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METHOD OF AND APPARATUS FOR CONTROLLING THE COMBUSTION OF FUEL IN FURNACES

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Fig. 1.

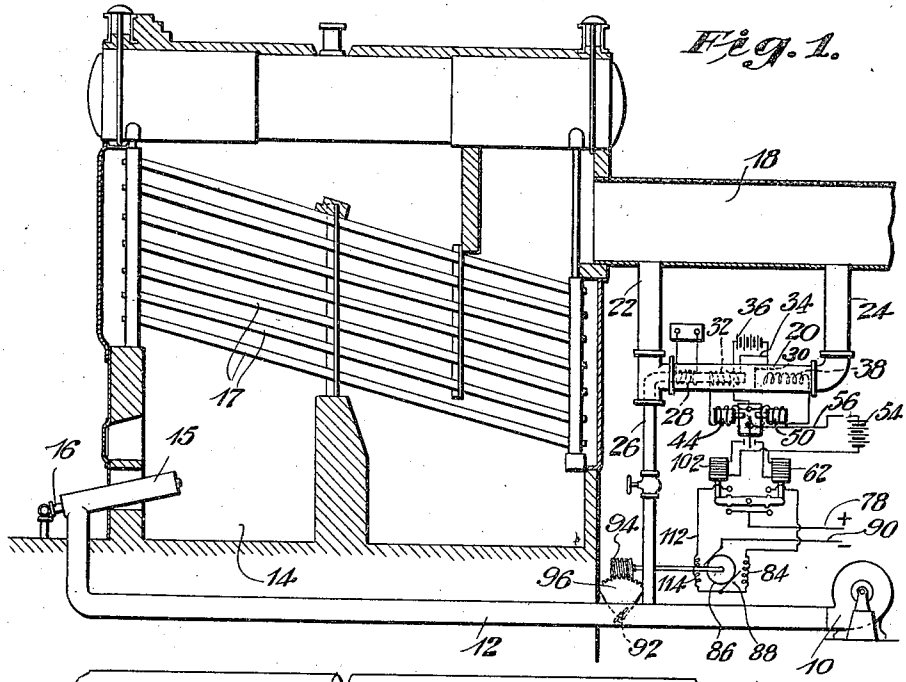
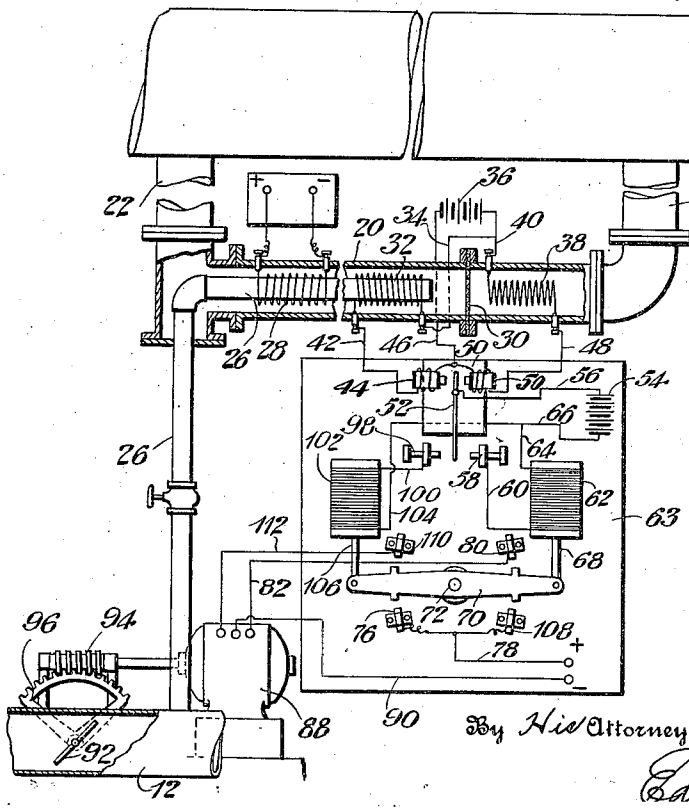


Fig. 2.



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UNITED STATES PATENT OFFICE.

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METHOD OF AND APPARATUS FOR CONTROLLING THE COMBUSTION OF FUEL IN FURNACES.

Application filed February 12, 1920. Serial No. 358,017.

This invention relates to a method of and apparatus for controlling the combustion of fuel in a furnace and more particularly to a combustion controlling method and apparatus in which the combustion of fuel is controlled by the composition of the flue gases to obtain the most effective ventilation for the complete combustion of the fuel.

To obtain perfect combustion of fuel, it is essential that sufficient air be supplied to the furnace to completely burn all of the fuel and prevent any unburned combustible gases from passing out of the furnace with the flue gases. However, in order to obtain the most efficient utilization of the heat of combustion with the most advantageous flame temperatures, a large excess of air over that necessary for complete combustion must be avoided. An excess of air tends to lower the efficiency of a steam boiler because it cools the flame, thereby intefering with combustion and increases the volume of the flue gases, thereby increasing the quantity of heat absorbed in heating the excess gases and the quantity of heat carried from the furnace by the exhaust gases. The heat losses caused by incomplete combustion of the fuel are, however, greater than those due to the use of excessive air, since the heat absorbed in heating the excess air from atmospheric temperature to the temperature of the flue gases is but a fraction of the quantity of heat involved in the combustion of an equal amount of fuel gases. It is, therefore, desirable to so control combustion as to avoid the occurrence of unconsumed combustible gases in the combustion products even though a small amount of free oxygen may also be present due to air leakage or lack of uniformity in the distribution of air to the fire box.

The presence of unconsumed combustible gases in the products of combustion may, in certain cases, be indirectly detected by a determination of the amount of carbon dioxide in the flue gases and a knowledge of the empirical relation between the percentage of carbon dioxide and the quantity of unconsumed combustible gases. For instance, in the combustion of a fuel which is composed almost entirely of carbon, nearly all of the oxygen of the air combines with carbon to form carbon dioxide, and the percentage of carbon dioxide in the flue gases when perfect combustion is obtained will accordingly be approximately the same as the percentage of oxygen in the air. If the composition of the fuel is changed, or if fuels having varying proportions of carbon and hydrogen are used, or if there is an air leak or an unevenness in the fuel bed or in the draft, the regulation of the combustion will accordingly be rendered unreliable.

The primary object of the present invention is to provide a method of regulating the combustion of fuel in a furnace in which the supply of gases for supporting combustion in the furnace is controlled directly by the quantity of unconsumed fuel gases in the products of combustion from said furnace.

Another object of the invention is to provide an apparatus for regulating the combustion of fuel in a furnace by which the supply of gases for supporting combustion to said furnace is controlled by the quantity of unconsumed fuel gases in the products of combustion from said furnace.

Another object of the invention is to provide a method of controlling combustion by which the air for burning a liquid fuel may be directly and accurately controlled to give a substantially perfect combustion of the fuel.

A further object of the invention is to provide an apparatus in which the supply of gases for supporting combustion is continuously under the control of the composition of the flue gases.

With these and other objects in view, the invention consists in the process and apparatus described in the following specification and defined in the claims.

The various features of the invention are illustrated in the accompanying drawings, in which:

Fig. 1 is an elevation, partly in section, of a boiler furnace having a combustion regulator applied thereto, embodying the preferred form of the invention; and

Fig. 2 is a detailed sectional view of the combustion controlling mechanism.

In the embodiment of the invention

shown in the accompanying drawings, the combustion regulator is applied to an oil or gas burning steam boiler of the water tube type. Air for supporting the combustion of the fuel is forced by means of a fan 10 through an air supply conduit 12 to the fire box 14 of the boiler. The air from the conduit 12 flows through a burner 15 to which a fluid fuel (either oil or gas) is delivered by a valved pipe 16. From the fire box 14, the products of combustion pass back and forth through a bank of water tubes 17 and leave the boiler furnace through a flue 18.

In the operation of the furnace 14, a sample portion of the flue gases is withdrawn from the flue 18 and analyzed, and the analysis is used for increasing or decreasing the air supply. The flue gas to be analyzed is mixed with air or oxygen in a suitable container and the mixture is then heated to a temperature which is approximately the ignition temperature of any combustibles which may be contained in the flue gases. The temperature of the heated gas mixture is then measured by means of an electric resistance thermometer, and the mixture is passed through a contact or catalytic material to insure the complete combustion of any combustible material which may be present in the mixture. If there are any combustible substances in the flue gases, the temperature of the mixture of gases will be raised in passing through the contact material by an amount proportional to the quantity of combustibles in the gases. The temperature of the gases after passing through the contact material is measured by a second electric resistance thermometer. The electric resistance thermometers are connected in parallel in a battery circuit which includes in each parallel branch a solenoid positioned to create opposing electromagnetic forces. The resistance in each branch of the circuit is so adjusted that when the temperatures of the resistance thermometers are the same, the electromagnetic forces of the two solenoids will be equal and opposed. As the temperature of the gases surrounding the second thermometer rises, due to the presence of combustible gases in the sample of flue gas, the resistance through the thermometer increases, the current decreases correspondingly, and the electromagnetic forces generated by the solenoids become unequal. The resultant electromagnetic force of the solenoids, therefore, acts on a pivoted contact pointer which is positioned to alternately close, in alternate positions, an electric circuit for governing a motor which controls a damper in the pipe 12. The damper and its driving motor are so arranged that when contact is made due to a rise in temperature in the second electric resistance thermometer, the motor will be rotated in a direction to open the damper, while, when the contact is made in the opposite direction, the motor will be operated to close the damper.

To accomplish this, a small portion of the flue gases passing through the flue 18 is withdrawn through a gas sample container in the form of a shunt pipe 20 connected to the flue 18 at either end by branch pipes 22 and 24. Air for supporting the combustion of any combustible material passing through the shunt pipe 20 is introduced through a pipe 26 leading from the air supply conduit 12 and extending a distance into the pipe 20 in a direction parallel to the axis of the pipe. The temperature of the gases in the pipes 20 and 26 is raised to approximately the ignition temperature by means of an electric heating coil 28 within the pipe 20 and surrounding the pipe 26. At the exit end of the pipe 26 the air supplied from the pipe 26 is mixed with the sample of flue gases in the pipe 20, and the mixture of gases passes through a platinum gauze or other contact material 30 to insure the complete union of the oxygen from the pipe 26 with any combustibles drawn through the pipe 20. The mixture of gases then passes from the pipe 20 through the pipe 24 to the flue 18. The temperature of the mixture of gases entering through the pipes 20 and 26 before being ignited by the contact gauze 30 is measured by means of an electric resistance thermometer 32 connected through a branch circuit 34 to a battery or other source of electric current 36. The temperature of the gases after passing through the platinum gauze 30 is measured by means of an electric thermometer 38 connected to the battery 36 through a branch circuit 40. The electric current flowing through the resistance thermometers 32 and 38 is caused to excite opposing solenoids controlling an electromagnetic contact pointer.

For this purpose, the current from the battery 36 flowing through the branch circuit 34 and thermometer 32 is conducted through a wire 42 to a solenoid 44. From the solenoid 44 the current returns to the battery 36 through a return wire 46. Similarly, current from the battery 36 flows through the branch circuit 40, thermometer 38, and a wire 48 to a second solenoid 50 to create an electromagnetic force opposed to that of the solenoid 44. From the solenoid 50 the current returns through the return wire 46 to the battery 36. The resistances of the branch circuits comprising the thermometer coils 32 and 38 are so proportioned that when the temperatures at the two thermometers are the same, the electromagnetic forces set up by the solenoids 44 and 50 will be equal, and the resulting component of these two forces will be zero. However, as the temperature at the thermometer 38 becomes greater than that at the thermometer

32, the resistance through the thermometer 38 increases and a correspondingly smaller current is sent through the solenoid 50 than passes through the solenoid 44. As a result, the electromagnetic force generated by the solenoid 44 is greater than that generated by the solenoid 50, and the component of the forces resulting from this unequal excitation of the solenoids 44 and 50 acts on a contact pointer 52 to deflect the pointer to the right. As the temperature of the thermometer 38 falls to that of the thermometer 32, or is brought to a temperature slightly lower than that of the thermometer 32, due to the absence of any combustible material in the sample withdrawn from the flue 18, and to a slight cooling action due to the introduction of air through the pipe 26, the resistance in the circuit comprising the thermometer 38 becomes less than that in the circuit comprising the thermometer 32. As a result, a larger current flows through the solenoid 50 than through the solenoid 44 and the resultant electromagnetic force swings the pointer 52 to the left.

As the pointer 52 is deflected to the right or left by the changes in the temperature of the thermometers 32 and 38, it operates a controlling mechanism governing a damper-operating motor to drive the motor in opposite directions. In governing the direction of rotation of the damper and motor, the pointer 52 alternately makes contact between a source of electric current and one or the other of branch circuits governing an electromagnetic switch. The electromagnetic switch operates in one position of the pointer 52 to close one branch of a main electric circuit through one of two opposing field windings of the damper-operating motor. As the pointer 52 swings in the opposite direction, it operates the electromagnetic switch to close the circuit through the other field winding of the motor to drive the motor in the opposite direction. In this manner, as the pointer 52 swings back and forth, it controls the damper-operating motor to open or close the damper and thereby control the volume of air supplied through the air supply pipe 12.

In operating the electromagnetic switch, an electric current flows from a battery 54 through a main 56 to the contact pointer 52. As the contact pointer 52 swings to the right, it engages with a contact 58 and closes a circuit leading from the contact 58 through a wire 60 to a solenoid 62 of an electromagnetic switch 63. From the solenoid 62 the current returns through a branch wire 64 and a main return wire 66 to the battery 54. As the solenoid 62 is excited by the current from the battery 54, it draws upwardly a core 68 and deflects a pivoted lever 70 to which the core 68 is connected at its lower end. As the lever 70 is deflected on its pivot 72, it contacts with a contact 76 leading from an electric main 78 and a contact 80 leading to the damper operated motor. Current then flows from the main 78 through the contact 76, lever 70 and contact 80 to a branch circuit 82. From the branch circuit 82 the current flows through a field winding 84 (Fig. 1) and armature 86 of a motor 88 and returns through an electric main 90. As the current flows through the field winding 84 and the armature 86, the motor 88 rotates a damper 92, by means of a worm 94 and a gear segment 96, in a direction to open the damper. The rotation of the motor 88 and damper 92 is continued until air sufficient for complete combustion is admitted to the furnace. When this point is reached the temperature of the thermometer 38 will fall until the electromagnetic forces of the solenoids 44 and 50 become equal and the pointer 52 comes to a mid-position or is deflected to the left.

As the contact pointer 52 is deflected to the left, due to a drop in the temperature of the thermometer 38, contact is made between the contact pointer 52 and a contact 98 connected to the electromagnetic switch 63. When this contact is made, current from the battery 54 flows through the wires 56, pointer 52 and contact 98 to a branch circuit 100 leading to a solenoid 102 of the electromagnetic switch. From the solenoid 102 the current returns through a branch circuit 104 and the main return wire 66 to the battery 54. As the solenoid 102 is excited by the current, it draws upwardly a core 106 connected to the end of the lever 70 opposite that to which the core 68 is attached. As the core 106 is drawn upwardly by the solenoid 102, contact is made through the lever 70 between a contact 108 connected to the main 78 and a contact 110 leading through a branch circuit 112 to the motor 88. The current from the branch circuit 112 passes through a field winding 114 of the motor 88 which is oppositely wound from the field winding 84 and through the armature 86 to the electric main 90. As the current passes through the field winding 114 and armature 86, it reverses the field and rotates the motor 88 in the opposite direction. When the direction of rotation of the motor 88 is reversed, the damper 92 is rotated in the opposite direction to close the draft through the pipe 12.

The operation of the device is briefly as follows: Air for supporting combustion is forced by the fan 10 to the furnace 14 at a rate controlled by the position of the damper 92 in the air supply conduit. The products of combustion resulting from the combustion of fuel in the furnace 14 are withdrawn through the flue 18. If the quantity of air supplied through the conduit 12 is insufficient for complete combustion, part of the fuel supplied to the furnace will not be

completely burned and the products of combustion passing from the flue 18 will contain unburned combustible gases. A small representative portion of the flue products passing through the flue 18 is continually bypassed through the shunt tube 20 in which it is mixed with an excess of air supplied from the pipe 12 through the branch pipe 26. The by-passed flue gases and the air supplied through the pipe 26 are heated by the electric heater 28 to the ignition temperature of the combustibles in the flue gases, and are burned while passing through the contact gauze 30. The rise in temperature of the gases due to combustion, is determined by the electric thermometers 32 and 38 which measure the temperatures of the air and flue gas before and after passing through the gauze 30. When the products of combustion from the furnace 14 contain combustible gases, the temperature, and accordingly the resistance, of the thermometer 38 become greater than that of the thermometer 32, due to the burning of the combustibles in the mixture, and a larger current passes through the thermometer 32 and the coil 44 than passes through the thermometer 38 and the coil 50. The contact pointer 52 is accordingly deflected to the right and closes the circuit from the battery 54 through the solenoid 62. When the current passes through and energizes the solenoid 62, the lever 70 of the electromagnetic switch 63 is deflected to connect the electric main 78 through the wire 82 and field winding 84 of the motor 88. The motor 88 will thereupon be set in motion to rotate the worm 94 and the gear 96 and damper 92 towards open position. The draft from the air supply conduit 12 will thereupon be slowly increased and the amount of combustible gases passing through the flue 18 will gradually decrease. When the draft through the conduit 12 increases to a point at which the combustible gases passing through the flue 18 are reduced to a minimum, the rise in temperature of the gases upon being mixed with air is reduced until the resistances through the thermometers 32 and 38 and corresponding branch circuits are substantially equal and the pointer 52 is brought to its middle position. The electromagnetic switch 63 is accordingly opened and current ceases to pass to the motor 88 and rotate the damper 92. The resistance set up in the thermometer 32 serves as a standard of comparison from which to measure the heating effect of the burning flue gas contacted with thermometer 38.

If the supply of air becomes too great, due to a decrease in the supply of fuel or from other causes, the temperature of the flue gases passing through the shunt pipe 20 will be unchanged upon being mixed with the air supplied from the pipe 26, or may even be slightly cooled due to a small difference in the temperature of the flue gases and the air from the pipe 26. Accordingly, the resistance through the thermometer 32 and its branch circuit will become greater than the resistance through the thermometer 38 and its corresponding branch electric circuit, and the contact pointer 52 will be swung to the left to connect the batteries 54 with the solenoid 102 of the electromagnetic switch 63. Upon the passage of current through and the energizing of the solenoid 102, the lever 70 of the electromagnetic switch 63 is deflected to connect the main 78 with the branch circuit 112 and field winding 114 of the motor 88. The direction of rotation of the motor 88 and worm 94 is thereby reversed and the damper 92 is rotated towards closed position by the gear 96. The damper 92 continues to be slowly rotated to decrease the draft through the conduit 12 until the free oxygen in the flue 18, due to the excess of air, is reduced to a minimum and the pointer 52 is brought back to its middle position. In this manner the damper 92 is rotated towards an open or closed position as the quantity of combustibles in the flue gases from the furnace 14 increases beyond or falls below a small limiting quantity.

The analysis of the products of combustion by the above device need not be quantitative, since it is only necessary to determine whether a sufficient amount of combustible gases is present in the products of combustion to move the contact 52 into engagement with the contact 58 or whether there is a deficiency of combustible sufficient to cause the contact 52 to be moved into engagement with the contact 98. If the amount of combustible gas lies within these limits, it will have no further influence on the regulation of the device. The pointer 52 may, however, be arranged to indicate quantitatively the amount of combustible gases in the flue products by arranging it to swing past the contacts 58 and 98 after making contact.

The time required for the passage of the products of combustion from the combustion chamber 14 to the flue 18 and through the tube 20 is very short, being but a few seconds. Any change in the rate or conditions of combustion in the combustion chamber 14 is therefore indicated substantially instantaneously by the analyzing apparatus in the tube 20, and the motor 88 is instantly set in motion to gradually but rapidly change the position of the damper 92 to correspond to the changed conditions in the combustion chamber 14. The position of the damper 92 may vary from closed to fully open position as the supply of fuel increases from a small amount of practically full load. When the supply of fuel varies between these limits, the damper is operated to supply the minimum amount of air to insure complete com-

bustion of the fuel and remains in this position until an increase or decrease in the supply of fuel requires that the damper be moved towards a more open or closed position.

While the invention has been described in connection with a boiler fired with fluid fuel, it may be used with solid fuel and with other types of furnaces. In many types of metallurgical furnaces, such as are used for brass melting for example, it is necessary, in order to obtain the required temperature, to use only sufficient air to insure complete combustion, since an excess of air cools the flame and lowers the temperature of the furnace. When the above described regulator is used, the supply of air is limited to that which is just necessary to insure complete combustion of the fuel and the highest possible temperatures may be obtained. In some classes of metallurgical furnaces, such as for example annealing furnaces, it is necessary in order to prevent flaking and scaling of the metal under treatment to maintain a reducing atmosphere and to operate with a slight degree of under-ventilation and without complete combustion, for the reason that any excess of air in the products of combustion has a detrimental oxidizing effect on the work. Accordingly when the combustion regulator forming the subject of the present invention is used in connection with this latter type of furnace, the amount of air supplied is kept slightly below that which would be required to insure complete combustion of the fuel. The regulating device is preferably adjusted so as to maintain a small limited quantity of combustible in the flue gases during operation.

Other means for measuring the rise in temperature upon mixing the gases, and for controlling the operation of the damper by such rise in temperature, may be used in place of the apparatus specifically described above, without varying the general principle of the invention.

The method and apparatus of this invention are similar in certain of their broader aspects to the method and apparatus for controlling the combustion of fuel in a furnace, disclosed in my co-pending application, Serial No. 358,016, filed Feb. 12, 1920. The subject matter common to this application and application, Serial No. 358,016, is claimed in the latter application.

The terms "measure" and "measuring" have been used in the specification and claims as generic terms to define the essential function of a temperature measuring device, namely a thermometer. While the thermometers illustrated diagrammatically in the accompanying drawings do not include a showing of auxiliary recording apparatus for taking a visible record of the temperatures measured, it is believed to be clearly apparent that such recording apparatus is not a necessary part of the apparatus forming the subject of the present invention. Accordingly the terms "measure" and "measuring" as they are used in the present case are intended to define only the actual act of temperature measurement performed by themometers, and are not used or intended to define the further step performed by registering thermometers, namely that of recording the results of said measuring act in terms of visible conventional readings.

Having described the invention, what is claimed as new is:

1. A method of regulating the combustion of fuel in a furnace, comprising continuously withdrawing a portion of exhaust products of combustion from said furnace, mixing said portion with a quantity of air, burning any combustible gases in said products, and controlling the supply of combustion supporting gases to said furnace in accordance with the difference in temperature of said exhaust products before and after ignition of any combustible content thereof to maintain a minimum of combustible gases in said exhaust products.

2. A method of controlling the combustion of gases in a furnace, comprising continuously withdrawing a portion of the exhaust products of combustion from said furnace and mixing the same with a quantity of air, burning combustible gases in said products, and continuously controlling the gases supplied to said furnace for supporting combustion to increase the proportion of air supplied as the temperature in said portion rises after burning any combustibles.

3. A method of regulating the combustion of fuel in a furnace, comprising continuously withdrawing a portion of the exhaust products of combustion and mixing the same with a quantity of air, burning any combustibles in said portion with said air, and gradually varying the volume of combustion supporting-gases supplied to said furnace to maintain the temperatures of said exhaust gases before and after burning substantially equal.

4. A method of regulating the combustion of fuel gases in a furnace, comprising continuously testing the products of combustion from said furnace for unconsumed fuel gases and automatically varying the proportions of gases supplied to said furnace to support combustion to hold to a minimum the quantity of unconsumed fuel gases in said products of combustion.

5. A combustion regulator for furnaces which comprises means for withdrawing a sample of products of combustion from a furnace, means for mixing air with said sample, means for igniting said sample and air mixture, means for controlling the supply of combustion supporting gases to the furnace, and means responsive to the differ-

ence in temperature of said sample and air mixture before and after ignition for governing the operation of said controlling means.

6. A combustion regulator for furnaces, which comprises the combination of means for withdrawing a portion of the flue gases, means for mixing said portion of flue gases with air or oxygen, means for igniting said mixture, a set of resistance thermometers positioned to measure the temperature difference of said portion of gas and air before and after ignition, a contact pointer acted on in opposite directions by electric currents through said thermometers, a motor driven damper positioned to control the draft to said furnace, a motor for driving said damper, branch electric circuits connected to rotate said motor in opposite directions, and contacts on said circuits arranged to be alternately connected to a source of current by the movement of said contact pointer in opposite directions.

7. A combustion regulator for furnaces which comprises the combination of means for withdrawing a portion of the flue gases from said furnace, means for introducing air into said portion of flue gases, an electric heater for said air and portion of flue gases, means for mixing and igniting said flue gases and said air, an electric resistance thermometer positioned in said gases before ignition, a second electric resistance thermometer in said gases after ignition, means connecting said thermometers in parallel, a contact pointer actuated in opposite directions by said parallel circuits, and a motor for varying the supply of combustion supporting gases to said furnace controlled by the movement of said contact pointer.

8. A combustion regulator for furnaces comprising means for mixing a portion of the gaseous products of combustion from a furnace with a gas, means for bringing said gas mixture to approximately its ignition temperature, means for insuring the reaction of any combustible with any free oxygen in said mixture, means for supplying combustion supporting gas to the furnace, and means governed by the rise in temperature of said gas mixture due to said reaction for controlling the supply of combustion supporting gases to the furnace.

9. A method of regulating the combustion in a furnace, comprising testing the exhaust combustion products to detect any combustible material therein, supplying fuel and air to the furnace, and utilizing the test for continuously controlling the supply of air to the furnace in order to maintain a substantially complete combustion of said gases in the furnace.

10. A method of regulating the combustion in a furnace, comprising continuously testing the exhaust combustion products to detect any combustible material therein, and utilizing the test for continuously controlling the supply of gases for supporting combustion to maintain a substantially complete combustion of fuel in the furnace.

11. A method of regulating the combustion of fuel in a furnace comprising taking a sample of the exhaust combustion products, mixing the same with air, passing the mixture through a contact material to burn combustibles therein, and controlling the supply of combustion supporting gases to said furnace in accordance with the difference of temperature in said mixture before and after passing through said contact material.

12. A method of regulating combustion in a furnace, comprising taking a sample of the exhaust combustion products, mixing the same with air, heating the mixture to substantially the ignition temperature of any combustible in said products, passing the mixture through a contact material to burn the combustible therein, and utilizing the temperature difference of said mixture before and after passing it through the contact material for controlling the supply of combustion supporting gases to said furnace.

13. That step in the method of controlling combustion which comprises, mixing air with gas containing a low concentration of combustibles, burning the mixture and measuring the temperatures of said gas mixture before and after burning the same.

14. That step in the method of controlling combustion, comprising burning gas containing a low concentration of combustibles with a combustion catalyst, and measuring the temperatures of said gas before and after burning the same.

15. In a method of controlling combustion, the analysis of gas containing a low concentration of combustibles, comprising mixing air with said gas, heating said gas to approximately the ignition temperature of the combustibles, burning the mixture, and measuring the gas temperatures before and after burning the same.

16. That step in a method of controlling combustion, comprising passing a heated gas containing a low concentration of combustibles in contact with a first electric resistance coil, then burning the gas with a combustion catalyst, passing the burned gas into contact with a second resistance coil substantially similar to said first coil, and measuring the temperatures of the gas before and after combustion by the resistances of said coils.

17. The combination of a gas sample container, two resistance wires mounted in said container, an electric circuit for each wire, a contact member mounted in said container between said wires arranged to burn gas passing from one wire to the other, and means for indicating the difference in current flow through said wires.

18. The combination of a gas sample con-

tainer, two resistance wires mounted in said container, an electric circuit for each wire, means to introduce air into gas passing through said container before the gas reaches the first of said wires, a contact member mounted in said containers between said wires arranged to burn gas passing from one wire to the other, and means for indicating the difference in current flow thru said wires.

19. The combination of a gas sample container, a combustion catalyst mounted in said container in position to force gas passing through said container to flow through said catalyst, and separate means mounted in said container at opposite sides of said catalyst arranged to measure respectively the temperature of the gas before and after passing through said catalyst.

20. The combination of a gas sample container, means for causing flow of gas through the container, a combustion catalyst mounted in said container in the path of flow of the gas, means for mixing air with the gas flowing through said container, and separate means mounted in said container at opposite sides of said catalyst arranged to measure respectively the temperature of the gas before and after passing through said catalyst.

21. The combination with a furnace of means responsive to the presence of combustible constituents in the gaseous products of combustion leaving the furnace for automatically regulating the ratio between the rate at which fuel is actually burned in the furnace and the rate at which air is supplied thereto for the combustion of the fuel.

22. The combination with a furnace of means responsive to the presence of combustible constituents in the gaseous products leaving the furnace for automatically decreasing the ratio between the rate at which fuel is actually burned in the furnace and the rate at which air is supplied for its combustion on an increase in the relative amount of said combustible constituents in said products.

23. Apparatus for regulating combustion in a furnace comprising means for oxidizing combustible constituents of the gaseous products of combustion from the furnace, and means responsive to the amount of oxidation produced for automatically decreasing the ratio between the rate at which fuel is actually burned in the furnace and the rate at which air is supplied for its combustion, as the amount of said oxidation increases.

24. Apparatus for regulating combustion in a furnace comprising in combination means tending to maintain the ratio between the rate at which fuel is actually burned in the furnace and the rate at which air is supplied for its combustion in excess of that at which complete combustion occurs, and means automatically responsive to the presence of combustible constituents in the products of combustion leaving the furnace for decreasing said ratio as required to keep the amount of said constituents small.

25. The combination with a furnace having a combustion chamber, a fuel supplying means and an air supplying means, of means for automatically increasing and diminishing the air supplied as the amount of combustible constituents in the products of combustion leaving the furnace increases and diminishes.

26. The method of controlling furnace combustion which includes the steps of preheating flue gas from said furnace and causing the combustion of an unconsumed element of combustion remaining therein, and utilizing the increased temperature resulting from the combustion of said flue gas to control the supply of an element of combustion to the furnace.

27. A method of controlling furnace combustion which includes the steps of heating flue gas from said furnace to substantially its ignition temperature and burning an unconsumed element of combustion remaining therein, comparing the heating effect of a quantity of flue gas so treated with a standard of comparison, and regulating the supply of an element of combustion to the furnace in accordance with such comparison.

28. The method of controlling furnace combustion which includes exposing a temperature responsive means to flue gas, causing the combustion of an element of combustion remaining in said flue gas, exposing a second temperature responsive means to the increased temperature caused by reason of said combustion, and controlling the supply of an element of combustion to the furnace in accordance with said temperature responsive means, substantially as described.

29. Furnace control apparatus including means for causing combustion of an unconsumed element of combustion remaining in the flue gas of the furnace, and means actuated in accordance with the comparative heating effect of a quantity of gas so treated with a standard of comparison, such means being effective for controlling a supply of an element of combustion to the furnace, substantially as described.

In testimony whereof I affix my signature.

JOHN WILLIAM GRISWOLD.