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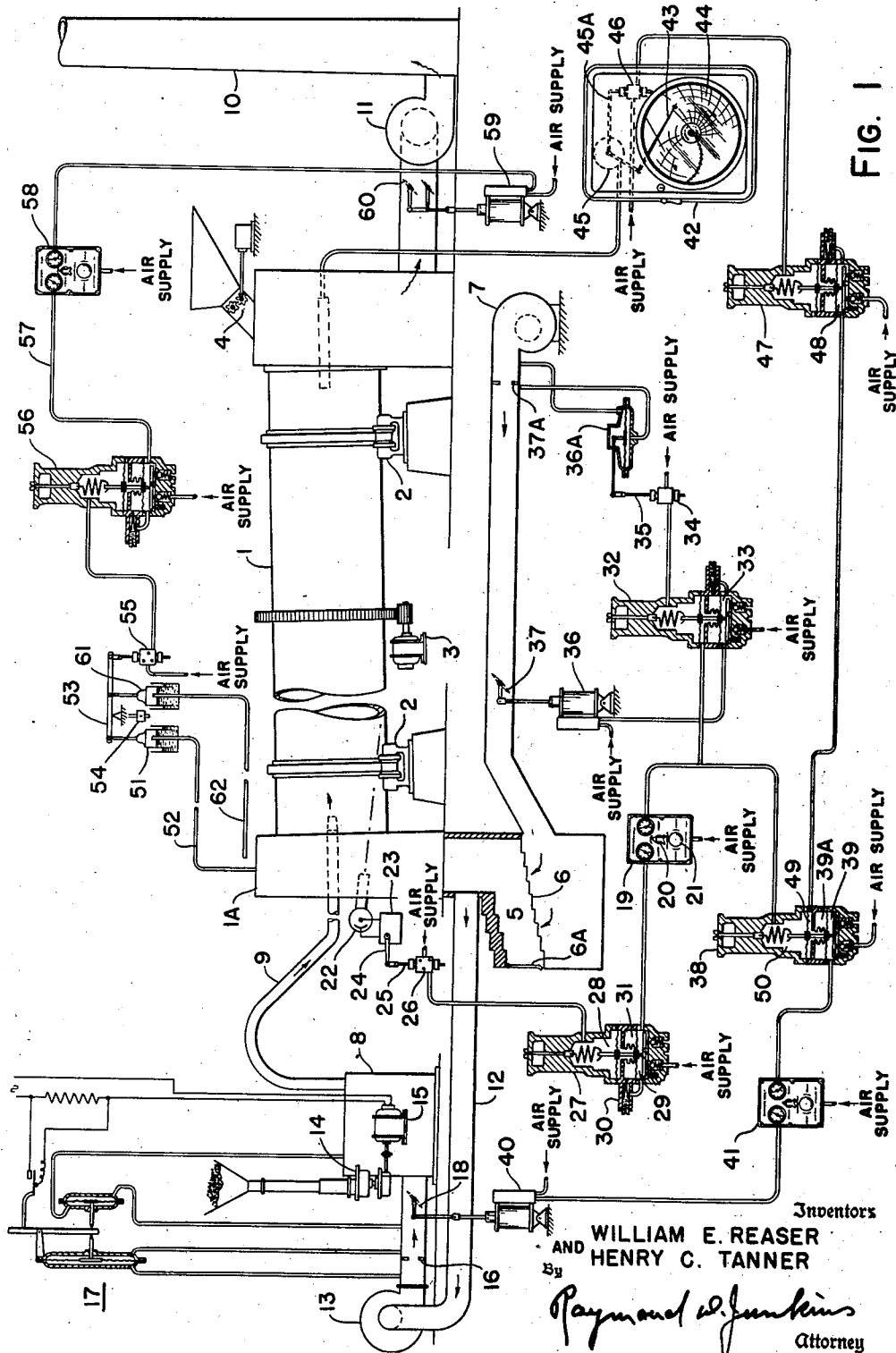
W. E. REASER ET AL

2,298,257

CONTROL METHOD AND APPARATUS

Filed Oct. 14, 1940

3 Sheets-Sheet 1



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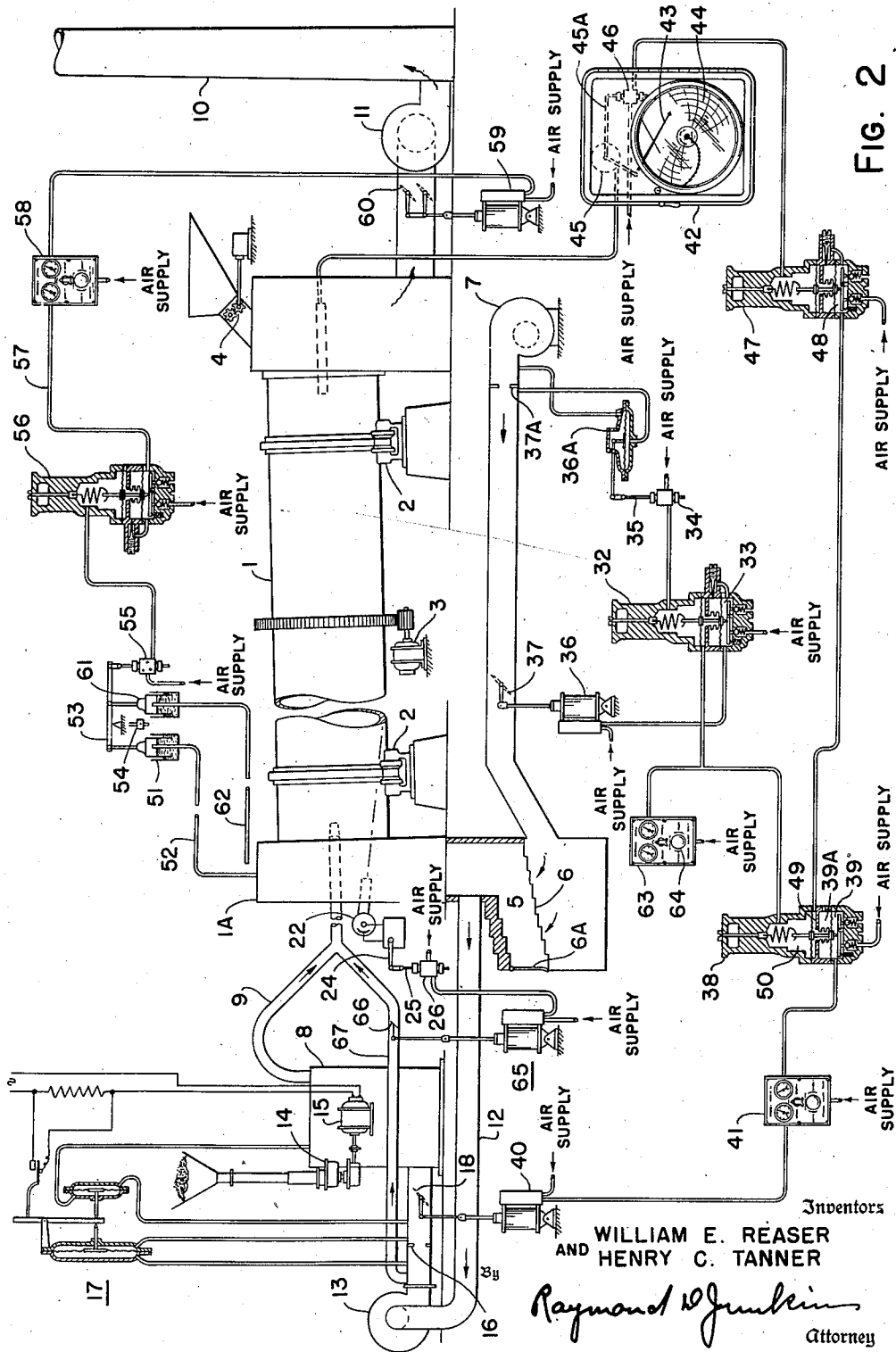
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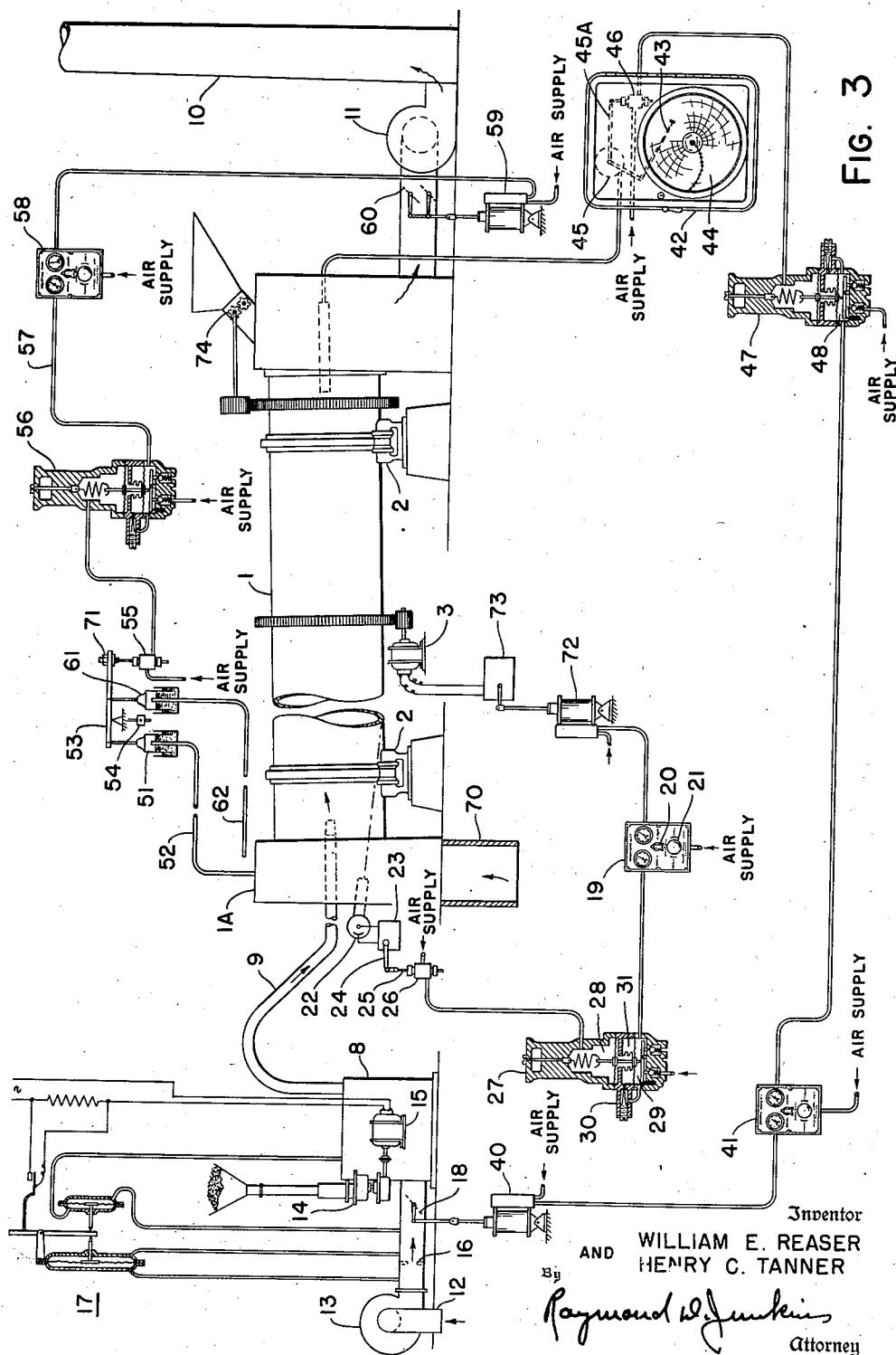
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UNITED STATES PATENT OFFICE

2,298,257

CONTROL METHOD AND APPARATUS

William E. Reaser, Easton, and Henry C. Tanner, Drexel Hill, Pa.; said Tanner assignor to Bailey Meter Company, a corporation of Delaware

Application October 14, 1940, Serial No. 361,038

13 Claims. (Cl. 263—53)

Our invention relates to a method and apparatus for controlling industrial furnaces. More particularly our invention relates to a method and apparatus for controlling rotary cement kilns and the like.

One object of our invention is to improve the efficiency with which fuel may be burned in industrial furnaces, such as rotary kilns.

Another object of our invention is to increase the production which may be obtained from such furnaces.

Still another object is to increase the quality and uniformity of the product which may be obtained.

A further object is to increase the safety with which rotary kilns and the like may be operated.

Further objects and advantages of our invention will be apparent from the description to follow and from the drawings in which:

Fig. 1 is a diagrammatic illustration of one form of our invention.

Fig. 2 is a diagrammatic illustration of a modified form of our invention.

Fig. 3 is a diagrammatic illustration of a further modified form of our invention.

We have chosen to illustrate and describe our invention applied to a rotary kiln, such as used to manufacture cement clinker. In the present day cement manufacturing plants, inclined rotary kilns of considerable length are utilized for effecting fusion of two or more materials. A homogeneous mixture of the materials is fed into the high end of the rotary kiln and during the rotation of the kiln passes through the different zones thereof to the low end or the clinkering zone. At the extremity of the clinkering zone, the cement clinker is discharged from the kiln and cooled. The union of the materials within the kiln is effected by the application of heat, which in the usual arrangement is produced by a burner projecting into the kiln at the lower end and discharging combustible material therein.

Referring now to Fig. 1, an inclined kiln 1 is rotatably supported on suitable bearings 2 and is rotated by a suitable driving means illustrated as an electric motor 3. The motor 3 may be of any suitable type and is preferably provided with a manually operated speed controller so that the speed at which the kiln 1 is rotated may be adjusted to suit varying conditions. However, our invention contemplates that the optimum speed of the kiln 1 once having been arrived at, thereafter its speed will be maintained constant unless there is a material change in operating conditions such as a change in the character of the materials being fed, or in the character of product desired.

The raw material, either in a dry, or in a wet state known as slurry, is introduced into the kiln at the high end through suitable feeding means

diagrammatically shown at 4. The feeding means is preferably adjustable so that material may be fed into the kiln at any desired rate which may or may not be in proportion to kiln speed. Our invention again contemplates that after the optimum feeding speed has been determined, thereafter it will be maintained constant.

The material in the kiln gradually travels to the low end or hood 1A of the kiln from which it is discharged into a cooler 5 provided with a perforated shaking or traveling grate 6 through which cooling air is blown by means of a fan 7.

This air after passing through the cooler 5 provides a convenient source of heated primary and secondary air for combustion, as will be described more in detail hereinafter. The clinker is discharged from the cooler 5 through a swinging gate or door 6A.

Any suitable fuel may be used to fire the kiln.

In the embodiment of our invention we have chosen to illustrate we have shown the kiln as being fired with pulverized coal from a unit air-swept pulverizer 8. The pulverized coal is transported from the pulverizer 8 to the kiln 1 through a burner pipe 9. The products of combustion resulting from the burning of the pulverized coal within the kiln 1 and any excess air present, which for convenience we collectively term "flue gas," are drawn through the kiln 1 by means of an induced draft fan 11 and discharged to the atmosphere through a stack 10.

The pulverizer 8 is illustrated as being of the air-swept type through which a stream of air, commonly called primary air, is passed. The primary air may be drawn from the cooler 5 through a duct 12 and forced through the pulverizer 8 by means of a fan 13. As will be readily understood by those familiar with the art, tempering air may be bled into the duct 12 from the atmosphere to maintain the primary air entering the pulverizer at a predetermined temperature sufficiently high to dry the coal in the pulverizer; but lower than that which would be likely to ignite the coal. The cooler 5 is also shown as being in communication with the hood 1A and accordingly also provides a source of heated secondary air for combustion.

Raw coal is fed the pulverizer 8 through a feeder 14 driven by a variable speed motor 15. As known, the quantity of pulverized coal discharged from an air-swept pulverizer is substantially proportional to the rate of flow of primary air therethrough so long as a proportional amount of coal is maintained therein. A measure of the primary air passing through the pulverizer may be obtained by means of a restriction in the primary air duct 12, such as an orifice 16, which produces a differential pressure varying in functional relation to the rate of primary air flow. A measure of the quantity of coal

in the pulverizer may be obtained by measuring the pressure differential across the whole or a part of the pulverizer. These pressure differentials are transmitted to a controller generally indicated at 17, which operates to vary the speed of the feeder motor 15 to maintain the correct quantity of coal in the pulverizer for the existing rate of flow of primary air. The rate at which pulverized fuel is discharged into the kiln 1 is adjusted by means of a damper 18 controlling the flow of primary air to the pulverizer. Thus if it is desired to increase the rate of heat liberation in the kiln 1 the rate of flow of primary air is increased proportional to the increase desired, and vice versa.

We have found that practically any type of fuel burning equipment for firing a fuel in suspension does not fire the fuel at an unbroken constant rate; but that fluctuations of greater or lesser magnitude continuously occur. For example, in the air-swept unit pulverizer we have shown, relatively minor variations in the amount or character of coal within the pulverizer may cause momentary fluctuations in the weight rate of flow of coal to the kiln 1. Likewise in the so-called storage system of pulverized fuel firing, feeders may flood or feed varying amounts, due to variations in fineness or moisture content of the coal. A feature of our invention resides in the means we have provided for insuring that fuel is fed at whatever rate is necessary to produce a uniform unvarying rate of heat release. Further, in accordance with our invention the air and fuel are proportioned to maintain optimum combustion conditions, so that neither an unnecessary excess of air exists in the due gas nor combustibles such as carbon monoxide.

As will be appreciated, for each pound of air supplied a furnace a definite heat liberation should be obtained. For example, over the entire variation in chemical composition of commercial coals it will be found that to produce 10,000 B. t. u. by burning any given coal substantially the same weight of air will be required as for any other given coal. The same is true of oils and gases used in industrial furnaces. In accordance with our invention, we make use of this principle by first predetermining or establishing the rate of air flow necessary for the desired rate of heat release, and thereafter regulate the rate of fuel flow to maintain a uniform oxygen content in the flue gas, thereby assuring that for each pound of air supplied a definite number of heat units are released. In this manner, not only are variations in the feeding of the fuel to the furnace correctly compensated, but changes in the chemical composition of the fuel as well.

Referring to Fig. 1, in the arrangement shown we establish a pneumatic loading pressure corresponding to the desired rate of heat release within the kiln 1. Such loading pressure may be established by an operator, who on the basis of observation of the material in the kiln from time to time manually adjust the loading pressure so that the desired heat release is obtained; or automatically from an indication of the temperature at a given location within the kiln.

The operator may select the method by which the loading pressure is to be established by means of a selector valve 19 which may be of the type illustrated and described in U. S. Patent No. 2,202,485 to Edward W. Fitch, to which reference may be had for a more detailed description. With the transfer knob 20 in the "automatic" po-

sition, then a loading pressure automatically established by a temperature responsive device hereinafter to be described is rendered effective. With the transfer knob 20 in the "hand" position, then a loading pressure established by manual manipulation of the knob 21 is rendered effective.

We show the temperature responsive device for establishing a pneumatic loading pressure as a photoelectric device 22 focused to receive light from the material passing a predetermined spot within the kiln 1. The correct spot upon which the photoelectric device 22 is focused may be determined experimentally, and usually corresponds to the point in the kiln at which the so-called clinkering zone begins. If the light, and accordingly the temperature of the material at the spot upon which the device is focused, is above a predetermined amount, it indicates that the heat release is greater than necessary, and that the clinkering zone is beginning too far up in the kiln, which will result in overburned clinker and an unsatisfactory product. Conversely if the temperature at the spot upon which the photoelectric device is focused is below a predetermined value, it indicates that the heat release is insufficient, and if the condition is permitted to continue underburned clinker will result.

The photoelectric device 22 through a suitable amplifier, shown diagrammatically at 23, serves to position an arm 24 in accordance with the temperature of the material at the spot on which it is focused. The arm 24 in turn positions the movable valve member 25 of a pneumatic pilot valve 26, which is illustrated as being of the type described in U. S. Patent No. 2,054,464 to Clarence Johnson, to which reference may be made for a more detailed description. This pilot valve serves to establish a pneumatic loading pressure corresponding to the position of the arm 24 and hence corresponding to the temperature of the material on which the device 22 is focused.

The loading pressure established by the pilot valve 26 may be transmitted directly to the selector valve 19, and thence to the devices regulating the rate of fuel and air supply to the kiln 1. However, we usually prefer to have the loading pressure established by the pilot 26 first transmitted to a device, such as a standardizing relay 27, which may be of the type described in U. S. Patent No. 2,098,914 to H. H. Gorrie.

The purpose of the device 27 is to maintain a sufficient rate of heat release within the kiln 1 so that the temperature of the spot upon which the photoelectric device 22 is focused will remain precisely at the desired value without overshooting or hunting. As shown, the pilot valve 26 is connected to a chamber 28 of the relay 27. Pressure changes in the chamber 28 are immediately reproduced in a relay chamber 29. Following such immediate reproduction of pressure changes a slow continuing change of the pressure within the chamber 29 occurs by virtue of an adjustable bleed passage 30 and chamber 31. The device 27 is initially adjusted so that when the loading pressure established by the pilot 26 corresponds to the desired temperature, it is in equilibrium, and the pressure within the chamber 29 remains constant. Any change in pressure within the chamber 28, however, acts, as stated, to produce an immediate corresponding change in pressure within the chamber 29 followed by a slow continuing change until the pressure within the chamber 28 is restored to

that value corresponding to the desired temperature.

Pressures established within the chamber 29 are transmitted to the selector valve 19 and, if the transfer knob 20 is in the "automatic" position, relay to a differential standardizing relay 32. The relay 32 is similar to the relay 27 heretofore described and operates to establish a loading pressure in a chamber 33 which may be considered as the resultant of the loading pressures established through the selector valve 19 and one established by a pneumatic pilot valve 34. The movable valve member 35 of the pilot valve 34 is operated by a rate of flow meter comprising a differential pressure responsive device 36A and an orifice 37A positioned in the duct leading from the fan 7 to the cooler 5. Accordingly, the pilot valve 34 establishes a pneumatic loading pressure corresponding to the rate of flow of air supplied the cooler 5 and used for combustion of the fuel within the kiln 1. The relay 32 is so adjusted that when the loading pressure transmitted from the selector valve 19 is equal to or in predetermined proportion to that established by the pilot 34, it is in equilibrium. However, if the loading pressure established by the pilot valve 34 is not equal to or in predetermined proportion to the loading pressure transmitted from the selector valve 19, then the pressure within the chamber 33 will vary. Thus, for example, assuming the loading pressure transmitted from the selector valve 19 and that established by the pilot valve 34 to be equal, if a change occurs in the loading pressure transmitted from the selector valve 19 an immediate and proportionate change in loading pressure will occur in chamber 33 and thereafter a slow continuing change will occur therein until the two loading pressures are again returned to equality or stand in predetermined proportion to each other.

The loading pressure within the chamber 33 is transmitted to a servo-motor 36 operating a damper 37 in the duct leading from the fan 7 to the cooler 5. Thus it will be evident that upon a change in the loading pressure transmitted from the selector valve 19 the rate at which air is supplied the cooler 5, and accordingly utilized in combustion of the fuel within the kiln 1, will continue to vary until a change in the rate of air supply has occurred which is proportional to the change in loading pressure transmitted from the selector valve 19. In other words, for each and every loading pressure transmitted from the selector valve 19 there will be established a predetermined definite rate of combustion air supply, which, by virtue of the fact that the damper 37 is positioned in response to changes in rate of air flow, will be precisely maintained. Briefly, it may be said that the control operates first to set up a desired rate of air supply and thereafter serves to maintain the actual rate of air supply equal to the desired rate.

The loading pressure, either automatically established by means of the photoelectric device 22 or manually established by means of the knob 21 of the selector valve 19, may also be transmitted to a chamber 50 of an averaging relay 38, somewhat similar to the relay 27 but which operates to produce changes in loading pressure within a chamber 39 proportional to changes in the difference between the pressures within the chamber 50 and a chamber 49. The pressure within the chamber 39 is transmitted to

a servo-motor 40 operating the damper 18 in the primary air duct 12. Accordingly, it will be seen that upon a change in temperature of the material at the spot within the kiln 1, upon which the photoelectric device 22 is focused, an immediate and proportionate change will occur in the rate at which air is supplied for combustion and in the rate of fuel flow from the pulverizer 8. If desired, a selector valve 41 may be introduced between the chamber 39 and servo-motor 40 so that changes in rate of fuel supply may be made manually rather than automatically.

We effect changes in the rate at which fuel is supplied the kiln 1 in accordance with changes in the loading pressure established by the pilot valve 26, in the form of our invention illustrated in Fig. 1, merely to anticipate required changes therein to maintain the desired heat release per unit weight of air supplied for combustion. Essentially the loading pressure established either automatically by means of the photoelectric device 22 or manually by means of the selector valve 19 is used to establish the desired rate of air supply, and accordingly the desired heat release per unit of time within the kiln 1. However, if a change in either of these loading pressures is made, it is evident that a corresponding change should be made in the rate at which fuel is supplied. Accordingly, such changes in either of these loading pressures may be used to anticipate changes in fuel supply which would later be found necessary. In order, however, to be assured that for each unit weight of air supply a predetermined heat release is obtained, we determine the oxygen content in the flue gases leaving the kiln and adjust the rate of fuel supply to maintain that oxygen content in the flue gas which from observation and experiment has been found to give optimum combustion conditions.

Arranged to continuously analyze the flue gases leaving the kiln 1 for oxygen we show a recorder 42 which may be of the type forming the subject matter of an application to Clarence Johnson filed in the United States Patent Office on January 16, 1940, Ser. No. 314,189, to which reference may be made for a more complete description. The recorder 42 is arranged to position an index 43 relative to a chart 44 to inscribe thereon a record of the oxygen content of the flue gas leaving the kiln 1. As diagrammatically illustrated, the mechanism 45 for operating the recording pen 43 may be provided with an auxiliary arm 45A for positioning the movable valve member of a pilot valve 46, which will operate to establish a pneumatic loading pressure corresponding to the oxygen content of the flue gas.

The loading pressure established by the pilot valve 46 is transmitted to a standardizing relay 47, which operates to establish in a chamber 48 pressure changes corresponding to changes in the loading pressure established by the pilot 46 and a continuing change corresponding to the amount of departure of the loading pressure established by the pilot 46 from that existing when the oxygen content of the flue gas is at the desired value. The loading pressure within the chamber 48 is transmitted to the chamber 49 of the relay 38, so that changes therein cause proportionate changes in the chamber 39 which are transmitted through the selector valve 41 to the servo-motor 40. It will be observed that the relay 38 is not provided with a bleed connection between the chamber 39 and a chamber

39A, but that the latter is open to the atmosphere so that changes in pressure within the chamber 39 occur only when there is a change in the loading pressure transmitted through the selector valve 19, or from the relay 47. By virtue of the standardizing relay 47 when the oxygen content in the flue gas is other than that desired, the loading pressure in the chamber 49 continues to vary in a direction necessary to adjust the rate of fuel supply in order that the oxygen content will be restored to the desired value.

While in Fig. 1 we have shown our invention applied to a kiln having a fan 7 for providing forced draft, it may fully as well be applied to a kiln having no forced draft and where the air for combustion is supplied solely by induced draft. Reference to Fig. 1 will indicate that notwithstanding that the fan 7 is eliminated the orifice 37A will still provide a measure of the air supplied for combustion. It is also evident that the location of the orifice 37A may be changed without departing from the teachings of our invention, for example, in some installations it may be preferable to locate the orifice 37A in the duct leading from the kiln 1 to the induced draft fan 11. It is further evident that any suitable flow measuring device other than an orifice may be employed if desired or that in some instances such an element may be dispensed with entirely and the pressure drop through the kiln used as a measure of the rate of flow of air for combustion. So also a different form of clinker cooler than the specific type we have shown or the elimination thereof entirely will not render our invention any the less applicable to a particular kiln.

Regardless of whether or not the kiln is provided with forced draft and/or a clinker cooler, it is highly important that a predetermined draft be maintained in the hood of the kiln so that air indraft will be held constant. It is usually preferable to maintain a slightly negative draft in the hood so that the air infiltration through inspection openings and clearances will be held at a minimum, while at the same time preventing smoke and flame from being blown into the atmosphere.

In the embodiments of our invention illustrated we maintain a constant hood draft of predetermined amount by means of a suitable draft gage comprising an oil sealed bell 51, the interior of which is connected to the interior of the hood 1A by means of a pipe 52. The bell 51 is pivotally connected to a fulcrumed beam 53 to which is secured a pendulum 54 so that for each and every draft within the hood of the kiln there will be a corresponding position assumed by the beam 53. The movable valve member of a pilot valve 55 is pivotally connected to the beam 53 so that a loading pressure is established corresponding to the draft within the hood of the kiln. The loading pressure so established is transmitted to a standardizing relay 56 similar to the standardizing relay 27, and which establishes a control pressure transmitted through a pipe 57 a selector valve 58, and thence to a servo-motor 59 arranged to operate dampers 60 within the duct leading from the kiln 1 to the induced draft fan 11. The arrangement is such that upon a departure of the draft within the hood of the kiln from that desired an immediate and proportional change takes place in the position of the damper 60 in a direction tending to restore the draft within the hood to the desired value. Thereafter the

standardizing relay 56 operates to gradually position the dampers 60 until the draft within the hood is restored to exactly the predetermined desired value. The selector valve 58 provides a convenient means for transferring operation of the damper 60 from automatic to manual control, as it will be appreciated that during certain times, for example in starting up or shutting down the kiln, it is preferable to have the hood draft controlled manually rather than automatically.

Usually it is necessary because of the severe atmospheric conditions existing adjacent a kiln to locate the draft responsive device at a different elevation and at a considerable distance from the kiln, for as will be appreciated such devices are relatively delicate and may not be able to withstand the high temperatures and dust-laden air immediately adjacent the kiln. As the ambient temperature surrounding the draft responsive device may therefore be quite different than that surrounding the kiln, an error, particularly where the draft responsive device is located at a different elevation than the kiln, may be introduced into its operation. To prevent such error we provide a second oil sealed bell 61 pivotally suspended from the beam 53 and the interior of which is connected by a pipe 62 to the atmosphere immediately adjacent the hood of the kiln. The pipe 62 throughout its entire length is located adjacent the pipe 52, so that both pipes will be maintained at substantially the same temperature and be subjected to the same atmospheric conditions throughout their length. Because of this arrangement the draft responsive device measures the difference in pressure existing between the interior of the hood 1A and the atmosphere immediately adjacent thereto rather than the difference in pressure existing between the interior of the hood 1A and that surrounding the bell 51, which would be the case if but a single oil sealed bell were provided. It will be apparent that we have shown an oil sealed draft responsive device merely by way of example, it being evident that any suitable differential diaphragm device or other type of gage may be substituted.

In Fig. 2 we show a modified form of our invention, which except for the differences now to be described, functions as the embodiment of our invention shown in Fig. 1. In the embodiment shown in Fig. 2 the kiln operator manually establishes a rate of air supply which from observation of the material in the kiln is necessary to give the required heat release. In other words, sufficient under normal and stable operating conditions to maintain the temperature of the material at the spot on which the photoelectric device 22 is focused at the desired value. Thereafter as the temperature of the spot increases or decreases, due to temporary upsets in operating conditions, the zone of combustion in the kiln is automatically moved forward or backward so that the temperature of the spot is restored to the desired value. The location of the combustion zone within the kiln is controlled by introducing more or less air into the burner pipe 9. An increase in the amount of air introduced increases the velocity with which the fuel is projected into the kiln, and hence will act to move the combustion zone forward. Conversely a decrease in the amount of air introduced will decrease the velocity of the fuel and cause the combustion zone to move backward.

Referring to Fig. 2, the rate at which air is

applied for combustion is established manually by means of a loading valve 63 similar in operation to the selector valve 19, in that any desired loading pressure may be established by manual manipulation of knob 64 in the same manner as any desired loading pressure may be established by manual manipulation of the knob 21. The kiln operator by means of the loading valve 63 may therefore establish a rate of air and fuel supply which from observation of the material in the kiln is necessary to give the required heat release. Such rates of air and fuel supply will thereafter be automatically maintained by means of the control explained with reference to Fig. 1. Likewise the rate at which fuel is supplied will be readjusted, as explained with reference to Fig. 1, to maintain a predetermined oxygen content in the flue gas. If operating conditions thereafter remain stable no further adjustments would be required. It has been found however that temporary operating upsets do occur which cause the burning or clinking zone to recede or advance in the kiln, resulting in a non-uniform and inferior product. Such upsets may be caused, for example, by a ring of material forming around the interior of the kiln, or by an uneven flow of material through the kiln. These upsets are usually temporary in character, and therefore require but a temporary correcting adjustment, which may be made as heretofore stated by introducing more or less air into the burner pipe 9.

In accordance with our invention we adjust the quantity of air introduced into the burner pipe 9 by having the loading pressure established by the pilot valve 26 transmitted to a servo-motor 65 operating a damper 66 in a duct 67 which forms a by-pass around the pulverizer 8. Accordingly, air under pressure may be directly transmitted from the outlet of the fan 13 to the burner pipe 9. Assuming for example that the temperature of the material at the spot in the kiln on which the photoelectric device 22 is focused decreases, the arrangement is such that the damper 66 is proportionately moved in an opening direction, thereby introducing more air into the burner pipe 9, so that the fuel is projected into the kiln 1 at a higher velocity and combustion thereof occurs at a greater distance from the burner pipe. This will cause a greater heat liberation to occur a further distance from the hood 1A, thereby acting to restore the temperature at the spot of the kiln on which the photo-electric device 22 is focused to the desired value. Upon an increase in temperature at the spot in the kiln on which the photoelectric device 22 is focused the reverse operation occurs, the damper 66 then being positioned in a closing direction, thereby causing combustion of the fuel and consequent maximum heat liberation to occur nearer the burner pipe 9. As the pilot valve 26 establishes a loading pressure proportional to the temperature at the spot within the kiln 1 on which the photoelectric device 22 is focused, it is evident that for each and every temperature there will be a definite position of the damper 66, and accordingly a definite location in the kiln at which maximum heat release will occur.

In Fig. 3 we show a further modified form of our invention wherein the rate of heat release is maintained constant and the kiln speed and feed of material to the kiln varied to obtain a properly burned clinker. We have shown this form of our invention applied to a kiln having no provision for forced draft, as we have found it particularly adaptable to this type.

Referring to Fig. 3, the secondary air for combustion is admitted to the hood 1A through a suitable opening indicated at 70. The hood draft controller, which as explained with reference to Fig. 1 maintains a constant draft in the hood of the kiln, also acts in this embodiment of our invention to maintain a constant rate of air flow into the hood as the area of the opening 70 remains constant. The exact draft maintained in the hood, and hence the rate of air flow thereinto may be regulated to any value desired by means of an adjustment device 71 which changes the relationship between hood draft and loading pressures established by the pilot valve 55.

We utilize the constant air flow so maintained to produce a constant desired rate of heat release in the kiln by adjusting the rate of fuel feed to maintain a predetermined oxygen content in the kiln, as explained with reference to Fig. 1. In Fig. 3 variations in the loading pressure established by the pilot valve 46 act to vary the rate of primary air flow, and hence the rate of fuel flow to the burner.

To provide for variations in the quality and quantity of the material as it passes through the burning zone of the kiln, the speed of the kiln 1 is varied to maintain the temperature of the material at the spot on which the device 22 is focused at a predetermined value. As shown, the control pressure established by the standardizing relay 27 is transmitted to a servo-motor 72 operating a speed control device 73 for the motor 3. The arrangement is such that if the temperature of the material at the spot on which the device 22 is focused changes, then an immediate and proportional change in the speed of the kiln 1 will occur, and thereafter a gradual change in speed will occur until the temperature of the spot is restored to the desired value. We have shown the speed control device 73 diagrammatically, inasmuch as it is evident that any suitable device, such as a drum controller, variable resistance, or the like, may be employed. It is further evident that if desired a constant speed motor may be employed and a suitable variable speed coupling interposed between the same and the kiln 1, such for example as a hydraulic or dynamic coupling, in which event the servo-motor 72 would be adapted to the particular control device required for such a coupling.

Concurrently with the change in kiln speed it is usually desirable to vary the rate of feed of raw material to the kiln, and we have therefore shown in Fig. 3 a feeder 74, the speed of which is maintained proportional to that of kiln 1. We have for illustrative purposes shown the feeder as being mechanically geared to the kiln. However, it is evident that any suitable mechanical or electrical means may be employed, or that the speed of the feeder may be maintained in proper proportion to the speed of the kiln by manually operated control devices.

While we have illustrated and described certain embodiments of our invention, it will be understood that we do not intend to be limited other than by what we claim in view of the prior art.

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

1. The combination with a rotary cement kiln, means for supplying fuel and air to the kiln to maintain combustion therein, means for measuring the rate at which air is supplied the kiln, means under the control of said last named means for maintaining a constant rate of air supply,

means for determining the oxygen content in the flue gas resulting from said combustion; and means under the control of said last named means for varying the rate of fuel supply to maintain the oxygen content at a predetermined value.

2. The combination with a kiln for heating a material, means for supplying fuel and air to the kiln to maintain combustion therein, means for automatically adjusting the fuel and air supply means responsive to temperature changes in the kiln, and means for automatically readjusting the fuel supply means in response to changes in the oxygen content of the flue gas resulting from said combustion.

3. In combination with a rotary kiln for heating a material, a burner from which fuel in suspension is discharged into the kiln, means for injecting a gas into the burner, and means responsive to the temperature of the material at a predetermined location in the kiln for automatically adjusting the rate at which the gas is injected into said burner while maintaining the rate at which fuel is discharged into the kiln constant.

4. In combination with a rotary kiln for heating a material, an air-swept pulverizer for supplying pulverized fuel suspended in air to the kiln, a burner pipe through which the fuel in suspension is discharged into the kiln, means for injecting air into the burner pipe, and means responsive to the temperature of the material at a predetermined location in the kiln for adjusting the rate at which air is injected into the burner pipe to thereby vary the velocity of the fuel discharged therefrom and accordingly the distance from the burner pipe at which combustion of the fuel takes place.

5. In combination with a rotary kiln for heating a material, an air-swept pulverizer for supplying pulverized fuel suspended in air to the kiln, a burner pipe for transporting the pulverized fuel from the pulverizer to the kiln, means for injecting air into the burner pipe, means responsive to the temperature of the material at a predetermined location in the kiln for adjusting the rate at which air is injected into the pipe, means for supplying air for combustion in the kiln, regulating means for automatically adjusting said last named means to maintain the rate of air supply constant, and means responsive to the oxygen content of the flue gas in the kiln for adjusting the rate of air flow through the pulverizer.

6. The method of operating a rotary cement kiln having fuel and air supply means for maintaining combustion therein which includes, maintaining a substantially constant rate of air supply for combustion, and concurrently varying the rate of fuel supply in accordance with the oxygen content in the flue gas.

7. The method of operating a rotary cement kiln having fuel and air supply means for maintaining combustion therein which includes, driving the kiln at substantially constant speed, maintaining a substantially constant rate of air supply for combustion, and concurrently varying the rate of fuel supply in accordance with the oxygen content in the flue gas.

8. The method of operating a rotary kiln for heating a material and having fuel and air supply means for maintaining combustion therein which includes, driving the kiln at substantially

constant speed, maintaining a substantially constant feed of material to the kiln, maintaining a constant rate of air supply for combustion, determining the oxygen content of the flue gas resulting in the combustion of the fuel and air in the kiln, and adjusting the rate of fuel feed to the kiln to maintain a substantially constant oxygen content in the flue gas.

9. The method of operating a cement kiln to which pulverized fuel suspended in air is supplied from an air-swept pulverizer and having air supply means, which includes, driving the kiln at substantially constant speed, maintaining a substantially constant feed of material to the kiln, adjusting the rate of air supply selectively in accordance with changes in the temperature of the material at a predetermined location in the kiln, and adjusting the flow of air through the pulverizer selectively in accordance with changes in the oxygen content of the flue gases resulting from the combustion of the fuel and air in the kiln.

10. In combination with a rotary kiln for heating a material to which fuel is supplied through a burner, means for determining the temperature of the material at a given location in the kiln, and means for adjusting the velocity of the fuel discharged from the burner while maintaining the rate of fuel discharged constant responsive to said last named means.

11. The method of operating a rotary kiln for heating a material and to which fuel is supplied through a burner which includes, maintaining a constant rate of fuel discharged from the burner while varying the velocity at which the fuel is discharged from the burner in accordance with the temperature of the material in the kiln at a predetermined location therein.

12. Apparatus for controlling the rate at which fuel is supplied to a rotary kiln for heating a material, comprising in combination, light sensitive means for determining the temperature of the material at a predetermined location in the kiln, means operated by said last named means for producing changes in a fluid pressure proportional to changes in the temperature of the material at said predetermined location and for producing a gradual continuing change in the fluid pressure at a rate corresponding to the difference between the actual temperature of the material and a predetermined temperature, and means under the control of said fluid pressure for varying the rate at which fuel is supplied the kiln.

13. Apparatus for controlling the rate at which fuel is supplied a rotary kiln for heating a material, comprising in combination, light sensitive means for determining the temperature of the material at a predetermined location in the kiln, means operated by said last named means for producing a fluid pressure corresponding to said temperature, means for determining the oxygen content in the flue gases resulting from the combustion of the fuel in the kiln, means operated by said last named means for producing a second fluid pressure corresponding to the oxygen content, relay means for establishing a resultant fluid pressure corresponding to the algebraic sum of the first and second fluid pressures, and regulating means of the fuel supply operated by the last named fluid pressure.

WILLIAM E. REASER.
HENRY C. TANNER.