regulate the proportion of air that is allowed to mix with the combustible gases prior to reaching their test flames. Only a relatively small amount of working fluid is intended to be bypassed through either valve.

Respectively mounted within each outlet tube 41A and 41B is a temperature responsive device such as 31 or 33, preferably of the thermocouple type. In order that said devices may accurately register the temperature of the gaseous fluids being crowded through their respective tubes, the cross-sectional tube area is preferably contracted relative to that of their concentrically mounted boxes 42A and 42B. Each device may comprise one or more alternately jointed thermocouple units, such for instance as copper and constantan, since these afford a relatively high E. M. F. per degree of temperature difference.

A substantially identical thermometer device 30 is placed within the primary passageway 12A. The secondary passageway 12B may be similarly equipt with a thermocouple 32 which may be entered through the housing wall by means of removable insulator plugs or the like. As shown in Fig. 1, all four of such thermocouples are series interconnected in opposed or bucking relationship and made to serve as a differential temperature responsive means in a manner that will presently be more explicitly described. To this end, a terminal of the thermocouple 31 may be carried to its mated couple 33 by the lead wire 35. A lead wire 36 extending from the opposite terminal of said mated couple, may be carried to the couple 32, which in turn is connected to the couple 30 by the lead wire 37. The remaining open terminals of the couples 30 and 31 are then operatively connected by the leads 34 and 38 to the main control relay 50 whose purpose will subsequently be explained.

Attention will now be directed to my gas pump controls and method for supplying the respective test flames in an automatically regulatable manner. As previously recited, the primary test burner 29A is supplied with gas through the feed pipe 60A. The primary fuel metering pump 61A delivers into said feed pipe and draws its supply from a source of gas whose unknown heating value is to be determined by my calorimeter. Such fuel pump is preferably of the positive displacement or rotating bucket carrying type capable of accurately measuring the gas delivery at a volumetric rate that shall be directly proportional to the speed of the pump.

The secondary chamber is shown equipt with separate, corresponding gas handling means including a test burner 29B, a gas feed pipe 60B and a secondary fuel metering pump 61B which latter draws its supply from a known source of standard reference gas such as hydrogen, acetylene, methane and the like pure combustibles adapted to burn with a substantialy non-luminous flame and whose lower heating value may be predetermined within a close limit. Both of such metering pumps are preferably installed within a common water bath to equalize the temperatures thereof and respectively supplied with gas at the same pressure by suitable regulator means.

My compensating apparatus is centered in an appropriate transmission mechanism for automatically altering the respective speeds of the gas metering pumps relative to each other. In the embodiment diagrammatically depicted in Fig. 1, a driven cylindrical drum 65 and a cooperative tapered drum 64 are rotatably mounted in any suitable manner. One end of the drum 64 may be gear driven at 63 by the main actuating motor 62, while its other drum end may be extended for direct connection to the secondary gas metering pump 61B which serves the test burner 29B with the stipulated standard reference gas. A shaft end of the driven drum 65 is similarly associated with the primary gas metering pump 61A that delivers unknown gas to the test burner 29A. A shiftable idler wheel 57 is shown interposed between said drums and positive adjusting means are provided to fix the operative position of said idler lengthwise of the contiguous drum surfaces in maintained frictional contact therewith. During any given calorimeter test, the secondary metering pump 61B is preferably run at some fixed predetermined motor speed and by adjustably shifting the idler, the speed of the primary metering pump 61A may be selectively advanced or retarded in relation thereto. It is

preferred to bring about a one to one speed ratio when the idler approaches the rightward end of its adjustable travel and to correspondingly augment the speed of the primary pump when the idler is moved toward its opposite extreme of travel.

By the proper selection of speed ratios and drum contour, such transmission mechanism can be so designed and calibrated as to make the idler movement directly proportional to a corresponding change in the lower B. t. u. or net heating value of the unknown gas. The adjusting screw 54 is provided with a carrier 56 which serves to shift the idler wheel in unison therewith. As indicated in Fig. 1, said carrier may also overhangingly mount a stylographic pointer 58 to graphicaly record the test findings upon a suitably indexed chart 59, which latter may be uniformly moved along by coordinated clock or other synchronizing means in a conventional manner.

Referring further to the previously cited relay unit 50, this may be of the galvanometric or potentiometer type of remote control adapted to intermittently start or stop a reversible auxiliary motor 52 as geared to the screw 54 and which relay may be electrically connected to the motor by the lead wires 51. Certain parts of the potentiometer recorder now being marketed by the Leeds & Northrup Company of Philadelphia, Pa., may be utilized for present purposes.

The minute differential voltage emanating from my thermocouples is sufficient to control such a recorder and to automatically bring about a starting up of the reversible remote control motor 52 in a fixed direction of rotation dependent upon the direction of effective current flow that may from time to time, be set up within the closed lead wire circuit that interconnects my thermocouples. This auxiliary motor 52 continues to adjust the idler position as long as the thermocouples send forth a current flow through the relay 50. The speed adjustments on part of the drums will automatically cease when the various electric thermometers have been brought into a thermally counterbalanced condition, which in turn shuts down the auxiliary motor. By virtue of the described compensating devices, said idler will however, be promptly shifted into a new position in response to any change in the heat value of the unknown gas, and thus continuously register its corresponding prevailing calorific content upon the chart 59.

Having described the more essential structural characteristics of the Fig. 1 style of calorimeter, its functional mode of operation may now be briefly traced as follows:

Assuming both the test flames 19A and 19B to have been lighted and stabilized thermal conditions established, then a steady circulation of the working fluid will be induced by the blower 67 to flow through the interconnected calorimeter chambers in a path direction indicated by arrows. Fresh atmospheric air is thereby drawn into the feed duct 26 and caried downwardly around the intercooler tubes 25 for delivery through the primary passageway 12A and the shield 27A into the primary combustion chamber 10A. The test flame 19A of itself, imparts slight mobility to the working fluid, which latter naturally rises because of being intermingled with a relatively small volume of hot combustion products. The calorimeter passages are preferably so proportioned that the addition of burned gas to the desired large excess of air will restrict the total temperature rise to about 50° Fahr. which limit is merely cited as a suitable working basis. Such initially heated working fluid then passes upwardly through the mixing tube 42A and into the contracted end of the outlet tube 41A, which brings said initially heated fluid in intimate contact with the thermocouple 31. The other thermocouple 30 is made responsive to the mean intake temperature prevailing in the passageway 12A. These mated couples tend to set up a differential current flow through their respective interconnecting lead wires that is directly proportional to the dominant temperature difference between such opposed couples.

The heated working fluid is then conveyed through the interior of the tubes 25 in a heat interchanging relation with the fresh air coming into the feed duct 26 which thereby brings about a preheating of such air current prior to reaching the test burner 19A. It is preferred to so proportion the intercooler that the working fluid upon reaching the secondary passageway 12B, shall be reduced in temperature to a point substantially equal to the temperature prevailing in the primary passageway 12A, in order that the thermocouples 30 and 32 may be subjected to approximately the same temperature influence.

The intercooled working fluid is thereupon entered through the intake passageway 12B of the secondary combustion chamber 10B and reheated by the secondary test flame 19B or equivalent supplementary heating means to a point that shall as nearly as possible, correspond to the temperature rise previously imparted by the primary test flame 19A.

After stabilizing or steady flow conditions have been established, the relative supply rates of the sample gas of unknown heating value and that of the standard gas may be effectively regulated by the previously described pump control means. The desired thermal balance may be brought about by resort to a plurality of thermocouples that are preferably interconnected in series with the main control relay unit 50 as described.

The electromotive force generated by the couples 30 and 31 is a function of the existing mean temperature difference between these two primary chamber regions. In a similar manner, the electromotive force generated between the couples 32 and 33 is dependent upon the temperature rise of the fluid flowing through the secondary chamber. The respective couples of the primary chamber are purposely so connected with those of the secondary chamber that their respective differential electromotive forces oppose one another; hence, when a substantially equal temperature rise occurs in both combustion chambers, the net resulting electromotive force at the lead terminals 34 and 38 will neutralize and equal zero. On the other hand, should the temperature rise in one chamber become larger than the other, this will generate a proportionate electromotive force whose polarity or direction will depend upon which of the two chambers is subjected to a higher temperature rise. The delicate relay 50 responds to such electrical stimulation and starts the auxiliary motor 52 in a proper direction. The idler 57 is thereupon shifted into a new position of adjustment, the control arrangement being such as to automatically regulate and thereby maintain an equalized temperature rise within the respective combustion chambers. Like results may be obtained by the use of a special Wheatstone bridge circuit that is more fully described in my prior application, Serial No. 477,888.

When by suitable means, the temperature of the fluid going into the primary passageway 12A is kept substantially identical with that entering the second ary passageway 12B, the thermocouples 30 and 32 may be dispensed with, since the desired thermal balance would be detected by use of the couples 31 and 33 alone. It is pointed out that regardless of the type or nature of the temperature sensitive device that may be employed, its purpose as herein contemplated, is not to actually measure a particular temperature nor even a given rise in temperature, but rather to automatically actuate a suitable temperature responsive device capable of bringing about an equality of temperature rise in the same working fluid weight that successively flows through the component chambers of my calorimeter irrespective of the use of any intermediary cooling means.

Owing to the accretion imparted by the slight addition of consumed gas, the weight of the discharged working fluid is slightly in excess of the fresh air originally fed into the duct 26. Since the weight of gas burned is insignificant relative to the amount of total air passed through my calorimeter, the resulting error is a negligible one. By intercooling the working fluid before undertaking to reheat the same, the radiation and internal conduction losses in the primary and secondary calorimeters are substantially balanced and made to neutralize each other.

Furthermore, no correction becomes necessary for a change in average specific heat of the working fluid, which might otherwise need to be taken into account in the event the multiple calorimeters were operated at an unlike temperature range of considerable magnitude. The cited preheating step also prevents moisture condensation even when the air entering section 26 is saturated with humidity. It will be observed that my instrument is also self-compensating as regards any barometric pressure change because both combustion chambers are kept identical in this respect.

As a further precaution against inaccurate temperature registrations, the imperforate crown plates lying directly over each test flame, protect the overlying thermocouple against direct radiant heat. The shield such as 27A serves a like purpose with respect to the mated thermostat 30. My improved radiation shield absorbs the impinging heat rays and converts such rays into sensible heat prior to reaching its contiguous thermocouple 30. The incoming air current sweeping between the somewhat warmer shield slats, carries off and returns to the test flame, most of the radiant heat that may have been dissipated in a direction counter to the air current flow in the passageway 12A. The accuracy of method on the part of my balanced thermal system is thereby kept inherently high, its error in determination has in actual practice, been found correct to within about one tenth percent.

It will be obvious that the disclosed calorimeter can also be manipulated without the use of the described cooperating adjuncts; also that as a simplification, it is not essential to resort to any intercooler, it being broadly within the scope of my invention to successively heat one and the same body of working fluid as applied to calorimeter purposes. Where a different temperature level prevails between the primary and the secondary combustion chambers, the slight discrepancy resulting from a change of specific heat in the working fluid, can readily be compensated for by correspondingly correcting the relative rates at which fuel is being fed to the respective test burners. In a like manner, other inherent instrument errors, such as a correction for the minor weight increase due to combustion products, may be allowed for by suitable calibration.

An outstanding advantage afforded by the described calorimeter instrumentalities, lies in the ease with which the accuracy of its performance and correctness of adjustment can be checked. For such purpose, standard gas is supplied to both pumps 61A and 61B and the calorimeter put into operation. If said pumps do deliver exactly the same amount of gas per revolution, then by placing the idler wheel 57 in its one to one ratio position, identical rates of heat output should be furnished by the respective test burners. However, owing to certain irregularities and different inherent pump characteristics, the secondary burner will usually require a slightly larger supply of standard gas than does the primary burner. Definite compensation for such inherent inequalities can readily be made by shifting the idler wheel to a corrected base reference position where the desired initial thermal balance does actually exist between both chambers. My calorimeter may be calibrated to read directly in British thermal heat units as corrected for standard conditions of temperature, barometric pressure and air humidity.

As a further modification of the same underlying principle, reference is had to Fig. 2. This disclosure is substantially similar to Fig. 1 as regards the calorimeter structure but provides for a different mode of control and measuring means. This simplified style of calorimeter is particularly intended for use in connection with illuminating gas plants or the like industries whose product is generally maintained at a substantially constant heating value. To avoid undue repetition, the numerals of all corresponding calorimeter elements shown in Fig. 2 will for identification, be advanced by 100 over those previously described in connection with Fig. 1 while reference numerals to parts not appearing in the latter, are placed in the 200 series.

The secondary pump 161B preferably handles standard reference gas and may be driven at constant speed by the motor 162 through the gearing 163 for delivery to the combustion chamber 110B. The primary pump 161A then furnishes the unknown sample gas to the chamber 110A and may be shaft driven from the motor 162 through two companion gear shift boxes 212 and 213, respectively adapted to selectively modify the shaft speed. Either of these gear boxes may at will independently alter the speed ratio between such metering pumps but which pumps are operated at relatively fixed speeds in conformity with the anticipated heating values of the aforesaid test gases. The auxiliary gear box 213 may be utilized to calibrate the index chart 159 in a manipulative manner that will presently be explained in detail. After having properly set the last named gear, the function of the adjusted gear box 212 during any given test run, is preferably confined to holding the respective gas deliveries to the test burners 119A and 119B in fixed relationship.

In my Fig. 2 embodiment, certain modifications have also been introduced in the temperature responsive control devices. It will be observed that the secondary chamber 110B is here equipt with two additional thermocouples 200 and 201 that are respectively located at the outlet and inlet regions of said chamber and arranged to

continuously generate an electromotive force that is directly proportionate to the prevailing temperature rise of the working fluid flowing through said chamber. The leads 203 and 205 coming from said additional couples are respectively connected to opposite ends A and B of a potentiometer slide wire 208, an adjustable resistance 207 being included in said circuit. The current flow through the slide wire 208 sets up a voltage drop between its center tap C and any given position of the sliding contact 209, which drop is made directly proportionate to the temperature rise imparted to the working fluid while flowing through the chamber 110B. The purpose of such supplementary, series connected thermocouples is to supply said slide wire with the required actuating current in a proportionate relation to the temperature rise occurring in the secondary combustion chamber.

The several cooperating thermocouples 130, 131, 132 and 133 are again connected in a manner such that when the temperature rise on the part of the working fluid flowing through the primary chamber 110A corresponds to that in the secondary chamber 110B, then no electromotive force will be effective at the terminals 134 and 138. The lead terminal 138 is connected to the tap C of the slide wire 208 while the lead terminal 134 is connected in series with the main control relay 150 through the sliding potentiometer contact 209 which latter is shiftably mounted upon a suitable carrier. This carrier may be slidably actuated by the screw 154 that is rotated by the reversible motor 152 through its gear 153; as in Fig. 1, the rotation of this screw is determined by the direction of the unbalanced electromotive force received by the relay 150 and which prevailing carrier position is similarly recorded upon the chart 159.

The mode of operation of my Fig. 2 calorimeter may be traced as follows: As a first step, the instrument is calibrated with standard gas as previously explained in connection with the Fig. 1 disclosure, except that the one to one pump speed ratio is secured by gear boxes 212 and 213. When the temperature rise in both the primary and secondary chambers becomes substantially identical, then no electromotive force will be generated by the bank of interconnected thermocouples 130, 131, 132, and 133. Owing to the current flow that is set up through the slide wire 208 by the thermocouples 200 and 201, a corresponding drop in voltage will occur between the tap point C of the slide wire and the location of its sliding contact 209. Such small potential head serves to start up the relay 150 and thereby actuate the motor 152 to bring about a proportionate displacement of the carrier until the desired degree of compensation has been attained. After correctly locating the reference position of the sliding contact, the middle of the index chart 159 is shifted to align with the stylus 158.

While manipulating the instrument for check purposes, the gear box 213 adjustably fixes any required correction in the pump speed ratio, this box being arranged to definitely alter the speed of the pump 161A in relation to that of the pump 161B so as to shift said stylus into a corrected reference position. Thereupon sample gas of unknown heating value is supplied to the primary metering pump 161A and any further pump speed adjustments required during a test run, may be confined to the gear shift box 212.

When the complementary combustion chambers are operated without intercooler means, then because of the successively increased temperatures, the mean specific heat of the working fluid flowing through the last chamber may become slightly greater than that prevailing in the first entered chamber. A minor discrepancy is attributable to combustion products that may be added in the last chamber. All such corrections may be effectively compensated for by a proper initial calibration of the respective fuel pump deliveries by which said last chamber is supplied with a slightly larger amount of fuel sufficient to maintain both component calorimeters in thermal balance. The pump delivery ratio is in part dependent upon the contemplated temperature range through which the instrument is intended to operate, to the end that the temperature rise in each of the respective combustion chambers may be kept substantially equalized. While the intercooler likewise rectifies the instrument readings, such provision is more largely intended to maintain correct test determinations in case the rate of air flow through the combustion chamber should widely differ from that under which the calorimeter was calibrated.

In the Fig. 2 disclosure, the relative temperature level of the working fluid need not be kept equal in both chambers, but instead allows a definite difference to occur and this difference in temperature rise changes directly with the heating value of the tested sample gas when the flow rate of working fluid is kept constant. The thermocouples of Fig. 2 automatically actuate the potentiometer in such fashion that the carrier movement is again made directly proportionate to a change in the heating value of the unknown gas.

In such application, the potentiometer is not used to measure the magnitude of temperature rise of the working fluid passing through one or both chambers, but to measure the difference between the rise of temperature in one chamber relative to the temperature rise occurring in the other chamber. Furthermore, the potentiometer registers the difference of two such differences as a percentage of the total temperature rise in the secondary chamber 110B.

If desired, an automatic potentiometer type of temperature recorder may likewise be used to register gas heating values, the only change being the center tapping of the slide wire. With this last arrangement, the thermocouple leads 134 and 206 would be connected directly to the galvanometer unit of the potentiometer recorder. It will be obvious that the described calorimeters can also be manipulated without the use of the automatic registering adjuncts, and that if desired, manual control can be effected by using a galvanometer or some other current sensitive device in place of the automatic control relay.

My prior application, Serial No. 477,888, operates in a manner essentially similar to the present calorimeter devices except that an adjustable electric heater coil is connected to a wattmeter or other power measuring instrument as a substitute for the present secondary chamber burner 29B in Fig. 1 or 129B in Fig. 2. A heating coil and wattmeter combination of this kind is shown in Fig. 3 and respectively designated by the numerals 300 and 301. Such combination may be used as a measurable reference basis against which to compare and balance the rate of heat output being delivered by the test flame in the primary chamber. The described reheating of a gaseous working fluid is believed to differ broadly from and to constitute a novel contribu-

tion over the prior calorimeter art. The same cooperative results can also be achieved when reversing the described heating steps by interchanging the primary test burner with the secondary test burner or its equivalent heating coil.

It is though that the foregoing rather explicit disclosure when taken in connection with the accompanying drawings, clearly teaches how to fabricate and manipulate my improved calorimeter. Other inherent advantages are thought to be made apparent to those skilled in the art, it being understood that I reserve the right to substantially modify the structural elements of my illustrative embodiments to meet commercial requirements, all without departing from the spirit and scope of my invention heretofore described and more particularly pointed out in the appended claims.

I claim:

1. A calorimeter of the multiple type comprising a pair of complementary heating chambers each provided with an intake port and a discharge port, conduit means operatively interconnecting the respective chambers in series, means establishing a flow of gaseous working fluid into and through the respective chambers, test flame means located within one such chamber and serving to initiate a temperature rise in the working fluid flowing therethrough, and measurable supplementary heating means located within the other chamber and serving to subject the same working fluid to a quantitatively measured heating effect sufficient to raise the temperature of said working fluid in a definite proportionate relationship to the aforesaid initial temperature rise.

2. A calorimeter comprising a pair of complementary heating chambers each provided with an intake and a discharge port, conduit means operatively interconnecting the respective chambers in series, means establishing a flow of gaseous working fluid through the respective chambers, test burner means located within one such chamber and serving to initiate a limited degree of temperature rise in the working fluid flowing therethrough, measurable supplementary heating means located within the other chamber and serving to subject the same working fluid to a quantitatively measured heating effect and thereby raise the temperature of said fluid a substantially like degree, and temperature responsive means for determining when a like degree of temperature rise has been attained in each of the repective chambers.

3. A calorimeter of the multiple upright type comprising a pair of complementary tubular combustion chambers that are vertically disposed and each provided with an intake port at the bottom end region thereof and a discharge port, at the upper end region thereof, an updraft test burner housed within each such chamber, conduit means operatively interconnecting the discharge port of one such chamber with the intake port of the other chamber, tubular cooler means disposed in the conduit means and between the respective conduit ends, and separate temperature responsive means located in each of said chambers.

4. A calorimeter of the multiple upright type comprising a pair of complementary tubular combustion chambers that are vertically disposed and each provided with an intake port at the bottom end region thereof and a discharge port at the upper end region thereof, an updraft test burner housed within one such chamber, conduit means operatively interconnecting the discharge port of one such chamber with the intake port of the other chamber, a heat exchanger including tubular intercooler means and a surrounding shell to constitute complementary heat exchanger compartments of which one such compartment is inbuilt into the aforesaid conduit as a component thereof, feed duct means for the other heat exchanger compartment, and a passageway interconnecting the last named compartment with the remaining intake port.

5. A calorimeter comprising a chamber of the tubular type of which one end region is provided with an intake port and the opposite end region is provided with a discharge port, a test burner mounted interiorly of said chamber, intercooler means disposed exteriorly of the chamber confines and comprising complementary compartments of which one such compartment communicates with the intake part and the other compartment communicate with the discharge port, means supplying fresh air to the intake port through its interconnected compartment, said air being thereupon heated by the burner and conveyed onward through said discharge port and the other intercooler compartment in a heat exchanging relationship with the fresh air being supplied to the aforesaid one compartment.

6. A calorimeter comprising a pair of component chambers each provided with an intake port and a discharge port, a heat exchanger comprising complementary compartments, conduit means interconnecting the discharge port of one such chamber with the intake port of the other chamber and which conduit delivers through one of the heat exchanger compartments, passageway means operatively connecting the companion heat exchange compartment for delivery to the remaining intake port, means supplying a continuous flow of working fluid to and through said companion compartment, a test burner disposed within the confines of the aforesaid one chamber, said working fluid being heated by said burner and conveyed onwardly into and through said conduit and serving to preheat the incoming working fluid supplied to said companion compartment.

7. A calorimeter of the multiple type comprising a pair of chambers that are cooperatively interconnected by conduit means, a test burner disposed in one such chamber and fed with a combustible of unknown heating value, measurable supplementary heating means disposed in the other chamber, and means delivering gaseous working fluid into and successively through both chambers, said test burner serving to heat the working fluid at a certain rate of input and the supplementary heating means subjecting the same fluid to a measured heating effect that shall be commensurate with the aforesaid certain input rate.

8. A calorimeter of the multiple type comprising complementary chambers that are cooperatively interconnected by conduit means, a test burner disposed in one such chamber and fed with a combustible of unknown heating value, measurable supplementary heating means disposed in the other chamber, means delivering gaseous working fluid successively through both chambers, said test burner serving to heat the working fluid at a certain input rate and the supplementary heating means serving to impart to the same working fluid a measured proportionate heating effect that is commensurate with the

aforesaid certain input rate, and temperature responsive means for each such chamber.

9. A calorimeter of the multiple type comprising complementary chambers that are cooperatively interconnected by conduit means, a test burner disposed in one such chamber and fed with a combustible of unknown heating value, measurable supplementary heating means disposed in the other chamber, means delivering gaseous working fluid successively through both chambers, said test burner serving to heat the working fluid at a certain input rate and the supplementary heating means serving to impart to the same working fluid a measured heating effect that is substantially balanced with respect to the aforesaid certain input rate, and temperature responsive means for each such chamber, said means being of the differential type arranged to make manifest when a balanced temperature rise has been achieved.

10. A calorimeter of the multiple type comprising complementary combustion chambers that are cooperatively interconnected by conduit means, cooler means disposed in the conduit means and between the respective conduit ends, a test burner arranged in one such chamber and fed with a combustible of unknown heating value, a supplementary test burner arranged in the other chamber and fed with standardized reference gas, and means delivering gaseous working fluid containing air successively through both chambers, one such burner serving to initially heat the working fluid prior to reaching the cooler means and the other burner serving to reheat the same working fluid subsequent to being cooled.

11. A calorimeter comprising a pair of conduit interconnected combustion chambers that are respectively provided with an inlet port admitting a common stream of gaseous working fluid containing air for delivery through both such chambers, a primary test burner operatively housed in one such chamber, primary metering means delivering a combustible of unknown heating value to said test burner, a secondary test burner operatively housed in the other combustion chamber, secondary metering means delivering a combustible of known heating value to the last named burner, and control means serving to alter the proportionate delivery between the primary and the secondary metering means.

12. A calorimeter comprising complementary communicating combustion chambers each provided with an inlet port respectively admitting therethrough a common gaseous working fluid containing air, a separate test burner operatively housed within each such chamber, a rotatable metering pump delivering a combustible of unknown heating value to one such test burner, another rotatable metering pump delivering a combustible of known heating value to the other burner, and drive means for actuating the metering pumps in unison, said drive including shiftable control means serving to selectively alter the speed ratio between said pumps.

13. A calorimeter comprising complementary communicating combustion chambers each provided with an inlet port which respective ports successively admit therethrough a common gaseous working fluid containing air, a separate test burner operatively housed within each such chamber, a rotatable metering pump delivering a combustible of unknown heating value to one such test burner, another rotatable metering pump delivering a combustible of known heating value to the other burner, an adjustable transmission mechanism including a pair of differential drums that are respectively connected to said metering pumps, said mechanism further including shiftable idler means operatively interposed between said drums, motive means arranged to directly drive one of said drums and to indirectly drive the companion drum through said idler means, and adjusting means for selectively shifting the position of the idler means.

14. A calorimeter comprising complementary communicating combustion chambers each provided with an inlet port which respective ports successively admit therethrough a common gaseous working fluid containing air, a separate test burner operatively housed within each such chamber, a rotatable metering pump delivering a combustible of unknown heating value to one such test burner, a second rotatable metering pump delivering a combustible of known heating value to the other burner, drive means for actuating the metering pumps in unison, said drive including shiftable control means serving to selectively alter the speed ratio between said pumps, stylographic pointer means arranged to shift in synchronism with the control means, and a chart serving to record the prevailing pointer position.

15. A calorimeter comprising complementary communicating combustion chambers each provided with an inlet port which respective ports successively admit therethrough a common working fluid containing air, a separate test burner operatively housed within each such chamber, a metering pump delivering a combustible of unknown heating value to one such test burner, a second metering pump delivering a combustible of known heating value to the other burner, adjustable transmission means driving the metering pumps in unison, said means including shiftable control means serving to selectively alter the delivery ratio between said pumps and thereby correspondingly change the rate of heat input imparted to the working fluid by the respective test burners, an electrical temperature responsive device for each such chamber, said devices being wired in opposition for differential action, relay means wired in a common circuit with the aforesaid devices, and a remote control motor commanded by said relay and serving to adjustably shift the aforesaid control means in response to current flow in said circuit.

16. A calorimeter comprising a pair of conduit interconnected chambers respectively provided with an inlet port admitting a common stream of gaseous working fluid containing air for delivery in series through both such chambers, a test burner operatively housed in one such chamber, and positively driven draft producing means serving to intensify the natural flow of working fluid through said chambers.

17. A calorimeter comprising a pair of conduit interconnected chambers respectively provided with an inlet port admitting therethrough a stream of gaseous working fluid containing air for delivery in series through both such chambers, a test burner operatively housed in one such chamber, and feed pipe means delivering a combustible to the burner, said means including a preheater loop section disposed within the aforesaid interconnecting conduit subjected to heat from the burner flame.

18. A calorimeter of the multiple type com-

prising a pair of complementary heating chambers each provided with an intake and a discharge port, conduit means operatively interconnecting the respective chambers in series, means establishing a flow of gaseous working fluid through the respective chambers, a test burner located within one such chamber and serving to initiate a temperature rise in the working fluid flowing therethrough, measurable supplementary heating means located in the other chamber and serving to subject the same working fluid to a quantitatively measured heating effect that raises the temperature of said working fluid in a proportionate relationship to the aforesaid initial temperature rise, temperature responsive means for each of said heating chambers, and actuated recorder means placed under the control of the respective temperature responsive means.

19. A calorimeter comprising a combustion chamber provided with an inlet port admitting a stream of gaseous working fluid thereto, a test burner operatively housed within said chamber, means responsive to the incoming temperature of the working fluid, and an antiradiation shield interposed between said thermometer means and the burner, said shield comprising a plurality of angle shaped slats spacedly stacked in superimposed relation and placed crosswise of the working fluid stream.

20. A calorimeter comprising a pair of complementary combustion chambers, each including upright tubular jacket means, a lining for each such combustion chamber that is interiorly spaced from the jacket thereof and cooperatively disposed to constitute an annular hermetically sealed vacuum chamber therebetween, a test flame housed within the lining of each such combustion chamber and which respective flames are protectively insulated by the vacuum chamber thereof, and conduit means serving to interconnect the top region of one such lining with the bottom region of the other lining.

21. A calorimeter comprising a longitudinally chambered jacket member, a tubular draft casing of which one end is closed and having crown delivery ports through said closed end region together with a draft intake port located at the opposite end thereof and which casing is telescopically entered into said jacket in a circumferentially spaced relationship, a test burner housed within said casing with its flame disposed intermediate the respective crown and draft ports thereof, means supplying a combustible to the burner, and means simultaneously supplying air to said draft port and also between the aforesaid circumferential spacing, said air flowing in a common direction toward said crown port and the products of combustion being continued onward in the aforesaid common direction.

22. A calorimeter comprising a combustion chamber including a tubular jacket member provided with a crown plate and an outlet tube depending from said plate, a test burner operatively housed within one end region of said jacket, and a tubular mixing box suspended from the free end of said outlet tube and located within the opposite jacket end region in a longitudinally spaced relation to the test burner, said box including an inflowing turbulence port that injects radially inward toward the box axis and having an axially disposed discharge port that delivers away from the test burner and through said outlet tube.

23. A calorimeter comprising a combustion chamber including an upright tubular jacket member, a crown plate for the upper end of said jacket, an outlet tube depending from said plate, a mixing box including inflowing turbulence ports and which box is carried by and delivers through said tube, a test burner mounted within the jacket confines beneath said box, and a temperature responsive device located within said tube.

24. A calorimeter of the multiple type comprising a pair of complementary heating chambers each provided with an intake and a discharge port, conduit means operatively interconnecting the respective chambers in series, means establishing a stream of gaseous working fluid through the respective chambers, a test burner located within one such chamber and serving to initiate a temperature rise in the working fluid flowing therethrough, measurable supplementary heating means located in the other chamber and serving to subject the same working fluid to a quantitatively measured heating effect sufficient to raise the temperature of said working fluid in a proportionate relationship to the aforesaid initial temperature rise, a pair of series connected thermocouples located respectively in advance of and behind the test flame, another pair of series connected thermocouples located respectively in advance of and behind said supplemental heating means, said pairs of thermocouples being respectively placed in the path of the stream of working fluid and made responsive to the rise in temperature thereof, and lead means interconnecting the aforesaid pairs of thermocouples in opposed relationship for differential action.

25. A calorimeter of the multiple type comprising a pair of complementary heating chambers each provided with an intake and a discharge port, conduit means operatively interconnecting the respective chambers in series, means establishing a current of gaseous working fluid through the respective chambers, separate heating means for each such chamber serving to raise the temperature of the working fluid flowing therethrough, temperature responsive means including a pair of series connected thermocouples respectively located in advance of and behind one of the aforesaid heating means and made responsive to the temperature rise occurring in said current, potentiometer slide wire means, and lead means operatively interconnecting such thermocouples with the respective end regions of said slide wire.

RAFAEL W. KEITH.

CERTIFICATE OF CORRECTION.

December 31, 193

Patent No. 2,026,180.

RAFAEL W. KEITH.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 8, second column, line 73-74, claim 17, strike out the words "subjected to heat from the burner flame"; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 3rd day of March, A. D. 1936.

Leslie Frazer
Acting Commissioner of Patents.

(Seal)