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COMBUSTION CONTROL

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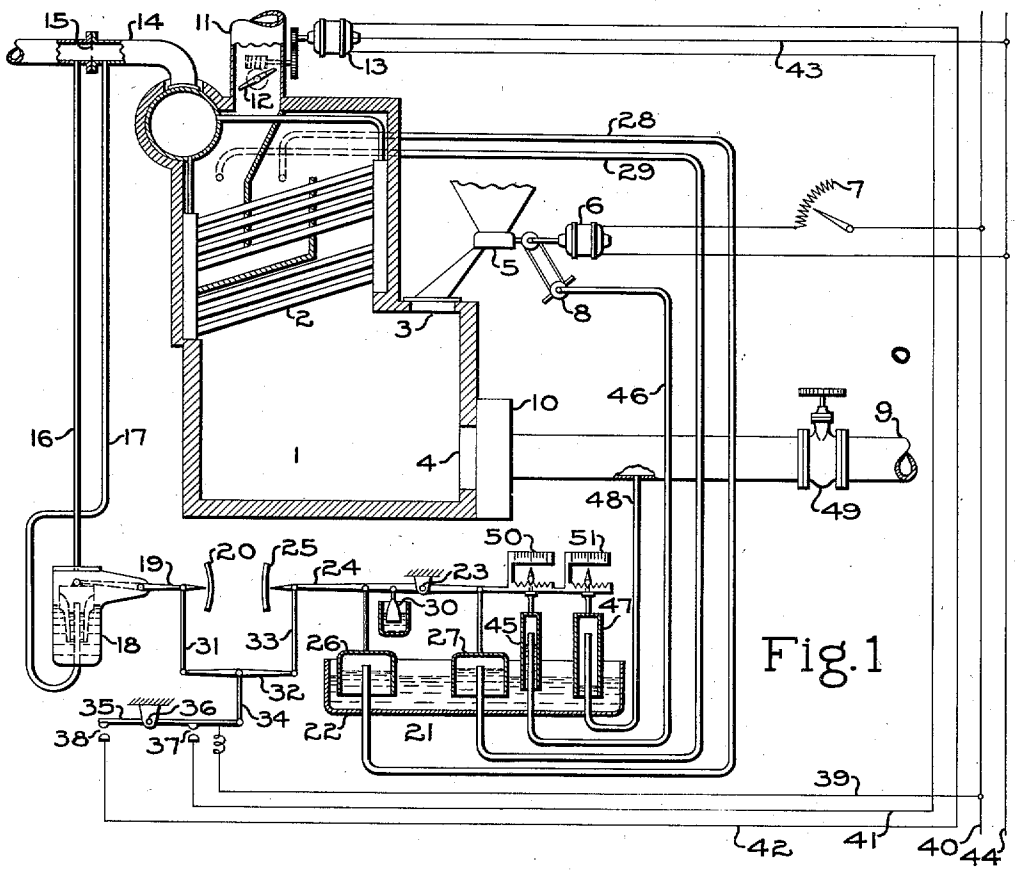


Fig.1

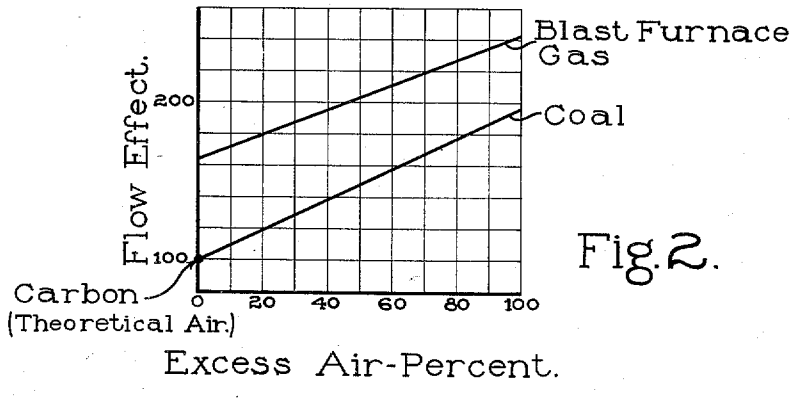


Fig.2.

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COMBUSTION CONTROL

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My invention relates to combustion control and especially to the control of the supply of air for combustion to the furnace of a vapor-generator or to heating furnaces in general, wherein the elements of combustion react to liberate heat, and where a plurality of fuels may be fed the furnace simultaneously and in any proportion.

Ordinarily a single fuel is burned in the furnace and an indication of combustion efficiency may be had through obtaining the relation existing between a measure of the air flow and a measure of output such as, for example, steam flow from a vapor-generator. Such indication of combustion efficiency may then be utilized as a guide for either manually or automatically controlling the supply of air for promoting combustion.

Relation indicators have been known for showing the instantaneous value of such relation, but have been used in connection with the burning of a single fuel. In the combustion of a single fuel at different rates of output and at a predetermined desirable excess of air, a definite rate of flow of products of combustion will result for each rate of output. The value of the rate of flow or its flow effect or the relation such as previously referred to, may be calculated for any given fuel; but when a plurality of fuels are burned simultaneously in a furnace and in varying proportions, the resulting volume of products of combustion will vary not only with the percentage of excess air and the rating developed, but also with the character of the fuels burned and the proportioning of these several fuels.

It is therefore a primary object of the present invention to control the supply of air for combustion in the most efficient manner, regardless of the rating developed or the proportionality of the fuels supplied for combustion.

It is a further object of the invention to provide a relation indicator for indicating, as a guide to manual or automatic control of the supply of air, the relation instantaneously existing between a measure of the output of the furnace or of some variable factor in the operation of the furnace and a measure of the air flow, taking into account the proportionality and characteristics of the various fuels simultaneously burned in any proportionality from 0 to 100% of maximum supply of each of the fuels.

Another object of the invention is to obtain a measure of the air flow for the purpose of controlling the air supply, automatically taking into account on such measure of the air flow the proportionality of supply of fuels being burned.

A still further object is to obtain a measure of each of a plurality of fuels burned simultaneously and cause such measures to effect a compensation of a measure of the air flow in relation to a characteristic such as calorific value of each of the fuels separately so burned.

Still another object is to combine as a readable guide for manually or automatically controlling the supply of air to a furnace, indications of the air flow and of each of several fuels burned simultaneously in the furnace, giving proper weight to the indications of the several fuels in accordance with their calorific value or other characteristic.

As a preferred embodiment of my invention I have illustrated and will describe the invention in connection with a steam generating boiler furnace to which are fed for combustion two fuels simultaneously and in amounts which may vary from zero to maximum of either of the fuels.

In the drawing; Fig. 1 represents a sectional elevation of a steam generator and its related heating furnace showing fuel and air supplying means, as well as the system and apparatus of my relation indicator and control system, in somewhat diagrammatic fashion.

Fig. 2 represents a graph of the flow effect of two fuels.

I illustrate at 1 a furnace arranged for heating a steam generator 2 through the combustion within the furnace 1 of fuel fed thereto from either or both of two sources 3 and 4.

3 represents a burner for admitting to the furnace coal in pulverized form, fed therethrough by a feeder 5 continuously rotated by a motor 6, whose speed and corresponding rate of coal feed may be varied by hand or automatically through the agency of a rheostat 7 in common manner. A pneumatic tachometer 8 driven by and with the feeder 5 serves to provide a measure of the rate of pulverized coal fed to the furnace 1.

At 4 a second fuel, such for example as blast furnace gas, is admitted to the furnace, being supplied to the burner 4 through a conduit 9 wherein the rate of flow and pressure of the gas may be regulated in any desired and well known manner, such regulation forming no part of the present invention. In general, and in common practice, the pressure of the gas supplied in the conduit 9 is held uniform, and the total quantity of the gas and pulverized fuel supplied is controlled in accordance with a measure of the output of the vapor-generator, as for example, steam pressure.

Air for combustion of the fuel is supplied in part through the burner 3 to form a carrier of

the pulverized fuel and in part through an air box 10 surrounding the gas burner 4. The rate of air supply is controlled by the suction exerted upon the furnace of a stack 11 having positioned therein a damper 12 through the agency of a stop-start-reversing pilot motor 13 for controlling the draft.

Steam generated in the boiler 2 passes therefrom through a conduit 14 in which is positioned a pressure differential creating device such as an orifice 15 for causing a drop in pressure bearing a definite and known relation to the rate of flow of steam through the conduit and providing a measure of the steam outflow.

Connected to the conduit 14 at opposite sides of the orifice 15 by means of the pipes 16, 17, I show a rate of flow meter 18 having an indicator arm 19 adapted to cooperate with an index 20 for advising the rate of flow of steam leaving the boiler through the conduit 14. Such a meter is illustrated as a known type having a variable diameter liquid-sealed bell whose wall is of material thickness, whereby the quadratic relation between differential pressure across an orifice and rate of flow therethrough is converted to a linear relation, to the end that positioning of the indicator 19 relative to the index 20 is in equal increments directly proportional to the rate of flow of steam from the boiler.

At 21 I designate in general an air flow meter comprising primarily a liquid holding casing 22 relative to which is located a pivot support 23. A beam 24 is adapted to be positioned around the pivot 23 in angular movement, and such movement or positioning is indicated by a projection at one end of the beam 24 relative to an index 25.

From the beam 24 at opposite sides of the pivot 23 are suspended liquid-sealed bells 26, 27 to the undersides of which is led respectively through pipes 28, 29 the pressure existing at two points in the gas passage through the boiler 2, between which there is resistance to the flow of products of combustion, thus producing a pressure differential between the points of connection bearing a known relation to the rate of flow of the air and gases therethrough. Such pressure differences, when applied to the underside of the liquid-sealed bells 26, 27 in the air flow meter 21 react on the beam 24 as a resultant force tending to rotate the beam around its pivot 23. Rotation is opposed by a displacer 30, suspended from the beam 24 within a second liquid, preferably mercury, and the displacer of a shape parabolic in function through whose agency the positioning of the beam 24 in rotation around the pivot 23 as indicated on the index 25 is by equal increments directly proportional to the rate of flow of air and gases through the boiler 2.

The displacer 30 may be of a modified parabolic functional shape. By this I mean that while the general shape of the displacer is such as to correct for the quadratic relation between differential pressure and rate of air flow, the shape may be modified whereby through its counteraction upon the air flow effect, the indicator 24 will indicate the rating equivalent of air flow for one value of excess air at one rating and a different value of excess air at another rating. For example, with the displacer shaped according to quadratic function and the system in calibration, then when the steam flow indicator 19 reads at 25% or at 75% of its index 20, the air flow indicator should read at 25% or 75% respectively of its index 25, if the correct and constant excess of air exists throughout the whole range of boiler operation. If, however, it were desired to operate under a combustion condition of 15% excess of air at 25% of maximum rating and 25% excess of air at 75% of maximum rating, then obviously the displacer 30 could be so shaped that at 25% of boiler rating the air flow indicator would read at 25% of its maximum index reading, with a combustion condition of 15% excess air, and read at 75% of its maximum index reading with a combustion condition of 25% excess air. In general, I show at 30 a shaped displacer whose shape may be such as to correct for quadratic relation or to take into account desirable variation such as I have just explained.

It will be observed that the pipe 29, connecting to the boiler at a location closer to the stack than the connection of the pipe 28, leads beneath the bell 27 and exerts upon the bell 27 a suction or downward force greater than the downward force applied beneath the bell 26. This differential in pressure will tend to cause a rotation of the beam 24 in a clockwise direction around its pivot 23. Such a tendency to rotate will be opposed by the lifting of the displacer 30 from the mercury, producing an increasing weight upon the beam 24 adjacent the bell 26 to counteract the tendency for clockwise rotation. The shape of the displacer 30 is made such that pressure differences exerted upon the bells 26, 27 bearing quadratic relation to the rate of flow of air and gases through the boiler 2, will be indicated directly upon the index 25 as equal increments of rate of flow.

By air flow through the furnace, as measured by the air flow meter 21, I mean not only air, but all of the products or gases of combustion leaving the furnace through the stack 11, and which are utilized for heating the generator 2 in their passage from the furnace to the stack. When the proper calibration and adjustments have been made, the air flow meter 21, by measuring the rate of flow of all of the air and products of combustion leaving the furnace will indicate the rate of flow of air supplied for combustion.

It is known that a comparison of the rate of steam flow leaving the boiler, as an indication of boiler output, with the rate of air flow through the boiler, comprises an adequate guide for manual or automatic control of the supply of air for combustion to the related furnace. I therefore connect the indicator arm 19 of the steam flow meter and the indicator arm 24 of the air flow meter through linkage for comparing the instantaneous values of the steam flow and air flow, and advising a departure of the relation of instantaneous values from desired relation.

From the steam flow indicator arm 19 I pivotally suspend a link 31 pivotally joined at its lower end to one end of a freely floating beam 32. From the beam 24 I suspend a similar link 33 pivotally connected at its lower end to the other end of the beam 32, and from the beam 32 at a point intermediate its ends I suspend pivotally connected thereto a link 34 connected to and for oscillation of a contact bar 35 around a pivot 36 intermediate the ends of the contact bar.

Carried by the contact bar 35 are one-half each of normally open-circuited contacts 37, 38 and the contact bar is connected through a conductor 39 with a main power line 40. The other half of the contact 37 is connected through a conductor 41 with the motor 13, and the other half of the contact 38 is connected through a conductor 42 to the motor 13. The return line 43 from the motor 13 joins the other main power line 44.

The arrangement is such in general that should the rate of steam flow from the boiler increase, such increase will be indicated through a downward movement of the indicator 19 relative to the index 20 and a corresponding downward positioning of the links 31 and 34, resulting in a positioning of the contact bar 35 in a clockwise direction around its pivot 36. This positioning causes a close-circuiting of the contact 37, completing a circuit comprising main power line 40, conductor 39, contact 37, conductor 41, motor 13 and conductor 43 to main power line 44, whereby the motor 13 is energized for rotation in a direction to increase the opening of the damper 12 and allow a greater flow of air through the boiler. Assuming that the rate of steam outflow remains the same, then the increased flow of air through the boiler, effective as an increased pressure differential applied to the bells 26, 27 of the air flow meter 21 will cause an upward positioning of the indicator 24 relative to the index 25 with an upward movement of the links 33, 34 and contact bar 35 until the contact 37 is open-circuited, thus stopping rotation of the motor 13, for the resulting air flow is then in desired relation to the increased steam flow.

The operation is the same in reverse manner, should the rate of steam flow decrease from any value. Correspondingly, should the steam flow remain steady, but for some reason such as change in wind across the top of the stack 11 the air flow through the boiler would increase or decrease, then its action upon the air flow meter 21 and the linkage 33, 34 would result in a positioning of the motor 13 in one direction or the other for an opening or closing of the damper 12 until again the air flow balances the steam flow in desired relation.

It will be observed that it is not necessary that the relation between air flow and steam flow be in 1 to 1 ratio, but through proper adjustment of moment arms, any desired and predetermined relation may be indicated or utilized for control. Proper adjustment as to size of the bells 26, 27, shape of the displacer 30, and moment arms of the bells and displacer relative to the pivot 23 take care, for the particular design and type of boiler, of the resistance between the points of connection at a given rate of output.

The indicator arms 19, 24 need not necessarily indicate relative to separate indexes 20, 25, but may readily be adapted to move relative to a common index or may comprise co-related pen traces upon a single recording chart, it only being necessary in a contemplation of my invention that a measure of steam flow and a measure of air flow be simultaneously observable for comparison as to desired relation or departure therefrom, and with the understanding that steam flow and air flow are used merely as examples of variable characteristics in the operation of the furnace. Furthermore, that the indicated relationship between such characteristics may be utilized as a guide for manual control of the supply of air, or as a part of an automatic control system.

I have described so far a steam flow meter and an air flow meter in co-relation as would be adaptable to a boiler furnace wherein a single fuel were burned, for example, gas alone through the burner 4. Assuming combustion with a constant percentage of excess air regardless of rate of operation, then the differential pressure existing through the boiler 2 and effective upon the air flow bells 26, 27 is in definite quadratic relation with the rate of flow of air through the boiler. If, however, we should suddenly shift from burning all gas to a condition of burning no gas but all pulverized fuel, and in sufficient quantity of B. t. u. input to maintain the same steam flow output or B. t. u. output of the boiler and the puverized fuel burned with the same excess air, then the pressure differential existing across the points of connection to the boiler and impressed upon the bells 26, 27 would vary from that of the previous example. This due to the fact that for a radically different fuel, the products of combustion will vary the one from the other, and what I term the "flow effect" of the particular fuel will vary for the one fuel as compared to the other fuel.

If, for example, when burning gas alone, the steam flow indicator read at 50% of maximum and the air flow indicator read at 50% of maximum, indicating a relation of the proper air flow for the fuel burned at a desired excess air condition in the furnace, then upon a sudden shift to burning pulverized fuel in proper B. t. u. quantity whereby the steam flow indicator would remain at 50% of maximum, the air flow indicator would instantly drop to some reading, for example, 48% of its maximum, thereby indicating the difference in flow effect between the products of combustion of blast furnace gas and the products of combustion of pulverized fuel at the same excess air for combustion.

Likewise a change in B. t. u. value of a given fuel will cause a change in the air flow reading, assuming the same excess of air and the same boiler output or steam flow reading, for in this case a greater or less amount of the fuel must necessarily be burned to give the same B. t. u. output.

Desirably in the operation of the furnace and boiler, the readings of steam flow and air flow are to be kept in desired relation as a guide to hand or automatic control of air supply and thus, as in the example, if the fuel were changed instantly from all gas to all pulverized coal, the steam and air flow indicators, in place of reading each at 50% of their maximum would now read 50 and 48 respectively, indicating to the operator or to the automatic control a condition which would need correction in the direction of increasing the supply of air so that the air flow indicator would come up to a unity relation with that of the steam flow. However, if the air flow were so increased as to bring the air flow indicator from 48 to 50 on its index, this actually would result in too great a supply of air, and the excess of air for combustion would have increased over the desired value with corresponding loss of efficiency of combustion.

What actually is desired is that the reading of the air flow indicator, when switching from one fuel to the other, should be compensated or moved mechanically from 48 to 50 so that to the operator or to the automatic control the proper relationship still exists and no correction in air supply is needed. My invention primarily contemplates such a correction of the actual air flow reading to take care of a difference in flow effect produced through the burning of different fuels, and the compensator which I will describe would automatically, upon the shifting of blast furnace gas to pulverized coal, mechanically move the air flow indicator from its reading of 48 to its previous reading of 50 whereby is indicated that the proper supply of air exists.

Such a condition as I have explained would occur in the sudden shifting from burning one fuel

to that of burning another wholly. However, I contemplate the possibility of burning the two fuels simultaneously in varying proportions, in which event I must apply as a compensation to the air flow mechanism an effect proportional to the flow effect of one of the fuels and at the same time an effect proportional to the flow effect of the other of the fuels, and furthermore proportion these effects to each other in accordance with the magnitude of the relative proportion of the two fuels burned or desirably in proportion to the total B. t. u. input from each of the two fuels.

Referring now to the drawing, I show additionally suspended from the beam 24 of the air meter 21, an oil sealed bell 45 to the underside of which is applied a suction through the pipe 46 from the pneumatic tachometer 8 whereby a force is applied to the beam 24 proportional or in functional relation to the speed of the feeder 5 as a measure of the rate of supply of pulverized coal to the furnace 1.

I further apply to the beam 24 a force indicative of the rate of supply of gas to the furnace through a bell 47 also suspended from the beam 24 and connected by the pipe 48 to the gas supply conduit 9 responsive to pressure therein. Positioned in the conduit 9 is a valve 49 for regulating the rate of supply of gas to the burner 4, and the valve may be throttled by hand or automatically, as desired, the control of the valve forming no part of my invention. However, I have found that the pressure of the gas between a regulating valve 49 and a burner 4 is in functional relation to the rate of flow of gas through the burner, and thus by applying such pressure to within the bell 47 I may apply to the beam 24 a force indicative of the rate of flow of gas to the furnace.

Through properly proportioning the bells 45, 47 I desirably arrange their relative effects on the positioning of the beam 24 to aid or counteract the force of the air flow. I have arranged upon the beam an indexed bell carrier 50, from which is suspended the bell 45, and a similar indexed carrier 51 from which is suspended the bell 47. The arrangement is such that the bells 45 and 47 may be separately moved, each along its carrier, to vary the moment arm of the bell relative to the pivot 23 to take account of change in the calorific value of the fuel to which the bell is related. For example, the index 50 might be graduated in calorific value of the pulverized fuel, and I may change the moment arm effect of the bell 45 relative to the pivot 23 by suspending the bell at different points along the carrier 50 opposite the graduations of its index in accordance with the calorific value of the fuel. Similarly, the bell 47 may be moved to vary its moment arm relative to the pivot 23 in line with graduations of the index 51 to take account of variation in the calorific value of the gas fed to the furnace.

The indexes 50, 51 may be also graduated in percent excess air at which it is desired to burn the respective fuel. In general, I have described an arrangement and contemplation of burning the blast furnace gas and the pulverized coal both at the same percentage of excess air, as for example, 20% excess air. It will readily be seen, however, that it might be desirable to burn the blast furnace gas at 18% excess air and the pulverized coal at 22% excess air, or otherwise. The adjustment illustrated, whereby the bell 45 may have its moment arm relative to the pivot 23 changed, and correspondingly the bell 47 have its moment arm relative to the pivot 23 changed, provides that the one may be calibrated for a fuel burned at one excess of air and the other at a different excess of air. The index 50, 51 therefore may be graduated in calorific value of the related fuel, or in percentage of excess air at which it is desired to burn the related fuel. In connection with the index, the related bell may be moved relative thereto, to correct for a deviation in calorific value of the fuel, or to vary the percentage of excess air with which it is desired to burn the fuel.

To bring out more clearly the principle of my invention, I will define what I mean by "flow effect" and illustrate the same in connection with the fuels mentioned. The term "flow effect" as I use it denotes the relative effects on a differential pressure responsive device, of the products of combustion produced by the burning at an equal rate of heat generation, of the fuel in question and of pure carbon with the theoretical amount of air necessary for complete combustion, and considered at the lower heating value, and may be expressed by the formula:

$$\text{Flow effect} = \frac{2160 \times W \times \text{Sp. vol.}}{H}$$

Where W = Weight of products of combustion per pound of fuel
Sp. vol. = Specific volume of products of combustion at 800° F. (considered as the average temperature at point of measurement)
H = Lower heating value of the fuel being compared to carbon
21600 = A constant which gives a flow effect of 100 when burning carbon with the theoretical amount of air.

In Fig. 2 I illustrate by means of curves the flow effect of blast furnace gas and of coal as calculated by the above formula, plotting flow effect for each of the two fuels against excess air over that theoretically required for perfect combustion.

From the formula, considering carbon burned with the theoretical amount of air necessary, we obtain a flow effect of 100. The flow effect of other fuels burned with the theoretical amount of air necessary, or at any specified percentage of excess air, may be calculated from the formula or read directly from a curve similar to that of Fig. 2, and the flow effect values so obtained may be compared to that of carbon or relative to each other.

For instance, ordinary coal burned at 20% excess air, has a flow effect from the curve of 120. Blast furnace gas burned at 20% excess air from the curve shows a flow effect of 180. The relation between the two flow effects, namely 180/120=1.5 which is the correction factor necessary to apply to the air flow pen reading if the air flow has been calibrated and adjusted for a condition wherein coal only is being burned and the operation is suddenly switched to a burning of blast furnace gas only. This, of course, on the assumption that the operator would desire to maintain a condition of 20% excess air for each of the two fuels.

At any given percentage of the index reading, that is, rate of output of the furnace, the correction factor necessary to apply to the air flow mechanism, if the mechanism had been calibrated for use on one fuel alone and it were desired to burn the other fuel alone, would be the ratio of the flow effects of the fuels, which is the same percentage correction factor at all

parts of the index. However, the indicator movement mechanically and due to the displacer 30 will vary as the square root. Therefore gas burner pressure applied to the bell 47 which varies as the square of gas flow, when applied as a moment arm in conjunction with the air flow displacer 30, will compensate the air flow mechanism directly and in amount dependent upon the proportions of the bell 47 and its moment arm from the pivot 23.

Should the basic calorific value of the gas being burned vary from that to which the bell and its moment arm is designed, then through use of the flow effect formula the new flow effect may be obtained, and the index 51 may be so graduated that the moment arm of the bell 47 may be shifted to take into account such change in calorific value of the gas.

The same procedure holds for the bell 45 which applies to the beam 24 a force indicative of a measure of the rate of supply of pulverized fuel to the furnace, for the law of the pneumatic tachometer 8 is also quadratic in function, and therefore may be applied directly to the beam 24 as a direct compensator of the movement of the indicator 24 relative to the index 25.

Inasmuch as the pneumatic tachometer 8 creates a suction, while the gas flow through the conduit 9 is at a pressure, the two forces resulting and indicative of a measure respectively of the two rates of supply of fuel, may be applied to the beam 24 at the same side of the pivot 23 wherein they tend to counteract each other, applying a force to the beam 24 resultant between the effects of the bells 45 and 47, determined by the predominance of the one fuel over the other, taking into account the related flow effects of the fuels.

The fact that the pneumatic tachometer law of suction is quadratic and that the gas pressure relation to flow is quadratic, but that one is a suction and the other a pressure, determines that for varying percentages of the two fuels burned simultaneously, the summation effect upon the beam 24 of the rapidly decreasing tachometer suction and the slowly increasing gas pressure, produces a uniform decrease in air flow with increasing percentage of gas burned. The reverse is true upon a decreasing percentage of gas burned, to the end that for a constant B. t. u. input to the furnace, the proper correction is applied to the beam 24, regardless of percentages of the two fuels burned.

I have thus broadly conceived apparatus for advising a relation between a measure of the output of a furnace and a measure of the air flow through the furnace, with such relation taking into account the variation in flow effect of the products of combustion resulting from the burning of a plurality of fuels simultaneously in varying proportions in the furnace. Furthermore, the advice of the indicators and relation of indications may be used for manual or automatic control of the supply of air to the furnace. In addition, an adjustment is arranged whereby the compensating effect through the relation of indications may be varied, dependent upon and in accordance with calorific value or other variation in composition or characteristic of the burning of the individual fuels. Additionally, the fuels may be burned in any relative proportion from zero to maximum rate for each or all of the plurality of fuels, and the correction dependent upon varying a flow effect is effective regardless of rate of operation of the furnace.

I illustrate and describe a control of the air supplied for combustion to a furnace through the usage of a relation between a measure of the air flow and a measure of each of a plurality of fuels burned simultaneously and in varying proportions in the furnace and show possible manual or aumatic control of the air supply from such indications, and with adjustment for change in calorific value or other characteristic or compensation of the fuels being so burned.

While I have illustrated and described a preferred embodiment of my invention, it is to be particularly understood that I am not to be limited thereby except as to the claims in view of prior art.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The method of controlling the air supplied for combustion of a plurality of fuels burned simultaneously in a furnace, which includes, obtaining an effect representative of the flow of air and gaseous products of combustion through the furnace, obtaining an effect representative of proportionality of the fuels burned, coordinating such effects, and controlling the supply of air from such coordination.

2. The method of controlling the air supplied for combustion of a plurality of fuels burned simultaneously in a furnace, which includes, obtaining a measure of furnace output, obtaining a measure of air flow, applying to the measure of air flow a compensating effect dependent upon proportionality of fuels burned, determining the relation between the measure of furnace output and the compensated measure of air flow, and subjecting the air supply to control in accordance with the departure of said relation from a predetermined value.

3. The method of controlling the air supplied for combustion of a plurality of fuels burned simultaneously in a furnace, which includes, obtaining a measure of furnace output, obtaining a measure of air flow, applying to the measure of air flow a compensating effect representative of total heat supplied the furnace by the fuels, determining the relation between the measure of furnace output and the compensated measure of air flow, and controlling air supply from such relationship.

4. The method of controlling the air supplied for combustion of a plurality of fuels burned simultaneously in varying proportion in the furnace of a vapor-generator, which includes, measuring the vapor generated, measuring the air flow, varying the value of the measure of air flow in accordance with heat input to the furnace, determining the relation between the measure of vapor and the measure of air flow after the latter has been so varied, and controlling the air supply in accordance with the departure of said relation from a predetermined value.

5. The method of controlling the air supplied for combustion of a plurality of fuels burned simultaneously in a furnace, which includes, obtaining an effect proportional to a measure of gases flowing through the furnace, obtaining an effect for each of the fuels burned and proportional to a measure of the fuel, correlating such effects, and controlling air supply from the correlation.

6. Apparatus for controlling the supply of air for combustion of a plurality of fuels adapted to be burned simultaneously in a furnace and which may have different heating values per unit quantity, comprising in combination, a vapor-

generator having a heating furnace, air supplying means and means for supplying each of a plurality of fuels separately to the furnace, a meter of vapor outflow, a meter of air flow, relation determining means for said meters, control means for the air supplying means actuated upon departure of said relation determining means from a predetermined value, and a meter of each of the fuels, said fuel meters conjointly effecting a compensation of the air flow meter.

7. Apparatus for controlling the supply of air for combustion of a plurality of fuels adapted to be burned simultaneously in a furnace and which may have different heating values per unit quantity, comprising in combination, a vapor-generator having a heating furnace, air supplying means and means for supplying each of a plurality of fuels separately to the furnace, a meter of vapor outflow, a meter of air flow, relation determining means for said meters, control means for the air supplying means actuated upon departure of said relation determining means from a predetermined value, a meter of each of the fuels, said fuel meters conjointly effecting a compensation of the air flow meter which for each fuel meter is the product of rate of supply of the related fuel and the heating value of the fuel, and hand adjustable means in connection with each fuel meter for varying the compensating effect thereof upon the air flow meter for different heating values of the related fuel.

8. A relation indicator for use with vapor-generators heated by combustion of a plurality of fuels adapted to be burned simultaneously in varying proportions, comprising in combination, a vapor outflow meter, an air flow meter, a meter for each of the fuels supplied to the furnace, and relation determining means of the vapor outflow and air flow, said fuel meters adapted to be coactively effective in positioning the indicator of the air flow meter.

9. An indicator for use with a furnace heated by combustion of a plurality of fuels adapted to be burned simultaneously in varying proportions, comprising in combination, a meter of the gases flowing through the furnace and having an indicator, and a device for each of the fuels which may be supplied to the furnace for combustion for obtaining an effect bearing a functional relation to the rate of supply of the related fuel, said devices adapted to modify the effect of the flow of gases upon its indicator.

10. The method of controlling the air supplied for combustion of a plurality of fuels burned simultaneously in a furnace, which includes, obtaining a measure of gases flowing through the furnace, obtaining a measure of at least one of the fuels burned, correlating such measures, and controlling air supply from the correlation.

11. The method of operating a furnace adapted to be heated by the combustion of a plurality of different fuels burned simultaneously in varying proportions, which includes, controlling the gases leaving the furnace at a rate continuously proportioned to rate of supply of the fuels.

12. The method of controlling the air supplied for combustion of a plurality of fuels burned simultaneously in a furnace, which includes, obtaining a measure of furnace output, obtaining a measure of air flow through the furnace, obtaining an effect representative of proportionality of the fuels burned, continuously comparing the measure of furnace output and the measure of air flow as a guide to controlling the air supply rate, and utilizing the effect representative of proportionality to modify the measure of air flow.

13. In the operation of a furnace, the method which includes, continuously indicating desirable relation between a measure of furnace output and a measure of air flow or departure therefrom, and modifying the measure of air flow by change in proportionality of a plurality of fuels simultaneously burned.

14. Apparatus for guiding the operation of a furnace, comprising in combination, a measuring device of furnace output, a measuring device of air supply, means for comparing the masurements relative to predetermined relations, and means responsive to proportionality of a plurality of fuels simultaneously supplied for combustion, said means effective in modifying the measure of air flow before it is compared with the measure of furnace output.

15. Apparatus for automatically controlling the supply of air for combustion to a furnace, comprising in combination, a measuring device of furnace output, a measuring device of air supply, means for continuously comparing the measurements relative to predetermined relation, means responsive to proportionality of a plurality of fuels simultaneously supplied for combustion, said means effective in modifying the measure of air flow before it is compared with the measure of furnace output, and means for automatically controlling the air supply responsive to said first-named means.

16. An indicator for use with a furnace heated by combustion of a plurality of fuels adapted to be burned simultaneously in varying proportions, comprising in combination, a meter of furnace output, an air flow meter, each of said meters having an indicator, and a device for each of the fuels which may be supplied to the furnace for combustion for obtaining an effect bearing a functional relation to the rate of supply of the related fuel, said devices adapted to modify the effect of the air flow upon its indicator.

17. A relation indicator for use with vapor-generators heated by combustion of a plurality of fuels adapted to be burned simultaneously in varying proportions, comprising in combination, a vapor outflow meter, an air flow meter, means responsive to the rate of supply for each of the fuels supplied to the furnace, and relation determining means connected to the vapor outflow and air flow meters, said fuel supply responsive means adapted to be coactively effective in positioning the indicator of the air flow meter.

18. A relation indicator for use with a furnace heated by combustion of a plurality of fuels adapted to be burned simultaneously in varying proportions, comprising in combination, a furnace output meter, an air flow meter, means responsive to the rate of supply for each of the fuels supplied to the furnace, and relation determining means connected to the output and air flow meters, said fuel supply responsive means adapted to be coactively effective in positioning the indicator of the air flow meter.

19. A relation indicator for use with a steam generator heated by combustion of two fuels of different heat value and adapted to be burned simultaneously in varying proportions, comprising in combination, a steam flow meter, an air flow meter, means responsive to the rate of supply for each of the fuels supplied to the furnace, and relation determining means connected to the steam flow and air flow meters, said fuel supply

responsive means adapted to compensate the air flow meter.

20. A relation indicator for use with vapor-generators heated by combustion of a plurality of fuels adapted to be burned simultaneously in varying proportions, comprising in combination, a vapor outflow meter, a meter for the gaseous products of combustion flowing through the generator, means responsive to the rate of supply of each of the fuels supplied to the furnace, said fuel supply responsive means adapted to compensate the air flow meter, and relation determining means conjointly positioned by the vapor outflow meter and by the compensated air flow indication.

21. A relation indicator for use with a furnace adapted to be heated by the combustion of a plurality of fuels burned simultaneously in varying proportions, comprising in combination, a meter for measuring furnace output, a meter for measuring the flow of the products of combustion and excess air from the furnace, means responsive to the rate of supply of each of the fuels, and means for comparing the measures of furnace output and products of combustion, the latter measure compensated by the fuel meters.

RALPH M. HARDGROVE.

CERTIFICATE OF CORRECTION.

Patent No. 1,972,990. **September 11, 1934.**

RALPH M. HARDGROVE.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, line 99, in the formula, for "2160" read 21600; 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 13th day of November, A. D. 1934.

Leslie Frazer

(Seal) Acting Commissioner of Patents.

responsive means adapted to compensate the air flow meter.

20. A relation indicator for use with vapor-generators heated by combustion of a plurality of fuels adapted to be burned simultaneously in varying proportions, comprising in combination, a vapor outflow meter, a meter for the gaseous products of combustion flowing through the generator, means responsive to the rate of supply of each of the fuels supplied to the furnace, said fuel supply responsive means adapted to compensate the air flow meter, and relation determining means conjointly positioned by the vapor outflow meter and by the compensated air flow indication.

21. A relation indicator for use with a furnace adapted to be heated by the combustion of a plurality of fuels burned simultaneously in varying proportions, comprising in combination, a meter for measuring furnace output, a meter for measuring the flow of the products of combustion and excess air from the furnace, means responsive to the rate of supply of each of the fuels, and means for comparing the measures of furnace output and products of combustion, the latter measure compensated by the fuel meters.

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