

Oct. 27, 1931.

T. R. HARRISON

1,829,649

ELECTRICAL GAS ANALYZING APPARATUS

Filed Nov. 12, 1925

2 Sheets-Sheet 1

Fig. 1,

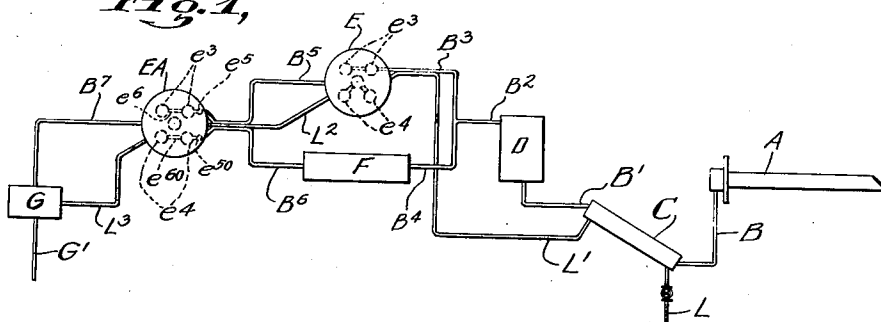


Fig. 2,

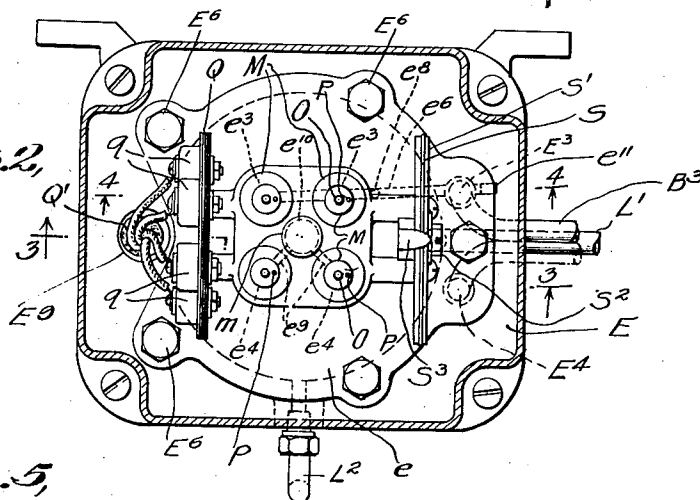


Fig. 5,

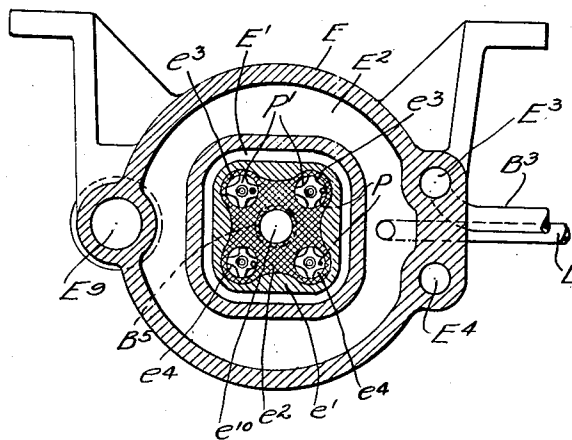
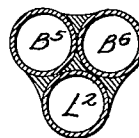


Fig. 6,



INVENTOR
Thomas R. Harrison
 BY
John E. Hubbard
 ATTORNEY

Oct. 27, 1931.

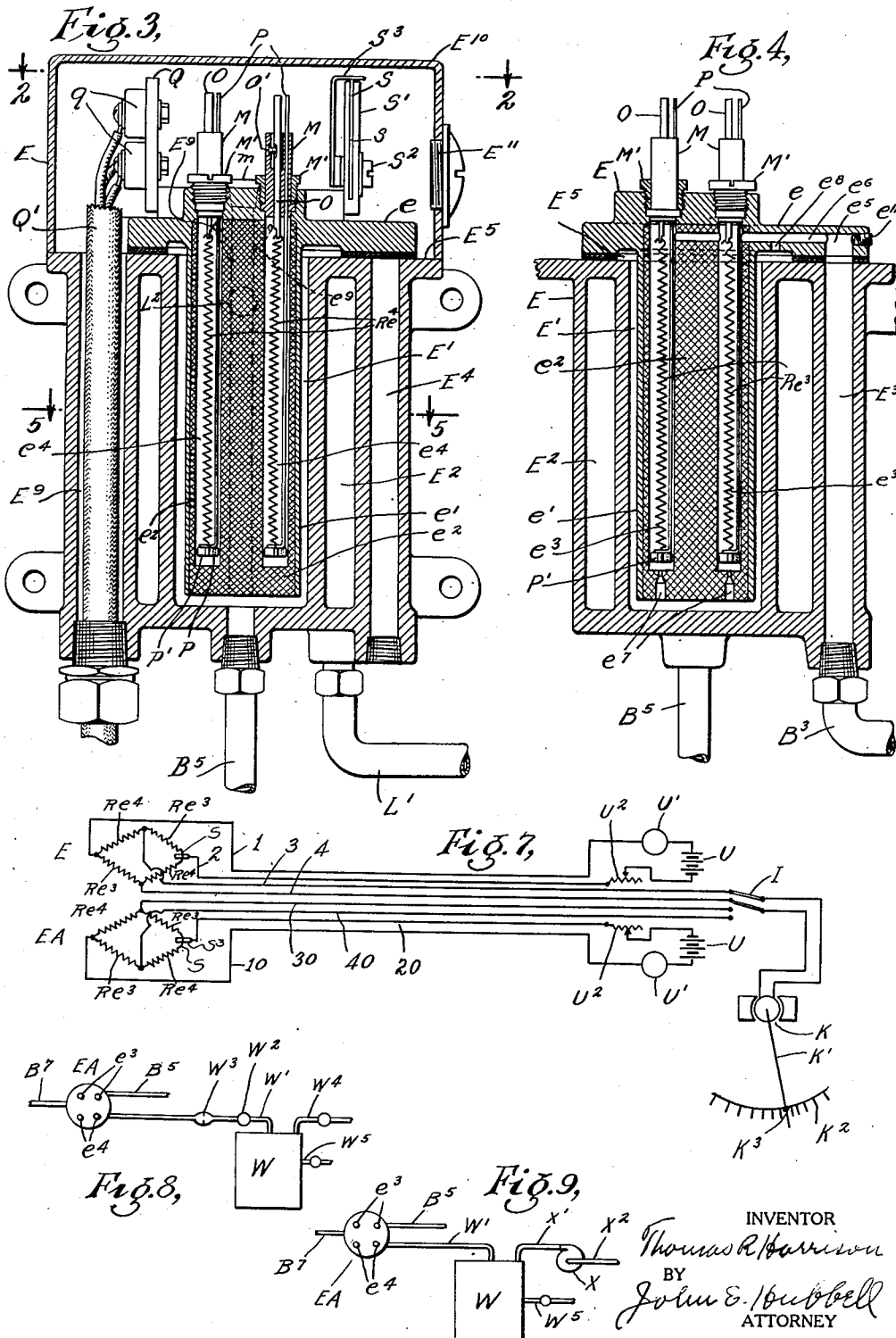
T. R. HARRISON

1,829,649

ELECTRICAL GAS ANALYZING APPARATUS

Filed Nov. 12, 1925

2 Sheets-Sheet 2



UNITED STATES PATENT OFFICE

THOMAS RANDOLPH HARRISON, OF PHILADELPHIA, PENNSYLVANIA, ASSIGNOR TO
THE BROWN INSTRUMENT COMPANY, OF PHILADELPHIA, PENNSYLVANIA, A COR-
PORATION OF PENNSYLVANIA

ELECTRICAL GAS ANALYZING APPARATUS

Application filed November 12, 1925. Serial No. 68,650.

The general object of my present invention is to provide improvements in apparatus for determining the composition of a gas by measuring or comparing electrical quantities which are dependent on the thermal conductivity of the gas, which depends in turn upon the composition of gas. My improved apparatus is like that heretofore known for the purpose in that it comprises a structure or housing containing cells in each of which is located a resistor, the resistance of which varies with the temperature of the resistor, and in that the temperature of each such resistor depends upon the heating effect of an electric current passing through it and upon the cooling effect of a body of gas filling the gas cell and conducting heat from the heated resistor to the surrounding wall of the cell. Usually such apparatus comprises at least one cell in which the corresponding resistor is surrounded by the gas to be analyzed and at least one other cell, the resistor in which is surrounded by a standard or comparison gas, which frequently is air, so that the composition of the gas to be analyzed is determined by a comparison of the resistance values of the different resistors which are ordinarily connected into a Wheatstone bridge.

My present invention comprises improvements in the cell containing structures which facilitate the proper construction of such structures at a relatively low cost of production.

The invention is further characterized by the provisions made for equalizing and regulating the temperatures of the resistors in the comparison cells and for regulating the temperature at which the test gas is introduced into the test gas cell. The invention is further characterized by the inclusion of means whereby the relative heat dissipating capacities of the resistors in the test and standard gas cells may be adjusted. In the preferred construction illustrated the heat dissipating capacity of each resistor may be independently adjusted. The invention in its preferred form is further characterized by the fact that each resistor comprises a body portion in the form of a helix the axis of which is disposed longitudinally of the elongated cell

in which the resistor is mounted and in that the terminals of each resistor are mounted in a closure part for one end of the corresponding cell so that the resistor and closure part constitute a resistor unit insertible in the cell through the end of the cell closed by said closure part in the assembled condition of the apparatus. With such a resistor unit the heat dissipating capacity of the resistor can be varied by adjusting one or both of the terminals relative to the closure part in which they are mounted so as to vary the convolution spacing of the resistor.

The invention is further characterized by the fact that the walls of the comparison gas cells, and particularly of the test gas cells, are formed of comparatively non-corrosive material such as lead which is materially more resistant to attack by corrosive furnace gases than are copper and brass which have heretofore ordinarily been employed as cell wall materials. It has been common practice in the past on account of this corrosive action of the gas to gold plate the interior wall of the brass cell. It has been difficult to secure a perfect and uniform coating by gold plating whereas if the cell walls are of lead, this difficulty is avoided. In addition to its high resistance to corrosion, lead is advantageous because convenient castings may be used which are less porous than cast brass, and with lead walled cells I avoid diffusion through the cell walls which is sometimes great enough to be objectionable when the cell walls are formed of cast brass. The invention is particularly useful in determining the CO and CO₂ contents of furnace gases, and comprises improved means for obtaining readily comparable measurements and records of the CO and CO₂ contents of the gases both of which must ordinarily be known to fully determine the character of the combustion conditions producing the furnace gases.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages and specific objects

attained by it, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described preferred embodiments of the invention.

Of the drawings:

Fig. 1 is a diagrammatic representation of apparatus for measuring the CO and CO₂ content of the flue gases;

Fig. 2 is a plan view of one of the comparison cell structures employed in Fig. 1, with the top cover broken away;

Fig. 3 is an elevation partly broken away and in section on the broken line 3—3 of Fig. 2;

Fig. 4 is a section on the line 4—4 of Fig. 2;

Fig. 5 is a section on the line 5—5 of Fig. 3;

Fig. 6 is a transverse section of piping employed in Fig. 1;

Fig. 7 is a diagram of circuit connections which may be employed with the apparatus shown in Fig. 1; and

Figs. 8 and 9 are diagrammatic representations of two different arrangements for continuously supplying a standard or comparison gas to a comparison cell structure.

The apparatus shown diagrammatically in Fig. 1, comprises a sampling tube A adapted to be inserted into the furnace chamber or flue from which furnace gases are to be withdrawn for analysis. The gases thus withdrawn from the sampling tube A pass through a pipe B to the inlet of a condenser C for eliminating moisture from the gases. From the condenser, the gases pass through a pipe B' to a filter D for eliminating furnace dust from the gases. The gas outlet pipe B² from the filter D, has two branches B³ and B⁴. The branch B³ leads to the gas inlet of a device E containing comparison cells for determining the CO₂ content of the gases. The gases entering the device E pass from the latter through a pipe B⁵ to a device EA containing comparison cells for determining the CO content of the gases withdrawn through the sampling tube A. The filter outlet pipe branch B⁴ leads to the inlet of a furnace F containing copper oxide or the like oxidizing agent for converting the CO content of the gases entering the furnace into CO₂. The gas thus modified passes from the furnace F through pipe B⁶ to the device EA. The gases entering the device EA through the pipes B⁵ and B⁶, are withdrawn from the device EA through a pipe B⁷ running to the inlet of an aspirator G in which water supplied under pressure through the pipe L³, creates the draft for causing the above described flow through the apparatus. G' represents the outlet from the aspirator through which the air, gas, and aspirating water are discharged.

As shown, the aspirating water is supplied from a pipe L and is utilized in cooling the

condenser C, the gases passing through the pipe B⁵ and B⁶, and the devices E and EA. For this purpose the supply pipe L is connected to the water inlet of the condenser C, and the water outlet of the condenser is connected by the pipe L' to a water inlet of the device E. The water outlet of the device E is connected to the water inlet of the device EA by a pipe L². The pipe L³ leads from the water outlet of the device EA to the aspirator G. Of the apparatus shown in Fig. 1, there is nothing specifically novel in the construction or use of the sampling tube A, condenser B, filter D, or oxidizing furnace F, but, on the contrary, these elements of the apparatus shown in Fig. 1, may well be of the known type.

The device E in the preferred construction illustrated in Figs. 2, 3, 4, and 5, comprises a cup shaped body member which may be made of cast iron or other suitable metal, and is formed with a water jacket space E² surrounding its main cavity E'. The cooling water supply pipe L' is connected to the bottom of the space E², and the cooling water outlet pipe L² is connected to the top of that space. As shown, the body member is formed with two vertical channels E³ and E⁴, the gas supply pipe B³ being connected to the lower end of the channel E³. At its upper end the body of the device E is provided with a seat E⁵ surrounding the cavity E' and against which is secured the flanged head of a member e, as by means of stud bolts E⁶, a gasket being advantageously interposed between the member e and seat E⁵ to prevent gas leakage.

The member e is provided with a depending portion e' which terminates a short distance above the bottom wall of the cavity E', and conforms more or less closely in cross sectional outline to the cavity E' but is smaller than the latter to provide a temperature equalizing gas space between the outer surface of the portion e' and the surrounding wall of the cavity E'. The member e may well be cast of a suitable metal as brass or lead, and is formed with a cavity which is open at its lower end and extends from the bottom of the portion e' up into the flanged head of the member, and is filled by a lead core e². The comparison resistance containing cells e³ and e⁴ are formed in the lead core e². As shown, there are two cells e³ which receive gas at their upper ends from the channel E³ through channels e⁵ and e⁶ formed in the brass portion of the member e. The cells e³ extend down through the lead core e² nearly to the bottom of the latter, and each communicates at its lower end through a restricted port e⁷ with the portion of the gas temperature equalizing space between the bottom wall of the cavity E' and the lower end of the portion e'. The gas outlet pipe B⁵ is connected to the last mentioned space. A portion of the gas entering the channel e⁵ passes

directly into the top of the equalizing space through a port e^8 . The cells e^4 , of which there are two in the construction illustrated, differ from the cells e^3 in having closed lower ends. Each cell e^4 communicates through a

leads or conductors of the device E which, as shown, are incorporated in a cable Q' advantageously entering the space under the hood E¹⁰ through a vertical channel E⁹ formed in the housing body.

The device EA may be identical in construction with the device E except that in the device EA the drying chamber e^{10} and the channel e^9 are not required and may be omitted, and in that the cells e^4 of the device EA are connected at their lower ends by ports e^7 with the space beneath the member e , and are connected at their upper ends by channels e^{50} and e^{60} to the channel E⁴ in the body of the device E. In the device EA the channel E⁴ is not closed as in the case of the device E. Instead the upper end of the channel E⁴ in device EA is open and a passage similar to passage e^6 connects the passage E⁴ with the gas receiving chambers e^4 , which in device E were used to contain the standard gas. The channel E⁴ of the device EA is connected at its lower end to the pipe B⁶, and the gas with its original CO content converted into CO₂ in the furnace F, is thus passed through the cells e^4 of the device EA, and is withdrawn from the latter through the pipe L³ along with the portion of furnace gases coming to the device EA from the device E through the pipe B⁵ which is connected to the lower end of the channel E³ and thereby to the upper ends of the cells e^3 of the device EA.

The channel E⁴ is not required in the device E and may be omitted. In general, however, it is desirable from a manufacturing standpoint, to have the devices E and EA as nearly alike as is possible, and the cast metal portions other than the lead core parts of the devices E and EA may, therefore, well be identical in form. An advantage of the cell containing structures illustrated is that they require a minimum of machining for their production. In general, the cast metal parts require no machining at all except drilling and tapping operations, and such grinding of their surfaces as may be required to fit the different parts together. The various channels in the body part of each of the devices E and EA may be formed by cores when the part is cast. The holes in the member e in register with cells e^3 and e^4 and with the drying chamber e^{10} when the latter is employed, ordinarily are drilled. After this the lead forming the core e^2 is poured into the portion e' , suitable cell forming pattern cores being then mounted in said holes. The channels or ports e^5 , e^6 , e^8 and e^9 or e^{50} and e^{60} , are then drilled. As shown, the channels e^9 are formed by drills extending into the cells e^4 through the upper ends of the latter. The outer ends of the channels e^9 and e^{60} are closed by screw plugs e^{11} .

To preliminarily cool the gases passing to the comparison cell devices E and EA, a por-

The upper end of each of the cells e^3 and e^4 is in register with a corresponding hole formed in the head of the member e , and shaped to provide a seat for a plug M closing the upper end of the cell and for threaded engagement with a gland M' securing the plug M in place. The plugs M closing the upper ends of the cells e^3 and e^4 may be all alike and are formed of insulating material. As shown, each plug M is formed with a central passage for a resistance terminal O in the form of a bar which extends through the plug, and may be secured in any desired axial adjustment therein by means of a set screw O'. The terminal bar O in each cell e^3 has its lower end secured to the upper end of a corresponding resistance Re³ which is in the form of a helix and has its lower end connected to a terminal P shown as a metal rod secured in a passage formed for the purpose in the corresponding plug M. As shown, the lower end of each terminal P carries a spider P' of insulating material for centering the lower end of the resistance in the corresponding cell without closing the latter. The terminal bars O extending into the upper ends of the cells e^4 , have their lower ends connected to the upper ends of helical resistances Re⁴ which have their lower ends supported by arms P and spiders P' just as do the resistances Re³. The upper end of the drying chamber e^{10} is closed by a plug m threaded into an opening formed in the head portion of the member e .

In the preferred construction illustrated, a so-called Wheatstone bridge balancing resistance in the form of a slide wire S, is mounted on the periphery of a semi-cylindrical block of bakelite or other insulating material S' secured to the head of the member e . The block S' has journaled in it a shaft S² carrying a brush S³ which bears against the resistance S at a point depending on the angular position of the shaft S². The latter, as shown, is provided with a kerf in one end to permit of its engagement and rotation by a screw driver or key which may be inserted through an opening E¹¹, normally closed by a screw plug, which is provided for the purpose in a metallic hood or cover E¹⁰ detachably mounted on the flanged head of the member E. In the construction shown, there is also secured to the top of the member e beneath the hood E¹⁰, a block Q of bakelite or other suitable insulating material which carries binding posts q through which the resistors Re³ and Re⁴ are connected to the terminal

tion of the pipe B^3 is arranged in a good heat transfer relation with a portion of the water supply pipe L' , and a portion of the pipe B^4 is arranged in a good heat transfer relation with portions of the pipes L^2 and B^3 . To further the transfer heat between the pipe portions, they may advantageously be placed in close contact as the pipes B^5 , B^4 , and L^2 are shown in Fig. 6, and brazed together.

In Fig. 7 I have illustrated diagrammatically, one form of circuit arrangements by which the resistances Re^3 and Re^4 of the devices E and EA may advantageously be employed in connection with a single meter K to exhibit in a readily comparable manner the CO, and CO₂ contents of the gases drawn into the apparatus through the sampling tube A. In Fig. 7, the two resistances Re^3 of the device E form opposing arms of a Wheatstone bridge, of which the other two arms are formed by the resistances Re^4 . The bridge is energized by a source of current as a battery U, conductors 1 and 2 connecting the battery to opposing junction points of the bridge. As shown, the conductor 2 is connected to the slide wire brush S' which forms one junction of the bridge, the slide wire resistance S connecting adjacent ends of one resistance Re^3 and one resistance Re^4 . U' represents an ammeter for measuring the bridge energizing current, and U² an adjustable resistance in the conductor 2 by which the strength of the bridge current can be regulated. The other two junction points of the bridge of the device E are connected by conductors 3 and 4 to terminals of a switch I.

The resistors Re^3 and Re^4 of device EA are connected into a Wheatstone bridge arranged, energized, and connected to terminals of the switch I as is the bridge of the device E. The connections to the bridge of the device EA comprise conductors 10, 20, 30, and 40 corresponding to the conductor 1, 2, 3, and 4, respectively, associated with the bridge of the device E. The switch I is intended for manual or automatic actuation to separately connect the two bridges in regular alternation to the winding of an indicating or recording galvanometer K. Advantageously, though not necessarily, the pointer K' of the meter K swings over the meter scale K² in one direction from the zero point K³ of the scale when connected by conductors 3 and 4 to the bridge E to thereby indicate the CO₂ content of the gas, and swings in the opposite direction from the zero point to indicate the CO content of the gas when the meter is connected through conductors 30 and 40 to the bridge of the device EA.

With the meter pointer thus swinging in opposite directions from the zero point of the instrument to indicate CO₂ and CO contents, respectively, the zero point is preferably located at one side of the center of the scale so that the instrument will give a wider range

of scale readings when measuring CO₂ than when measuring CO, which is desirable in view of the fact that the CO₂ variations will normally require a wider range of movement of the pointer for their proper indication than will the CO measurements. With the arrangement for this purpose shown in Fig. 7, the portion of the scale K² at the right of the zero point K³ will ordinarily be graduated in CO₂ percentage units, while the portion of the scale at the left of the zero point will be graduated in CO percentage units. When, as will be usually the case, the meter K is a recording meter, the location of the CO and CO₂ records at opposite sides of the zero line makes it unnecessary to have the two records made in different colors, though of course, they may be colored differently, but records in two colors will ordinarily be desirable, though not essential, if the instrument is arranged to have its pointer swing in the same direction from zero in making the CO and CO₂ records. Except as it may be desirable to have the above mentioned specially formed scale, the meter K and the switch I may be of known type.

As those skilled in the art will understand, when the instrument K is connected by the conductors 1 and 2 to the Wheatstone bridge of the device E and the bridge is properly energized and calibrated so that the pointer K will stand at the zero point when the resistors Re^3 and Re^4 are at the same temperature, the lower thermal conductivity of the CO₂ content of the gases in the cells e^3 as compared with the air in the cells e^4 , will cause the resistors Re^3 to be hotter and in consequence to have higher resistances than the resistors Re^4 by an amount which is dependent on the amount of CO₂ in the gases passing through the cells e^3 . Similarly when the bridge of the device EA is connected to the winding of the meter K, the instrument pointer K' will be deflected more or less according to the excess in the CO₂ content of the gases passing through the cells e^4 over the CO₂ of the gases passing through the cells e^3 , the CO in the gases passing through the cells e^3 having about the same thermal conductivity as air and other constituents, aside from CO₂, of ordinary furnace gases. It will be understood that in the Wheatstone bridges shown in Fig. 7, the same general operation would follow if one resistance Re^3 and one resistance Re^4 of each bridge were replaced by fixed resistance arms. The use of two resistances Re^3 and two resistances Re^4 , as shown, makes it unnecessary to provide fixed bridge resistance arms, while adding to the sensitiveness and range of the bridge indications. An advantage of the cell block and resistor mounting structure illustrated, is the ready feasibility of incorporating more than one pair of comparison cells in a single metallic block or body, since each cell block can be made large

enough to incorporate as many cells as may be required and the different resistors are insulated from the cell block.

In practice, the electrical determination of gas composition, based on the thermal conductivity of the gas, requires a comparison of effects due to the different thermal conductivities of the test gas and of a standard gas as the electrical quantities measured differ so slightly as to make absolute measurements based on the test gas alone, uncertain and unreliable. In comparing a test gas with a standard gas, the latter instead of being sealed in the cells e^4 of such a device as the device E described above, may be passed at a suitable rate through the cells e^4 of a device like the device EA. One arrangement by which a proper flow of a standard gas through the cells e^4 of a device EA may be maintained is illustrated in Fig. 8, wherein the cells e^3 are supplied with the test gas through the pipe B^5 as in the arrangement shown in Fig. 1, while a standard gas is supplied to the cells e^4 from a source of gas under pressure of gas as a tank W. To maintain a constant rate of flow through the pipe W' into the cells e^4 , the pipe W' is shown as provided with a pressure reducing valve W^2 , and with a measuring orifice W^3 between the valve W^2 and the cells e^4 . In Fig. 8, W^4 represents a valved filling connection for the tank W, and W^5 an outlet through which gas may be withdrawn from time to time for analysis by chemical or other suitable methods. Fig. 9 illustrates another form of apparatus for obtaining the same general result. The apparatus shown in Fig. 9 differs from that in Fig. 8, in that the tank W is employed as a flow equalizing reservoir which is interposed between the pipe W' and the outlet pipe X' of an air or gas pump X drawing the standard gas from the atmosphere or other source of supply through the pump inlet X^2 . The arrangement shown in Fig. 9, makes it unnecessary to employ the measuring orifice W^3 and reducing valve W^2 , and particularly the latter, of Fig. 8. With arrangements of the character shown in Fig. 8 and Fig. 9, the standard gas may be air or may be any other suitable and available gas, and in particular may be whatever available gas is best adapted for comparative purposes to the character of the particular gas being analyzed.

The apparatus disclosed possesses numerous important practical advantages. The accuracy of comparison cell measurements depends, of course, upon the elimination of all temperature differences between the cells compared except the difference which results from the different thermal conductivities of the gases in the cells. The provisions made herein for cooling the gases and equalizing temperature conditions in the devices E and EA, tend to eliminate temperature differences other than those upon which the operation of

the apparatus depends. The flow of water through the water jacket space E^2 of each of the devices E and EA tends, of course, to equalize the temperatures in the cell structure as a whole, and in conjunction with the preliminary cooling of the gas by heat transfer between the pipe B^3 and the pipe L' in the case of the device E, and by heat transfer between the pipes B^5 , B^6 and L^2 in the case of the device EA, tends to bring about a desirable equality in temperature of the gases entering the comparison cells and the metal walls of the cells. In addition to the temperature equalizing effect of the water cooling provisions, the reduction in gas temperature produced by those provisions is of itself a desirable matter as it tends to reduce the moisture content of the gases and thereby to eliminate the errors which variations in the moisture content of the gases produce.

The mechanical structure of the devices E and EA is obviously simple and desirable for reasons already explained. Furthermore, the fact that the gas cells are formed in a cell block separable from the body of each comparison cell structure, makes it possible to do rough mounting work including the attachment of all pipe connections to each such body before the corresponding cell block is put into place, and thus eliminates a source of injury by mechanical shock to the resistance filaments which are relatively delicate and easy to injure.

With the described construction, the resistors Re^3 or Re^4 , which are helical in form, are each connected at its opposite ends to rigid conductors O and P both mounted in the same insulation plug M. The axial adjustment of each of the terminal conductors O in its supporting plug M is an important characteristic of the apparatus since such adjustment permits of a variation of the temperature and thereby the resistance attained by the resistor under any given conditions of operation. This follows from the fact that the rate at which the resistor dissipates heat is increased, other things being equal, by spreading the resistor convolutions farther apart, and is diminished by bringing them closer together. This feature of the invention makes it readily possible to accurately calibrate the apparatus by first making the various resistors of the proper lengths to have equal resistances when carrying currents too small to produce appreciable heating, and then, after the cold resistances of the resistors are thus equalized, spacing the convolutions of the different resistors to equalize their resistances when the resistors are heated by a current large enough to produce an appreciable heating effect and are exposed to the same cooling conditions.

The resistor arrangement disclosed offers an easy method of obtaining a condition which has heretofore been impracticable to

obtain; namely, of having the bridge in balance when the test gas cells e^3 contain gas of normal or average composition, as for example furnace gases containing 14% of CO_2 , while the comparison cells e^4 contain a convenient standard gas such as air. In this case the convolutions of resistors Re^3 may be spaced further apart, or be wound with a larger diameter, to increase the cooling effect of the gas of relatively low thermal conductivity contained in cells e^3 . Since the distance between the resistor convolutions may be adjusted while the apparatus is in, or in condition for operation, the necessary adjustment may readily be made with each individual instrument, which is evidently impossible if different sizes of resistor wires are used for resistors Re^3 and Re^4 , or if different diameters are used for cells e^3 and e^4 as have heretofore been suggested. The method just described is superior also to the method of balancing the bridge when using unlike gases in cells e^3 and e^4 by adjustment of the slide wire S, because when the slide wire is placed in a position other than that which balances the bridge when the resistors are unheated, the meter reading will change when the bridge current varies slightly when "normal" gas is in cells e^3 . When balanced with normal gas no error is produced at this reading by the galvanometer temperature coefficient.

The disclosed mode of mounting the resistors in the cell blocks avoids all necessity for grounding the resistors to the cell block, and thus permits of the use of two resistors Re^3 and two resistors Re^4 mounted in a single cell block and connected in a single Wheatstone bridge as shown in Fig. 7 which is not possible when one end of each resistor is grounded by contact with the cell block, as has heretofore been the usual practice. The formation of the cells in a lead body is advantageous not only from the standpoint of simplicity and cheapness of the mechanical construction, but also because lead is not subject to injurious attack by sulphur compounds or other constituents of furnace gases which have a corrosive action on such metals as iron, copper, and brass. Lead, moreover, is sufficiently nonporous to prevent the pollution of the standard gas in the cells e^4 of the device E, for example, by the gas passing through the cells e^3 , as a result of gas diffusion through the pores of the cell wall, as would occur with a cast iron or brass cell block. The corrosion of the cell walls, if not otherwise objectionable, is to be avoided because it tends to vary the rate of heat transfer between the cell wall and the enclosed resistor.

Some indication of the importance of the desirable properties possessed by lead, in a material forming the walls of gas cells is afforded by the fact that it is now common commercial practice to form gas cells in a brass body and then to coat the cell walls with

another metal as gold notwithstanding the fact that it is difficult in the practical production of commercial apparatus to form a good gold plating on a brass cell wall.

A desirable feature of the cell block illustrated is the formation of what may be called the mouth of the gas cell in which the insulating block M is mounted, of brass or the like relatively strong metal rigidly interlocked with the cell containing lead body by casting the lead into recesses in, or about projections from the piece of stronger metal. This interlocking of the strong metal cell mouth piece and cell containing body can be obtained, of course, with strong metal parts very different in shape from the parts e shown in the drawings. For example, the part e may be replaced by a simple ring or collar cell mouth part imbedded in the lead cell containing body, by casting the latter about such mouth piece and a cell forming core part mounted in the mouth piece.

Certain novel features of the invention disclosed, but not claimed herein, are claimed in my copending application Serial No. 130,216, filed August 19, 1926, resulting in Patent Serial No. 1,818,619, granted August 11, 1931, which in certain respects is to be regarded as a continuation of the present application.

While in accordance with the provisions of the statutes, I have illustrated and described the best form of embodiment of my invention now known to me, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims and that in some cases certain features of my invention may be used to advantage without a corresponding use of other features.

Having now described my invention what I claim as new and desire to secure by Letters Patent is:

1. A cell block for use in measuring the thermal conductivity of a gas comprising a body of lead with a gas cell therein and a support for said body made of metal which is stronger than lead and formed with a hole in register with one end of said cell, and a resistor support mounted in said hole.

2. A cell block for use in apparatus for measuring the thermal conductivity of a gas comprising a body of lead, a member made of a metal stronger than lead and formed with a chamber open at one end and closed at the other in which said lead body is held and having a hole extending through the closed end of said chamber, and having a gas receiving cell formed in said lead body and communicating at one end with said hole.

3. A cell block for use in apparatus for measuring the thermal conductivity of a gas comprising a body of lead, a member made of a metal stronger than lead and formed

with a chamber open at one end and closed at the other in which said lead body is held, and having a hole extending through the closed end of said chamber and having a gas receiving cell formed in said lead body and communicating at one end with said hole, and a resistor support mounted in said hole and closing the corresponding end of said cell.

4. A cell block for use in apparatus for measuring the thermal conductivity of a gas comprising a body of lead, a member made of a metal stronger than lead and formed with a chamber open at one end and closed at the other in which said lead body is held and having a hole extending through the closed end of said chamber, and having a gas receiving cell formed in said lead body and communicating at one end with said hole, and a gas passage communicating with said cell and formed partly in said lead body and partly in said member.

5. Apparatus for measuring the thermal conductivity of a gas comprising a metallic body member formed with a chamber open at one end and closed at the other and a cell block formed with a gas cell and extending into said chamber through the open end thereof and separated from the surrounding wall thereof by a gas receiving temperature equalizing space.

6. A cell structure for use in determining the thermal conductivity of a gas comprising a metallic body member formed with a chamber, a water jacket space surrounding said chamber, and a cell block removably received in said chamber and separated from the surrounding wall thereof by a gas receiving temperature equalizing space.

7. In apparatus for measuring the thermal conductivity of a gas, a body part formed with a cell block cavity, a water jacket space surrounding said cavity, and a gas channel, pipe connections to said body part for passing water through said jacket space and for passing gas through said channel, and a cell block formed with a gas cell and a channel communicating with said cell and adapted to be detachably secured to said body part with the portion of the block containing said cell received in said cavity and with the channel in said cell block in communication with the channel in said body part.

8. In apparatus for measuring the thermal conductivity of a gas, a cell block formed with a cell open at one end, a body of insulation mounted in the open end of the cell, terminal conductors carried by said body and extending into said cell, and a resistor located in said cell and having one end connected to one of said terminal conductors adjacent one end of the cell and having its opposite end connected to the other terminal conductor adjacent the opposite end of the cell.

9. In apparatus for measuring the thermal

conductivity of a gas, a cell block formed with a cell open at one end, a body of insulation mounted in the open end of the cell, terminal conductors carried by said body and extending into said cell, and a resistor located in said cell and having one end connected to one of said terminal conductors adjacent one end of the cell and having its opposite end connected to the other terminal conductor adjacent the opposite end of the cell, one of said conductors being adjustable in said body in the direction of the length of the cell.

10. In gas analysis apparatus, a cell block formed with a cell open at one end, a body of insulation mounted in the open end of the cell, terminal conductors carried by said body and extending into said cell and a helical resistor located in said cell and having one end connected to one of said terminal conductors adjacent one end of the cell and having its opposite end connected to the other terminal conductor adjacent the opposite end of the cell, and means for relatively adjusting said terminal conductors axially of the cell.

11. In apparatus for measuring the thermal conductivity of a gas, a body part formed with a cell block cavity and with a gas channel, and a cell block formed with a gas cell and with a channel communicating with said cell, and adapted to be detachably secured to said body part with the portion of the block containing said cell received in said cavity and with the channel in said cell block in communication with the channel in said body part.

12. A cell block for use in measuring the thermal conductivity of a gas comprising a body of lead having a gas cell formed therein, and a piece of metal which is stronger than lead and which is formed with a hole constituting an extension of said cell at one end of the latter, and which is imbedded in said lead body.

13. A resistor unit comprising a supporting part adapted to form a closure for one end of a cell chamber of gas analysis apparatus, a helical resistor adapted to be inserted in said cell chamber, and means including a terminal of said resistor connecting the latter to said supporting part and adjustable to vary the convolution spacing of said resistor.

14. In gas analysis apparatus comprising a cell chamber open at one end and a resistor unit insertible in said cell chamber through the open end thereof comprising a resistor supporting part forming a removable closure for said open cell chamber end, a helical resistor, and means connecting said resistor to said part and adjustable to vary the spacing of the convolution of said resistor.

15. In gas analysis apparatus comprising a cell chamber open at one end and a resistor

unit insertible in each cell chamber through the open end thereof comprising a body adapted to be mounted in and close said open chamber end, and a helical resistor having terminals passing through said body, said body and terminals being relatively adjustable to vary the spacing of the resistor convolutions.

16. In gas analysis apparatus comprising a cell chamber, a resistor located in said cell chamber, and adjustable means for varying the heat dissipating capacity of the resistor.

17. In gas analysis apparatus comprising a cell chamber, a resistor located in said cell chamber, and means including a part extending through the cell chamber wall for adjusting the heat dissipating capacity of said resistor.

18. In apparatus for gas analysis comprising a cell chamber, a resistor mounted in said chamber, and means for adjusting said resistor in said chamber to vary its heat dissipating capacity.

19. In apparatus for gas analysis comprising a cell structure formed with a cell chamber, a resistor mounted in said chamber, and means for relatively adjusting said structure and resistor to vary the rate of heat transfer between the resistor and the structure.

20. In apparatus for gas analysis comprising a cell chamber, a helical resistor within said chamber, and supporting means for said resistor adjustable to vary the convolution spacing of said resistor.

21. In gas analysis apparatus comprising a test gas cell, a comparison cell, a resistor in each cell, and means for adjusting the heat dissipating capacity of one of said resistors.

22. In gas analysis apparatus comprising a test gas cell, a comparison gas cell, a helical resistor in each cell, the two resistors having the same resistance value when cold, and means for adjusting the convolution spacing of one of said resistors to regulate the relative resistance values of the two resistors when heated.

23. A device for use in determining the thermal conductivity of a gas comprising a metallic body member formed with a chamber, a cell block received in said chamber and separated from the surrounding wall thereof by a gas receiving, temperature equalizing space and formed with a cell communicating at one of its ends with said space, means for withdrawing gas from said space, and means for separately supplying gas to said space and to said cell at its second end.

24. Gas analysis apparatus comprising in combination a cell structure including a standard gas cell, a test gas cell, a resistor in each cell spaced from the walls thereof and arranged for heat dissipation therefrom through the gas and cell structure, an electrical indicating instrument and an energiz-

ing and balancing circuit into which said resistors and instrument are connected, said resistors having such resistances when cold, and relative heat dissipating effects that with the circuit balanced to give zero instrument deflection when the resistors are cold the instrument will also give zero deflection when the resistors are at the normal temperatures attained in operation with a gas in the test gas cell having a particular thermal conductivity which is different from that of the standard gas.

25. A cell structure for use in determining the thermal conductivity of a gas comprising a metallic body member formed with a chamber and a cell block, received in said chamber and separated from the chamber wall thereof by a gas receiving, temperature equalizing space.

26. A gas analysis apparatus comprising thermal conductivity cells for the reference gas and for the analysis gas, resistance heating elements in each cell, and means associated with the heating elements of the respective cells for equalizing the heat dissipation of the cells.

27. In apparatus for analysis of fluids by thermal conductivity having a unit comprising a body provided with a chamber to receive fluid and a heating element in said chamber, said unit being constructed and arranged for substantial dissipation of heat from said heater through said fluid and body, and means operating on said unit for adjusting the relative positions of parts of said unit to thereby vary the heat dissipation from the element.

28. In apparatus for analysis of fluids by thermal conductivity having a unit comprising a body provided with a chamber to receive fluid and a heating element in said chamber, said unit being constructed and arranged for substantial dissipation of heat from the element through the fluid and body, and means available exteriorly of and operating on the unit for adjustment for adjusting the relative positions of parts of said unit to vary the heat dissipating capacity of said unit.

29. In apparatus for analysis of fluids by thermal conductivity having a unit comprising a body provided with a chamber to receive fluid and a heating element in said chamber, said unit being constructed and arranged for substantial dissipation of heat from the element through the fluid and body, and mechanical means available exteriorly of the unit operable to vary the spatial relation of the heating element and the fluid in heat transfer relation therewith for varying the rate of heat dissipation from said element.

30. In apparatus for analysis of fluids by thermal conductivity having a unit comprising a body provided with a chamber to receive fluid and a heating element in said chamber,

said unit being constructed and arranged for substantial dissipation of heat from the element through the fluid and body, and means operable to vary the spatial relation of the heating element and the fluid in heat transfer relation therewith for varying the rate of heat dissipation from said element.

31. In apparatus for analysis of fluids by thermal conductivity having a body provided with a chamber to receive fluid, a heating element arranged in said chamber for substantial heat dissipation through the fluid and body, and means for adjusting the area of contact effective for heat transfer between the fluid and the element and chamber walls.

32. In apparatus for analysis of fluids by thermal conductivity having a body provided with a fluid receiving chamber open at one end, a unit insertable into said chamber through said open end, said unit comprising a closure for the open end and a heating element carried by said closure, and means operable to vary the spatial relation of the heating element and the gas in heat transfer relation therewith for varying the rate of heat dissipation from said element.

33. In apparatus for analysis of fluids by thermal conductivity having a test cell and a standard cell, each cell being provided with a fluid receiving chamber, a heating resistor in each cell arranged for substantial heat dissipation through the fluid, a Wheatstone bridge containing said resistors, means for balancing said bridge when the heating resistors, fluids and cells are in a steady temperature state, and means operating to modify the heat dissipation of at least one system comprising cell, resistor, and fluid, adjustable to balance said bridge at a different steady temperature state.

34. In a gas analysis apparatus having a cell structure including a standard gas cell, a test gas cell, a resistor for each cell arranged for dissipation of heat through gas within the cell by thermal conductivity, a Wheatstone bridge containing said resistors, electrical means for balancing the bridge when the resistors are cold, and means for adjusting the capacity of the system, comprising the cell structure and gas and resistors contained therein, for dissipating heat from the resistors so as to balance the bridge when the resistors are at operating temperatures and the test gas cell contains gas of predetermined composition and the standard gas cell contains a standard gas.

35. Apparatus for the analysis of gas having a pair of cells, a gas sampling device, a gas conditioning device, pipe connections to convey gas from the sampling device to the conditioning device, pipe connections to convey gas from the conditioning device to a cell, a gas pump for causing gas to flow through said sampling device, conditioning device and cell, a comparison gas in the other

cell, a resistor in each cell, a Wheatstone bridge containing said resistors, each cell together with the resistor and fluid contained therein forming a unit, means for adjusting at least one unit to vary the rate of heat dissipation from the resistor.

36. Apparatus for the analysis of gas having a pair of cells, a gas sampling device, a gas conditioning device, pipe connections to convey gas from the sampling device to the conditioning device, pipe connections to convey gas from the conditioning device to a cell, a gas pump for causing gas to flow through said sampling device, conditioning device and cell, a comparison gas in the other cell, a resistor in each cell, a Wheatstone bridge containing said resistors, said resistors being above room temperature in normal operation, and adjustable means operable to vary the spatial relation of at least one resistor and the gas in heat transfer relation therewith for varying the rate of heat dissipation from said resistor.

37. A thermal gas analysis structure comprising a cell body formed with an elongated gas receiving cell chamber, an elongated resistor in said chamber extending longitudinally of the chamber and separated from the surrounding wall of the latter by a gas space, and means including an operable part extending through the chamber wall for varying the cross sectional area of the portion of said gas space through which heat may pass in a direction transverse to the length of the chamber from said resistor to the surrounding chamber wall.

38. A thermal gas analysis structure comprising a cell body formed with an elongated gas receiving cell chamber, a resistor in said chamber in the form of an elongated helix extending longitudinally of the chamber and separated from the surrounding wall of the latter by a gas space, and means including an operable part extending through the chamber wall for varying the cross sectional area of the portion of said gas space through which heat may pass in a direction transverse to the length of the chamber from said resistor to the surrounding chamber wall.

Signed at Philadelphia, in the county of Philadelphia, and State of Pennsylvania, this 10th day of November A. D. 1925.

THOMAS RANDOLPH HARRISON.