PHOTO-PYROMETRIC CONTROL SYSTEM FOR EFFICIENT COMBUSTION
IN MULTIPLE-BURNER, RESIDUAL-FUEL-FIRED FURNACES

Filed April 12, 1965 2 Sheets-Sheet 1

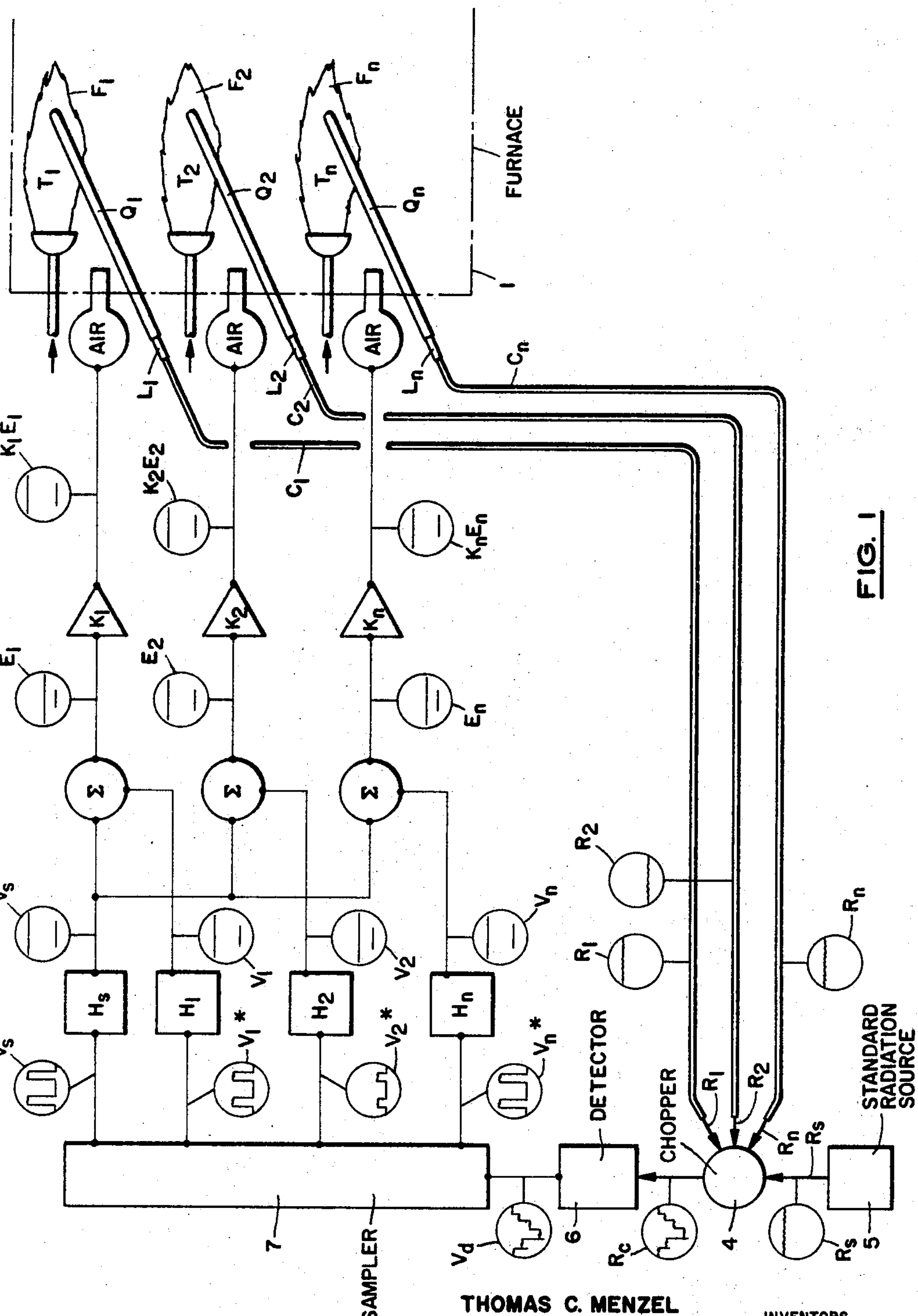

FIG. 1

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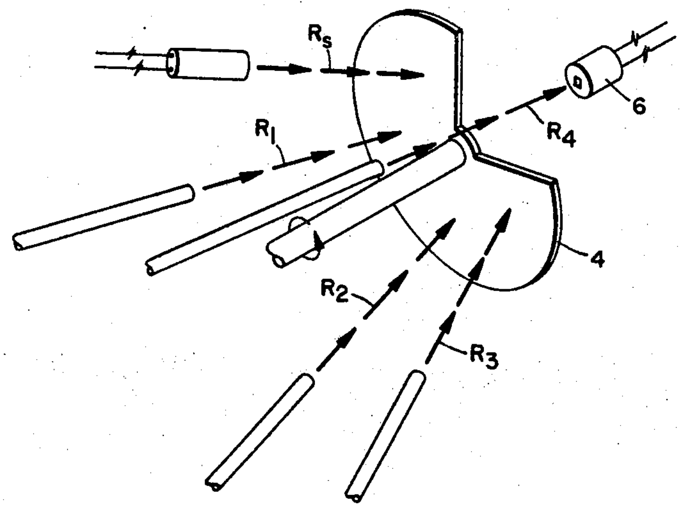

FIG. 2

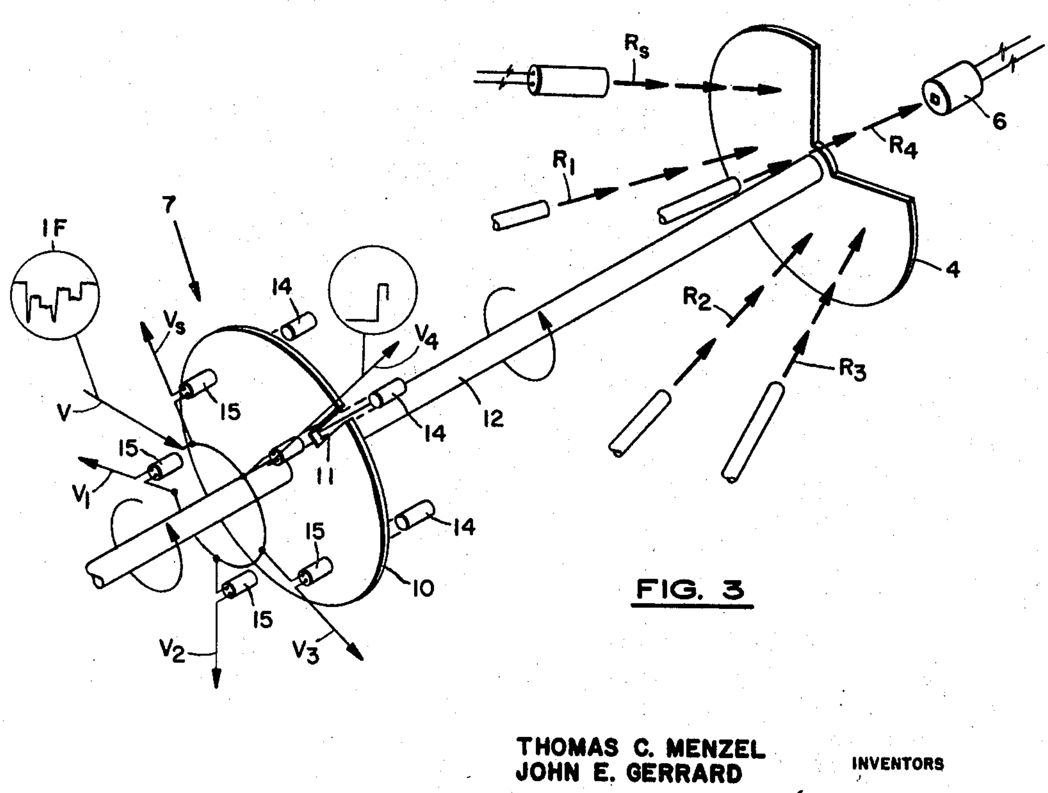

FIG. 3

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PHOTO-PYROMETRIC CONTROL SYSTEM FOR EFFICIENT COMBUSTION IN MULTIPLE-BURNER, RESIDUAL-FUEL-FIRED FURNACES

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The present invention relates to multiple-burner, residual-fuel-fired boilers. In general, it concerns a process and device which maintain the flames in such a multiple-burner furnace at a predetermined temperature level. In particular, it provides a photo-pyrometric control system for maximum efficiency operation of such multiple-burner furnaces.

It is well known that the operation of residual-fuel-fired furnaces is substantially improved in terms of superheater slagging and corrosion of both superheaters and air preheaters by carrying out the combustion at levels of excess air only slightly higher than stoichiometric, i.e. 2–3%. One of the problems associated with this "low excess air" combustion is assuring that the individual burners of a multiple-burner system are each operating at the same level of excess air. For instance, if half the burners in a multiple-burner system operate at 6% excess air and the remainder operate at stoichiometric, the flue gas analysis will show the overall combustion to be at 3% excess air while conditioners are actually catastrophic in terms of smoke and corrosion.

According to the present invention, a photo-pyrometric control system assures that the individual burners of a multiple-burner system are each operating at the same level of excess air and thus afford a practical realization of the inherent benefits of "low excess air" combustion.

In the present invention, the closed ends of temperature-resistant tubes are inserted into or near each flame of a multiple-burner boiler. These tubes glow and produce radiation according to the well-known Planck's Law for radiation from a black body. The radiation signals from the tubes are conducted to a central location where, along with a standard source of radiation, they are focused on an optical detector.

An optical chopper is employed so that radiation from only one source at a time is allowed to reach the optical detector. The optical detector produces a voltage wave which over one period represents the succeeding levels of radiation from the tubes at each flame and from the standard source.

In one embodiment of the present invention, the voltage wave from the optical detector is recorded and the temperatures at the appropriate burner are calculated from the corresponding amplitude of the voltage wave. Knowing the flame temperature at each burner, the furnace operator may manually balance the furnace by adjusting the appropriate air and/or fuel feeds to the respective burners.

In a preferred embodiment of the present invention, the voltage wave from the optical detector is used to balance and automatically control each burner at a predetermined temperature level. In this embodiment, a sampler, which is synchronized with the optical chopper, samples each

level of the voltage wave from the optical detector at a rate equal to the chopper's. The resulting impulse trains are each passed into holding devices which produce essentially direct current levels proportional to the radiation sources. Error signals are then generated by subtracting the direct current level corresponding to the radiation from a particular burner from the direct current level corresponding to the standard source of radiation. The error signals are amplified and the amplified signals drive controllers on the air and/or fuel supply to the appropriate burner. The increase or decrease in the air or fuel supply increases or decreases the flame temperature and the automatic control loop is thus completed.

The nature of the present invention is best understood when described in connection with the accompanying drawings in which FIGURE 1 is a schematic diagram of the photo-pyrometric automatic control system of the instant invention. FIGURE 2 is an isometric view of a typical optical chopper and optical detector employed in the present invention. FIGURE 3 is an isometric view of one embodiment of the present invention.

With reference to FIGURE 1, at furnace **1** is shown a temperature-resistant tube, Q_1, extending into or near the flame, F_1, at temperature, T_1, of an n burner furnace. The tube is sealed at the flame end and has sufficient length to extend through the furnace wall. The tube is made of a suitably inert material, such as alumina. Under steady state conditions, the inside of the tube reaches a temperature which is proportional to the flame temperature and, due to the geometry of the tube, its flame end becomes an almost perfect black body radiator. Radiation, R_1, is viewed by a suitable optical system, L_1, which is positioned in the open end of the tube and consists of a set of apertures or a lens system. From the optical system the radiation, R_1, is then passed into a suitable radiation conductor, C_1, such as a flexible fiber optic, and transmitted to an optical chopper **4**. The optical chopper is a device which alternately allows the radiation from each tube and from the standard source **5** to be focused on the optical detector **6**.

Radiation signals R_1, R_2, R_n and R_s show the radiation from Q_1, Q_2, Q_n and the standard source, respectively. The optical chopper can consist of an opaque disc with a wedge removed of an angle $\phi=360°/(n+1)$, where n equals the number of burners in the furnace. The optical chopper is driven by a small electrical motor (not shown) at a speed which is determined by the number of burners, such as 80 r.p.m. for a four-burner furnace. R_c is the radiation signal at the output of the chopper. The standard source **5**, the details of which are not shown, may consist of an aged tungsten filament lamp in series with a one-ohm standard resistor, variable resistors to control the current to the lamp, and a power supply. The current to the lamp is determined accurately, for example by measuring the voltage drop across the standard resistor with a potentiometer. The optical detector **6**, the details of which are not shown, is a photoresistive cell in series with a fixed resistor and a power supply. A photoresistor is chosen which has its maximum spectral sensitivity at or near the wave length at which the maximum radiation is expected. This wave length is computed from a knowledge of the working temperature of the furnace and

Wien's displacement law. The sensitivity (i.e. change in output for change in temperature) is increased at the expense of signal level by using a cell with a narrow spectral response curve or by filtering the radiation into a narrow band. Radiation fluctuations on the photoresistor cause its resistance to change (radiation increase causes resistance decrease) and this in turn causes the current in the circuit to change. The voltage across the fixed resistor is then proportional to the radiation impinging on the photoresistive cell. V_o is the voltage output from the photodetector. The circuitry involved in the system to his point is extremely simple and free of any critical requirements. The photoresistor does not require extreme temperature stability, a distinct advantage since in general the more sensitive photoresistors have poor temperature stability. Therefore, sensitive photoresistors may be used. The voltage supply does not have to be precisely regulated and is not a critical factor.

A system, for example, which employs a photoresistive cell at each tube has several disadvantages over the present invention. In the former case, the temperature stability becomes a critical consideration. The supply for each detector also becomes a problem with respect to stability, and inter-calibration of the photocells is necessary. The use in the present system of fiber optic radiation conductors eliminates many of these problems in that a single transducer converts all the radiation signals into an electrical signal and therefore any instability affects all the burner signals and the standard signal in the same manner.

Before describing the automatic control portion of the system of the present invention, it should be noted that manual balancing, as earlier described, can be achieved with the system described thus far. For example, the output of the optical detector may be connected to the alternating current input of an oscilloscope. The waveform observed is the alternating current portion of the waveform shown in FIGURE 1 at V_o. The air and/or fuel supply is changed to each burner so that the horizontal portion of this wave falls on the same line. Spikes occur in the wave because it is very difficult to make an optical chopper which allows equalized transition from one radiation level to the next. These spikes are not entirely objectionable, however, since they provide a marker for identification of the burner associated with a particular part of the waveform.

Still referring to FIGURE 1, for automatic control of a multiple-burner furnace, according to the present invention, a sampler device **7** samples the output of the optical detector **6** in such a way that $n+1$ pulse trains are produced (where n is the number of burners in the furnace). The samples for a particular train are taken at a time corresponding to the middle of a voltage level representing a particular source of radiation. Therefore, the sampler frequency is the same as the optical chopper frequency. The sampler output signal extracted from the standard source level is shown at V_s* as well as those from flames F_1, F_2 and F_n sources shown respectively at V_1*, V_2* and V_n*. Many sampling devices will perform this operation, such as mechanical switches attached to a chopper shaft. A preferred sampler is shown in FIGURE 3 and will be described in further detail hereafter. The pulse trains generated in the sampling device **7** are fed to zero order holding circuits where they are converted to analog signals whose amplitudes are essentially proportional to the temperatures at the appropriate burner. The signals coming from the holding circuits H_s, H_1, H_2 and H_n are shown at V_s, V_1, V_2 and V_n respectively. Differential amplifiers produce system error signals, $E_n=V_s=V_n$, generated by applying the outputs of the holding circuits to the inputs of differential amplifiers. The error signals, E_1, E_2, and E_n, are then amplified and the resulting signals, K_1E_1, K_2E_2, and K_nE_n, are used to drive the furnace air and/or fuel supply (not shown) devices in a corrective direction.

One embodiment of the present invention showing the relationship of the optical chopper, the optical detector and the sources to be chopped is shown in FIGURE 2. In FIGURE 2, radiations R_1, R_2, R_3, R_4 and R_s from the four burners of a furnace and from a standard source of radiation, respectively, are conducted through a plane parallel with the optical chopper **4** and is evenly spaced on the circumference of a circle lying in that plane whose axis passes through the center of the chopper disc and the optical detector **6**.

FIGURE 3 showse a sampler **7** consisting of an opaque disc **10** in which a radial slit **11** has been cut. The center of the disc is fixed to the optical chopper drive shaft **12** and rotates with it. $n+1$ light sources and photoswitch combinations (**14** and **15** form a combination) are positioned in such a way that the appropriate switch is closed when the radiation associated with it is passing through the chopper opening.

As described above, the process and device of the present invention find their greatest utility in multi-burner applications; however, they may also be applied to single-burner furnaces. While a general description has been given and a preferred embodiment of the present invention has been described and illustrated, it is to be understood that various modifications and adaptations thereof to different uses may be made without departing from the spirit of the invention and the scope thereof as defined by the following claims.

What is claimed is:

1. A process for the continuous photo-pyrometric control of low excess air combustion in multiple-burner furnaces which comprises: inserting a temperature-resistant tube into or near each burner flame, thereby producing a black body radiator at each flame; viewing the radiation from each radiator by a suitable optic system; transmitting said radiation from each radiator through a suitable radiation conductor to an optical chopper; providing a standard source of radiation; alternately allowing the radiation from each of said tubes and from said standard source to be focused on an optical detector, said optical detector producing an output voltage proportional to the input radiation focused upon said optical detector; observing the output voltage waveform from said optical detector; and adjusting the fuel-air supply to each of said burners in said furnace so that said output voltage waveform is a constant.

2. A process according to claim **1** wherein the output voltage of said optical detector is sampled so as to produce pulse trains, the number of said pulse trains being equal to the sum of the number of burners in said furnace plus one; feeding each of said pulse trains to a zero order holding circuit; converting each of said pulse trains to analog signals whose amplitudes are essentially proportional to the temperature at the appropriate burner; generating error signals by applying the outputs of said holding circuits to the inputs of differential amplifiers, the magnitude of said error signals being equal to the difference between the voltage of said standard source and the voltage from the appropriate holding circuit; amplifying said error signals and using the resultant amplified signals to adjust the air-fuel supply devices of said furnace in a corrective direction.

3. Apparatus for the control of a multiple burner furnace comprising means for optically viewing the temperature of each burner, a standard radiation source, means for comparing the optically viewed temperature of each burner with said standard radiation source, and means for adjusting the air-fuel supply of each of said burners so that the viewed optical temperature of each of said burners is substantially equal to said standard radiation source.

4. Apparatus for the control of a multiple burner furnace comprising means for measuring the radiation of each burner flame; a standard radiation source; means for converting the measured radiation of each burner flame and of said standard radiation source to proportionally equivalent electrical signals; means for sequentially comparing each electrical signal proportional to said radiation of each burner flame with the electrical signal from said standard radiation source; and means responsive to the difference between the compared signal levels for adjusting the air-fuel supply to each burner.

5. A photo-pyrometric control system which comprises in combination a plurality of temperature-resistant tubes, a flexible fiber optic for each said tube for transmitting radiation therefrom, a standard radiation source, a sole optical detector and a sole optical chopper positioned to receive radiation signals from said standard radiation source and each said fiber optic and to transmit the radiation signals to said optical detector.

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