Oct. 8, 1935. F. G. SCHWALBE 2,016,458

METHOD OF DIRECT HEATING OF MATERIALS IN FURNACES

Filed May 5, 1932 4 Sheets-Sheet 1

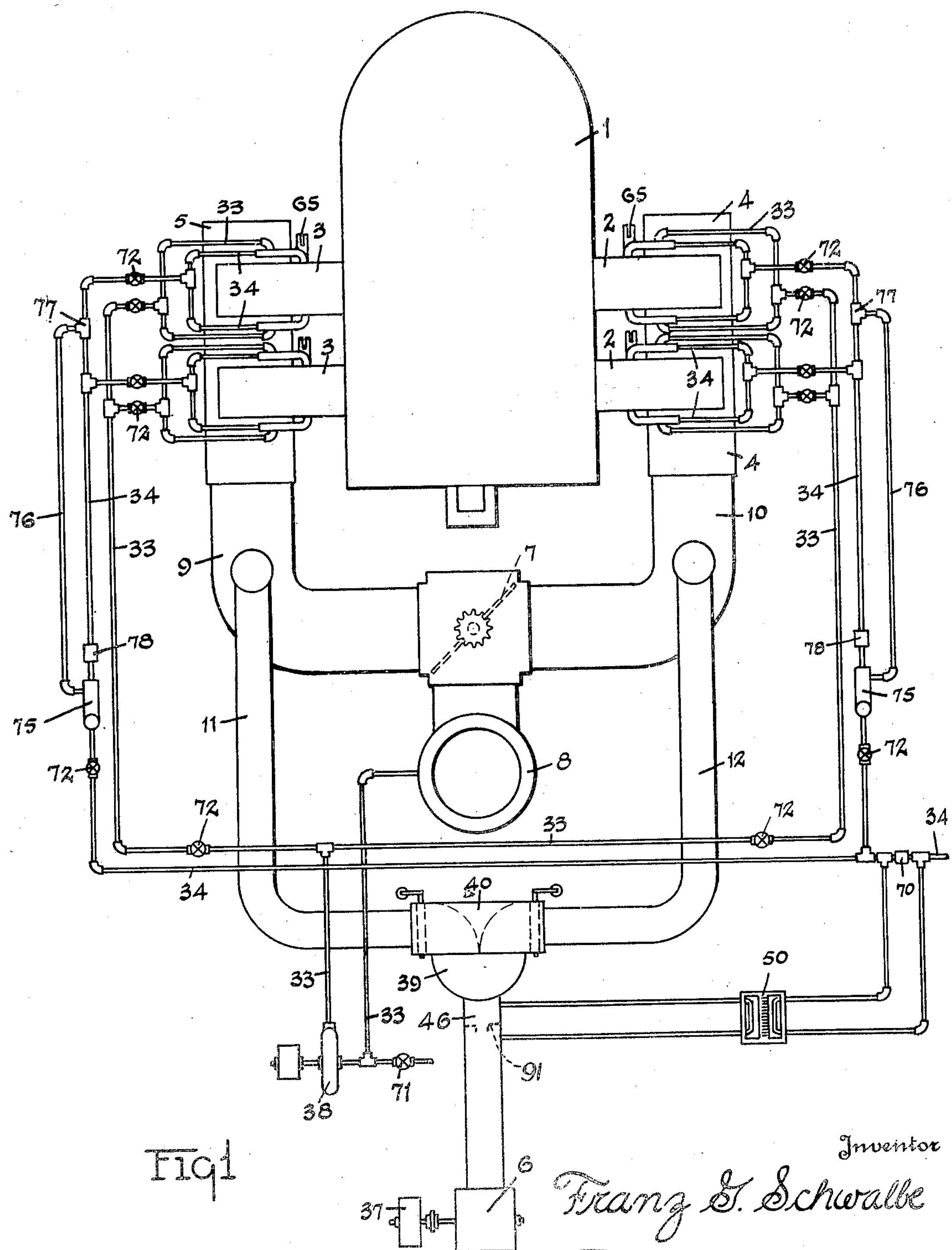

Fig 1

Inventor

Franz G. Schwalbe

By Faust F. Crampton

Attorney

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METHOD OF DIRECT HEATING OF MATERIALS IN FURNACES

Filed May 5, 1932 4 Sheets-Sheet 2

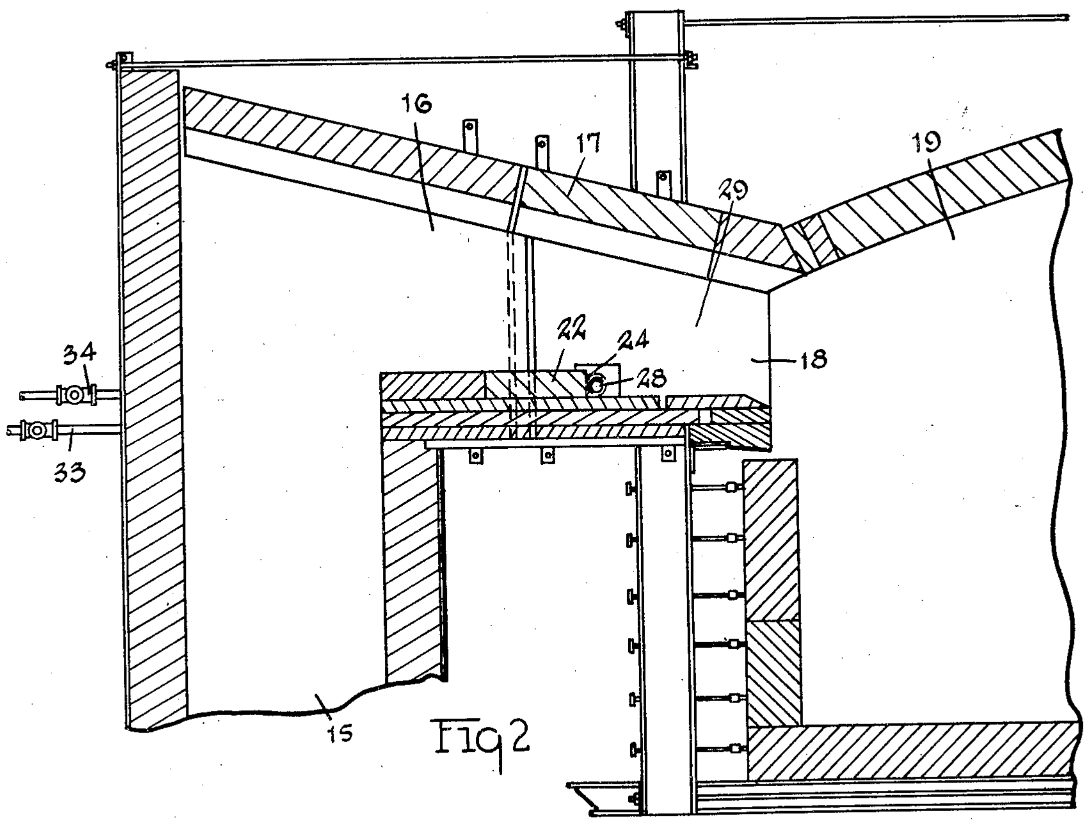

Fig 2

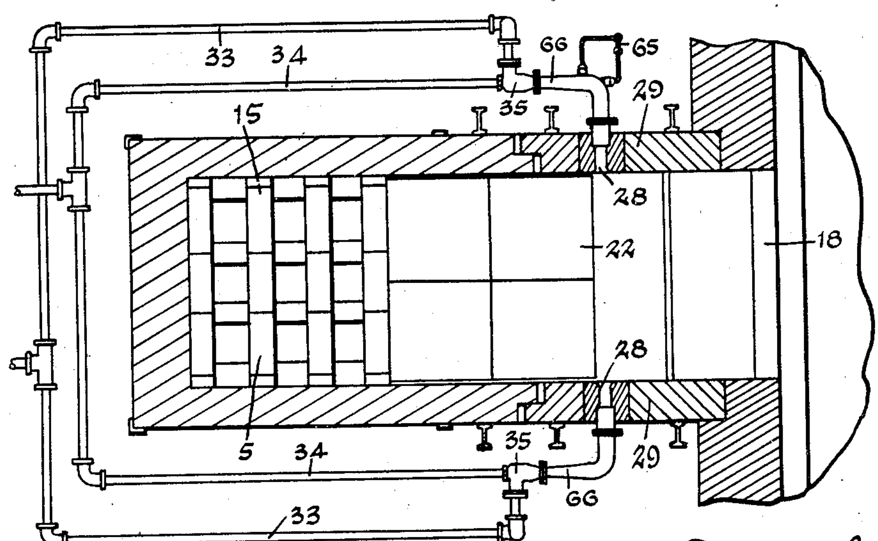

Fig 3

Inventor

Franz G. Schwalbe

By Faust F. Crampton

Attorney

METHOD OF DIRECT HEATING OF MATERIALS IN FURNACES

Filed May 5, 1932 4 Sheets-Sheet 3

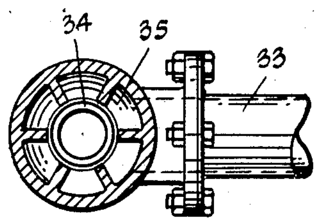

Fig 6

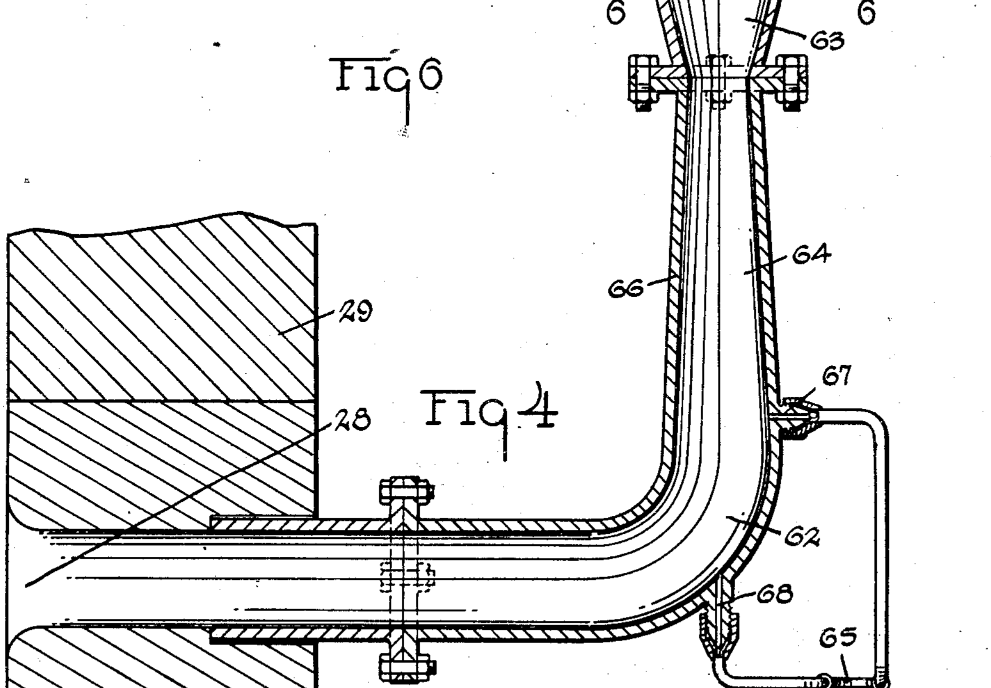

Fig 4

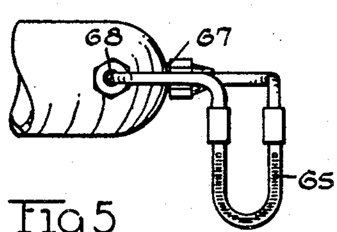

Fig 5

Inventor

Franz G. Schwalbe

By Faust F. Crampton

Attorney

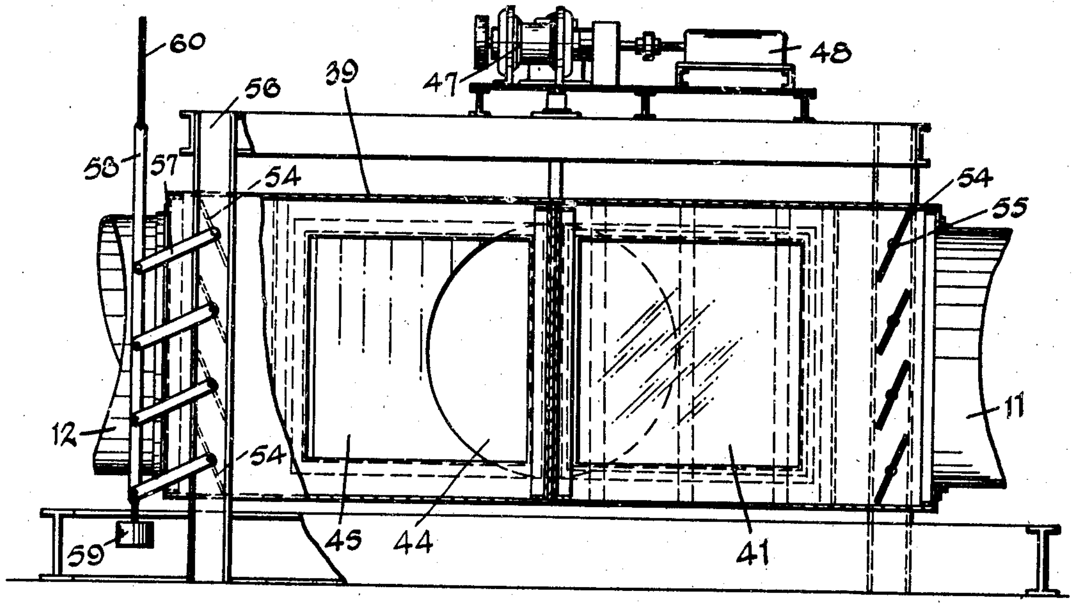

Fig. 7.

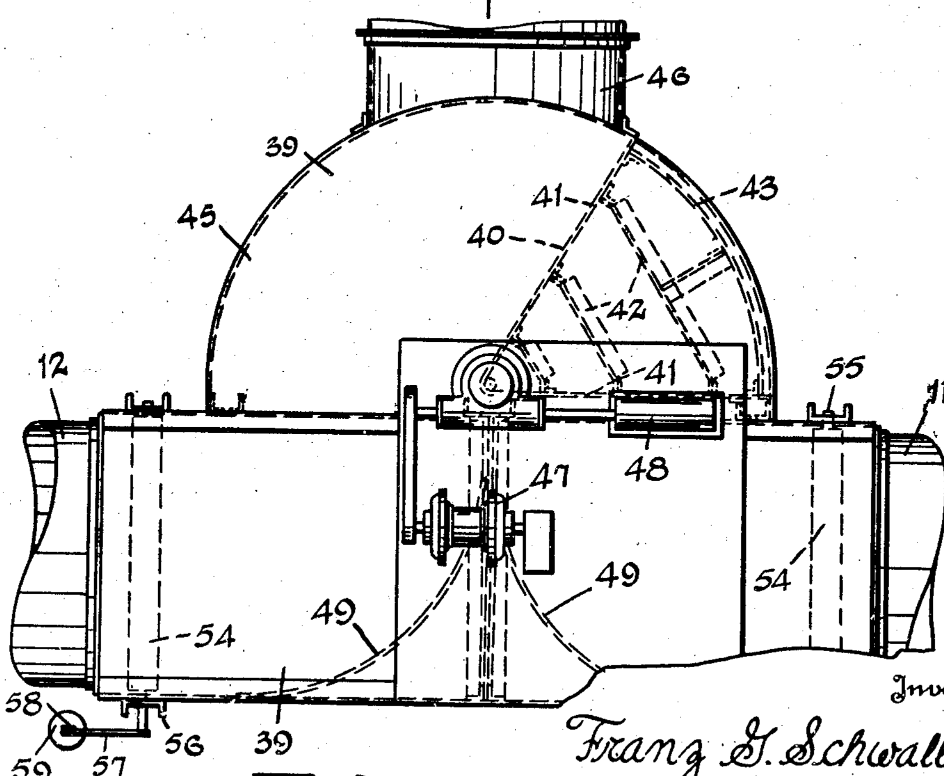

Fig. 8.

Inventor

Franz G. Schwalbe

By Faust F. Crampton

Attorney

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UNITED STATES PATENT OFFICE

2,016,458

METHOD OF DIRECT HEATING OF MATERIALS IN FURNACES

Franz G. Schwalbe, Toledo, Ohio

Application May 5, 1932, Serial No. 609,370

19 Claims. (Cl. 263—15)

My invention provides a method of flame control whereby the desired rate of heat transmission to material is produced at a great saving of fuel. Thus the invention provides a method whereby the flame may be readily altered to adapt it to changes in quantity or character of the material heated by the flame or the heat treatment to which it is desired to subject the material. It is particularly advantageous where the time element or rate of heat transmission from the flame is a material factor when heating materials in furnaces by radiation direct from the flame. Thus, it is particularly suitable for heating materials of any kind by a flame that passes over the materials in the same chamber of the furnace that the materials are located in, to produce such reactions as may be desired, that is, thermo-chemical or the mere physical change of melting solids or both chemical conversion and production or maintenance of a molten or fused condition.

Air and fuel gas is introduced into a somewhat confined burner chamber to enable cracking down of the hydrocarbons as the gas moves through the burner chamber and in advance of its entrance into the heating chamber. The flame is controlled by producing substantially the same rate of flow in the air and fuel gas streams and a rate of combustion that corresponds to the rate flow of the streams. This is done by introducing into the fuel gas primary air or neutral gas or both in required proportion and amount depending on the rate of flame propagation and the rate of heat transmission that it is desired to produce. More particularly, the invention provides a method of heating furnaces wherein the fuel gas and air is directed into the furnace so as to produce a stratified arrangement formed of two layers, one of a fuel gas and the other of air, to produce a gradual diffusion of the fuel gas and air as they move across the furnace. The stream of air is preferably located above the stream of fuel gas to form a blanket of air over the flame and shield the crown of the furnace. When the method of my invention is used in glass furnaces, there is produced a reduction of fuel consumption required to heat the same body of glass to the same temperature. That is, 8,000 cubic feet of fuel gas per ton of glass is ordinarily required and this, by my invention, may be reduced at least to 6,000 cubic feet of fuel gas per ton of glass. Also, the crown temperature may be reduced at least 200 degrees Fahrenheit while a greater heat transmission to the body of the glass is produced. The invention thus provides for economical heat treating of the batch materials and melting of the glass notwithstanding variation in the tonnage. It enables the ready production of variation in the rate of the flame propagation to effect complete combustion before the gases are exhausted from the furnace heating burner.

Due to the use of a multiplicity of ports in a regenerative fired furnace and the difference in the length of travel of the air to the ports, that is the remoteness of one of the ports from the source of air supply, there has heretofore been produced a greater pressure loss in the air entering the more remote ports and a lower velocity in the more remote ports. Consequently, a decreased volume of air is delivered to the more remote ports. This is due to variation in frictional losses. The fixed velocity of the air through each port is maintained only providing a definite unvarying quantity of air is supplied to the furnace. The amount of air taken into the opposite sides of the furnace will differ due to differences in construction and obstructions, and will vary according to wind direction and change of orifices due to erosion. Furnaces being thus subject to changes in atmospheric conditions, the amount of air taken into the furnace is dependent on the adjustment of parts, which are in turn dependent solely upon the judgment of the furnace operator.

The invention more particularly provides a method and a means for causing the same rate of movement in the currents of the air and the fuel gas as they are introduced into the furnace to enable them to move at the same speed across the furnace from each of the ports and prevent local disturbance caused by the ejectment of a faster moving gas in the vicinity of another gas, which produces a whirling effect and prevents the distribution of the combustion of the fuel gas over the furnace and until the gases reach, and are about to enter, the exhaust ports. My invention substantially eliminates all "hot spots" within the glass furnace and enables the air to blanket the crown of the furnace and maintain the flame of substantially uniform high temperature at and over the surface of the glass.

The invention thus provides a method for controlling the combustion to produce a uniform highly luminous flame and maximum heat radiation over an extended area and complete the combustion progressively at substantially the point of delivery or departure of the gases from the material.

The invention consists in other features and possesses advantages which will appear from the following description and upon examination of the drawings. Furnaces in which the method involving the use of the invention may be conducted may partake of different forms and the steps in the method may be varied and still embody the invention. To illustrate a practical application of the invention, I have selected a regenerator type of furnace that embodies the invention and a method of operation of the regenerator type of furnace as examples of the structures and the details of such structures, and the methods that contain the invention, and shall describe the selected structure and method hereinafter, it being understood that variations may be made and that certain features of my invention may be used to advantage without a corresponding use of other features of the invention, and without departing from the spirit of the invention. The particular furnace selected is shown in the accompanying drawings.

Fig. 1 illustrates a plan view of the furnace referred to. Fig. 2 is a view of a vertical section of one of the burners. Fig. 3 is a view of a horizontal section of the burner shown in Fig. 2. Fig. 4 illustrates a view of a section of a gas velocity gauge. Fig. 5 illustrates the velocity indicator. Fig. 6 illustrates a view of a section of a gas mixer taken on the plane of the line **6—6** indicated in Fig. 4. Fig. 7 is a top view of an air valve for directing and regulating the flow of air to the burners. Fig. 8 illustrates vertical sections taken on two planes of the air valve illustrated in Fig. 7.

The regenerator furnace **1**, illustrated diagrammatically in Fig. 1 of the drawings, has associated therewith the burners **2** and **3** that communicate with the checker work constructions **4** and **5** that are connected through the butterfly valve **7** with the stack **8** by means of the flues **9** and **10**. Air is directed to the flues **9** and **10** and thence to the checker work through the pipes **11** and **12**. The movement of the air to the checker work is dependent upon the position of the butterfly valve **7** and the air valve which connects one or the other of the pipes **11** and **12** to the atmosphere or, if forced air draft is used, to the blower **6**. Thus the air is directed to the checker work during alternate periods to receive the heat of the checker work which has been heated by the exhaust gases, or products of combustion during the preceding period in the manner well known in the art.

As shown in Figs. 2 and 3, the burners communicate with the checker work through the passageways **15** through which heated air is conducted to the chambers **16** of the burners. The top wall **17** of each of the burners is inclined downwardly to its respective ports **18** where the chambers **16** communicate with the glass heating chamber **19** of the furnace **1**. The burner is also provided with a ledge or raised portion **22** to enable distribution of the fuel gas that enters through the ports **28**.

The fuel gas ports **28** are located in the side walls **29** of the burner and in proximity to the surface **24** of the ledge **22** and below the upper edge of the ledge, whereby the gas enters at a point below the air stream caused by the movement of the air being drawn through the passageway **15** into the chamber **16** and over the ledge **22**.

This produces a layer of fuel gas that, in its formation, is sheltered by the wall **22** to form a width the same as that of the bottom of the chamber and which moves along the lower surface of the chamber **16** of the burner into the furnace through the port **18**, while the air moves above the layer of gas. The rate of the movement of the gas depends upon the amount of gas that is supplied through the inlet ports of the chamber.

In order to produce the same rate of flow of gas that is produced in the secondary air current by the stack and to prevent lagging of the gas with respect to the air and the interdisturbance of the gas and air locally and, consequently, to produce uniform distribution of the combustion over the surface of the glass, the rate of movement of the gas, as it enters the ports **28**, is stepped up to the movement of the air as it passes over the dam or wall **22** by the introduction of neutral gas or waste gas or air into the fuel gas in advance of its introduction into the heating chamber.

The fuel gas is directed from a source of supply of fuel gas to the ports of the furnace through the pipes **34**, while the primary air, the waste gas or a neutral gas, or a mixture of two or more such gases that may be referred to as the auxiliary gas, is directed from a source of supply through the pipes **33**. Each burner is provided with a pair of mixing chambers **35** for mixing the fuel gas directed through the pipe **34** and the auxiliary gas that is directed through the pipe **33**. The fuel gas is directed axially while the auxiliary gas is directed circumferentially into the mixing chamber **35**.

The mixing chamber is located at one end of a gas gauge **66**. The gauge is bent to form a curved elbow, as at **62**. Preferably the portion of the gauge intermediate the mixing chamber **35** and the elbow **62** is formed Venturi shaped, it being provided with flaring portions **63** and **64**. A velocity indicator **65** is located at the elbow **62**. An opening is provided in one side of the portion **64** of the gauge **66** to connect the fluid indicator **65** and obtain, at this point, the static pressure, and an opening **68** is formed in axial alignment with the portions **63** and **64** of the gauge **66** to obtain a combined static and velocity pressure on the fluid of the U-shaped indicator **65**. The velocity of the gases that pass through the gauge is thus indicated by the difference in the static and the combined static and velocity pressures produced on the two surfaces of the fluid in the indicator **65**.

The other end of the gauge **66** communicates with the port **28** and the mixture of the fuel gas and the auxiliary gas enters the port **28** at a point below the upper edge of the ledge or dam formed by the portion **22** of the bottom wall of the chamber **16**.

The amount of air supplied to the checker work **4** and **5** is also measured by the meter **50** which is connected on opposite sides of a ported baffle plate or air orifice **91** which determines the difference in pressure on opposite sides of the baffle plate and, consequently, the amount of air that is furnished to the checker work on either side of the furnace, as determined by the location of the butterfly valve **7**, is measured. The meter **50** may be a double meter and a similar ported baffle plate or orifice **70** may be located in the pipe line **34** through which the fuel gas is supplied to the burners. The movement of the fuel gas through the pipe **34** will thus also be indicated by the meter **50**. The meter **50** will thus indicate the movement of the air to the checker work and of the fuel gas to the burners, while the velocity indicators 65 will indicate the rate of the movement of the mixture of fuel gas and auxiliary gas to each of the burners.

In order to maintain the desired rate of movement of the mixture of fuel gas and auxiliary gas to the rate of movement of the air through the checker work and the chambers, suitable valves are provided in the pipe lines, such as the valve 72 and the adjustable air valve 39. This will enable the production of the same rate of flow of the fuel gas and air in the burner chambers and also enable the production of a highly luminous flame. The location of the burner port 28 in the side wall of the port 29 is remote from the port 18. This remoteness allows the fuel gas stream to be raised to a temperature sufficient to cause decomposition or "cracking down" of the hydrocarbons resulting in luminous carbon particles. In order to limit the extent of hydrocarbon dissociation, auxiliary air is admitted to the burner 35. The amount of primary air admitted is controlled without alteration of the gas velocity by varying the proportion of air by volume to waste gas in the auxiliary gas supplied. The primary air and waste gas proportions are controlled by the operating valve 71 in a pipe 33 open to the atmosphere and connected to the pump 38. Closing of the valve 71 increases percentage by volume of waste gas from the stack making up the auxiliary gas supply.

In order that a uniform flow of fuel gas may be delivered to the mixer 35, it is essential that the gas be maintained at a constant pressure. The pressure of gas may be greatly varied. The gas pressure for the particular system shown is approximately 4 oz. The pressure of the main gas supply is usually 8 oz. or more. A standard type of pressure regulator 75 is used. The regulator reduces and maintains the gas pressure to the desired amount. The line 76 is a pressure transmission line. The line 76 connects to the gas line 34 and acts to maintain the desired pressure at a point midway of the points of delivery of line 34 to the furnace. When the furnace has been fired through one set of ports 2 and the gas supply is cut off and diverted to ports 3, the pressure regulator 75 acts to establish the desired pressure at the point 77. Due to the absence of pressure at the point 77, the regulator 75 opens wide. When a pressure head is suddenly built up at 77, the pressure regulator line 76 conveys the pressure head to the regulator 75. This causes the regulator to close rapidly. This action continues for a few seconds, causing the regulator to flutter or alternately open and close rapidly. To avoid fluttering, a back pressure plate 78 is inserted in the line which retards the flow of gas and causes the desired pressure head to be built up gradually at point 77. The back pressure plate consists of a flat plate pierced with small holes which reduces the cross sectional area of the pipe through which the gas flows.

To insure the same movement of air into the furnace from opposite sides during alternate periods and notwithstanding the changes in atmospheric condition which produce variations of draft caused by the stack, the air may be directed into the pipes 11 and 12 by a pressure means, such as by means of the air fan 6 that may be driven by a suitable motor or belt wheel 37. The air enters the valve casing 39 and is directed by a suitable movable valve member 40 into one or the other of the pipes 11 and 12 and thence through that checker work that has been heated during the preceding part of the operation of the furnace. The movable valve member 40 is formed of a pair of plates 41 that are arranged V-shaped and are tied together by suitable reinforcing members 42 and the arcuate wall 43 that interconnects the outer ends of the plates 41. The plates 41 are spread sufficiently to cover the inlet port 44 of the casing 39 as it passes from one extreme position to the other. The movable valve member 40 is located in a semi-cylindrical part 45 of the casing to which the inlet pipe 46 is connected. The cylindrical part 45 of the casing communicates with the body part of the casing in which are located two walls 49, preferably curved so as to direct the air towards one or the other of the ends of the body part of the casing 39, and into one or the other of the pipes 11 and 12, depending upon the position of the movable valve member 40. Thus, when the movable valve member 40 is in one position, the air will be directed into the pipe 11, and when it is in the other position, the air will be directed into the pipe 12, and during an intermediate position the inlet port 44 will be closed. The valve member 40 may be operated in either direction after desired intervals of time by a suitable motor 47 and control mechanism 48 of the type well known in the art.

In order to provide for the variations of the effective stack draft when operating from one side or the other side of the furnace, due to changes in operating conditions, such as clogging and difference in wall construction or difference in wind or atmospheric air pressures, suitable dampers may be located in opposite ends of the body part of the valve casing 39 to vary the effective areas of the outlet ports of the casing. Thus the damper members 54 are connected to suitable rods 55 that are pivotally supported in suitable uprights 56 located on opposite sides of the valve casing and are connected to arms 57 that may be connected to rods 58. If desired, the rods 58 may be suitably weighted, as by the weights 59, and operated by suitable cables 60 to raise and lower the rods 58 and, consequently, to rotate the damper members 54 to a more or less closed position to obtain the desired relative adjustment of one side or the other of the effective port areas of the valve casing 39 and thus control the rate of flow of air as may be determined by the quantity of air moving through the pipe 46.

The method involving the use of my invention maintains uniform distribution of the heat of the flames over the entire surface of the material in a furnace and also enables a ready variation of the load upon the furnace—that is, a ready variation of the quantity or character of material or ready adaptation to variation in the rate of heat absorption. It thus enables ready variation in the rate of heat transmission required to produce required or desired results.

Irregular heating, although the flame may completely cover the material, is caused by a difference in the velocities of the fuel gas stream and the air stream, which produces local agitation and turbulence and non-uniform diffusion of the gases.

Gaseous fuels having low heating value due to the large percentages of inert gases contained have a lower rate of flame propagation than high heating value fuels containing little or no inerts. As an example, producer gas having a low calorific value burns with less speed than natural gas, which has approximately 7 times the calorific value. Introducing air into the fuel gas stream tends to perform the function of premixing, resulting in an increase in the rate of flame propagation. The amount of air of the auxiliary gas introduced into the fuel gas, however, is outside of the limits of inflammability, and is less than that which would produce with the fuel gas an inflammable mixture to prevent combustion in the fuel gas stream independent of the combustion produced by the overlying air stream.

After the proper ratio of fuel gas to air has been established to take care of the increase in load or quantity of material that is to be heated within a given time, it becomes necessary to adjust the fuel gas stream velocity to cause it to flow at the same rate as the secondary air stream. This is accomplished by increasing or decreasing the amount of primary air introduced into the fuel gas stream. Having thus adjusted the velocities to eliminate turbulent flow, we are confronted with the necessity of burning this greater quantity of fuel in the same length of flame travel as existed under light load operation. In the operations heretofore used in furnaces, this is never fulfilled, resulting in unburned fuel gas leaving the furnace. In such operations complete flame coverage of the material to be heated may be obtained, but it is wasteful of fuel gas, and does not result in the maximum transfer of heat to the material and soon destroys the exhaust ports of the furnace. The fuel gas stream may be completely consumed and the flame confined to the heating chamber of the furnace and still maintain a flame of uniform heat radiating properties by decreasing the proportion of waste gas in the auxiliary waste gas-air mixture introduced into the fuel gas stream by substituting therefor a like volume of air.

When the load is lightened—that is, the rate of heat transmission is reduced, the velocity of the secondary air stream is reduced, and the fuel gas stream is adjusted to meet that of the air stream. If the same waste gas-air ratio is used in the auxiliary gas that was used with the heavier load, the flame does not completely cover the furnace to be heated. It is evident, therefore, that the rate of flame propagation must be decreased, tending to lengthen the flame. This is accomplished by increasing the percentage of waste gas and decreasing the percentage of air in the auxiliary waste gas-air mixture introduced into the fuel gas stream. The waste gas so introduced mixes with the fuel gas stream and dilutes it through the addition of inerts. This addition reduces the net heating value of a cubic foot of the fuel gas stream. The result is a decrease in the rate of flame propagation, resulting in a longer flame and complete coverage of the material to be heated.

The alteration in the ratio of primary air and neutral gas that make up the auxiliary gas mixture may be varied from no air to maximum air, or from no waste gas to maximum waste gas, that is, it may be varied from zero to maximum in either case.

While the furnace is operating under a moderate load, there would ordinarily be introduced into the fuel gas at least a moderate amount of neutral gas depending, of course, on combustion rate to effect complete combustion at the point of delivery of the gases from the material.

If a furnace is operating under a relatively moderate load, and the load is increased, the change will necessitate the introduction of an additional amount of fuel gas, and to maintain the combustion ratio, an additional amount of air will be required. An increase in the amount of air increases the velocity of the air, and to avoid local agitation by the streams of different velocities and thus local increased rate of combustion, the rate of flow of the fuel gas stream ordinarily must be stepped up to that of the air stream. This will produce a ratio of air and gas that will not be such a combustion ratio as to produce maximum luminosity or maximum and uniform heat radiation over the surface of the material. This also results in exhaustion and waste of fuel gas since the increase of the air and fuel gas supply causes the flame to over-shoot the material, that is, the combustion is completed beyond the edge portion of the material remote from the port from which flames protrude into the furnace. In order that the progressive combustion may be completed substantially at the edge of the material located remote from the burner chamber, the neutral gas introduced into the fuel gas is decreased, but the rate of flow of the fuel gas must be maintained the same as that of the air stream. This is done by increasing the proportion of the air to the neutral gas that is introduced into the fuel gas in an amount that will sufficiently shorten the flame, or increase the flame propagation rate, such as to complete the combustion at the edge of the material nearer to the exhaust ports.

I claim:

1. The method of heating furnaces having ports through which gases are introduced and exhausted and forming inlet and exhaust ports which consists in directing a stream of fuel gas into the heating chamber of the furnace and a stream of air substantially parallel with and in proximity to the fuel gas and introducing a current of gas other than fuel gas into the fuel gas stream to cause the streams of air and fuel gas to move at the same rate and to produce a flame propagation at a rate corresponding to the rate of the movement of the stream of the fuel gas and air to complete progressively the combustion between the ports in the furnace.

2. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel juxtaposed streams, and introducing a gas other than fuel gas into the fuel gas in quantities to produce at the point of introduction of the fuel gas a fuel gas stream velocity substantially the same as that of the air stream.

3. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel juxtaposed streams, and introducing a substantially neutral gas into the fuel gas stream in amount to produce substantially the same stream velocity throughout the length of the said streams.

4. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel juxtaposed streams, and introducing air into the fuel gas stream in amount to produce substantially the same stream velocity in the said streams.

5. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the furnace in substantially parallel streams, and introducing into the fuel gas a mixture of air and neutral gas in amount to produce the same velocity

in the said streams and in proportions to produce a rate of flame propagation corresponding to the velocity rate of the streams to complete the fuel gas combustion within the furnace.

6. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the furnace to produce substantially parallel juxtaposed streams, and introducing an auxiliary gas other than fuel gas into the fuel gas stream in amount to produce a rate of fuel gas combustion according to the rate of flow of the air and fuel gas streams to complete the fuel gas combustion substantially at the edge of the material nearer to the gas outlet of the furnace.

7. The method of heating furnaces having ports through which gases are introduced and exhausted and forming inlet and exhaust ports which consists in directing a plurality of streams of fuel gas into the heating chamber of the furnace, each of the streams having a width substantially equal to that of the port through which it is emitted into the furnace and introducing streams of air above and in proximity to the streams of fuel gas and having substantially the same widths as the fuel gas streams to form a layer of fuel gas and a layer of air, all of the air located above all of the fuel gas and extending throughout a length of the furnace equal to the summation of the lengths of the ports; and introducing into the fuel gas streams gas other than the fuel gas in amount to produce a velocity in the fuel gas streams substantially the same as that of the velocity of the air streams and in proportion to the said fuel gas and air as to produce substantially complete conversion of the air and fuel gas into products substantially at the ports through which the products of combustion are exhausted.

8. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel juxtaposed streams and introducing a gas other than fuel gas into the fuel gas in advance of the liberation of the fuel gas and in amount to produce substantially the same stream velocity in the said streams.

9. The method of heating furnaces which consists in forming a stream of fuel gas in a furnace and a stream of air substantially parallel with and in proximity to the fuel gas and introducing a gas other than the fuel gas into the fuel gas stream in advance of the liberation of the fuel gas to maintain a proportion of the air and combustible constituents of the fuel gas according to the heat to be produced in the furnace and cause complete combustion of all of the combustible constituents of the fuel gas within the furnace and the same rate of flow of the said streams.

10. A method of controlling flame propagation in furnaces to produce transmission of heat as required, which consists in introducing air and fuel gas into the furnaces in juxtaposed relation, the amount of fuel gas introduced within a given time varying according to the heat desired to be produced, and the amount of air varying according to the amount of the fuel gas introduced into the furnace, and introducing into the fuel gas, in advance of its liberation, a neutral gas in amount that varies according to the quantity of the fuel gas introduced into the furnace, to produce the same velocity in the said streams and a rate of flame propagation corresponding to the velocity rate of the streams.

11. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel juxtaposed streams, varying the quantity and rate of flow of the fuel gas stream according to the heat quantity to be produced in the furnace, introducing gas other than fuel gas into the fuel gas in advance of the liberation of the fuel gas stream and in an amount to produce substantially the same stream velocity in the said streams and progressively producing complete combustion according to the rate of flow of the streams, and producing complete combustion substantially at the edge of the material from which the streams are exhausted.

12. A method of controlling flame propagation in furnaces according to the variation of the heat quantity required to heat materials, which consists in introducing fuel gas and air in juxtaposed streams, varying the quantity of the fuel gas introduced into the furnace according to the heat quantity required, varying the quantity of air introduced into the furnace according to the amount of the fuel gas introduced into the furnace, introducing a mixture of air and neutral gas into the fuel gas in advance of the liberation of the fuel gas, in amount to maintain the rate of flow of the fuel gas stream the same as that of the air stream, the amount of the neutral gas with reference to the air of the said mixture varying according to the amount of the fuel gas introduced into the furnace, the amount of the neutral gas to the air of the said mixture being reduced and the amount of air in the mixture increased as the quantity of the fuel gas is increased to produce complete combustion of the constituents of the fuel gas substantially at the edge of the material from which the gases of the furnace are exhausted, notwithstanding the variation of the heat quantity produced by the flame.

13. The method of control of flame propagation to produce desired heat quantities for heating materials and terminating the flame at the edge of the materials from which the gases are exhausted which consists in producing a stream of fuel gas and a stream of air, the air stream located in proximity to and covering the fuel gas, and introducing a gas other than a fuel gas and air into the fuel gas in advance of the liberation of the fuel gas, the air and gas other than a fuel gas varying from zero to maximum and the mixture varying in amount to cause the fuel gas to move at the same rate at which the air stream moves to produce a flame propogation at a rate corresponding to the rate of the movement of the streams of the fuel gas and air to progressively complete the combustion of all the combustible constituents of the fuel gas substantially at the desired point in the movement of the streams.

14. The method of control of flame propagation to produce desired heat quantities and desired lengths of flame which consists in producing a stream of fuel gas and a stream of air, the air stream located in proximity to and covering the fuel gas, and introducing a mixture of a neutral gas and air into the fuel gas in advance of the liberation of the fuel gas in amount to cause the fuel gas to move at the same rate at which the air stream moves and in a ratio to each other to produce flame propagation at a rate corresponding the rate of the movement the streams of the fuel gas to progressively complete the combustion of all of the combustible

constituents of the fuel gas at the desired point in the movement of the streams.

15. The method of controlling flame propagation in furnaces for heating material which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel juxtaposed streams, all of the air introduced into the furnace located above all of the gas introduced into the furnace, and introducing a mixture of neutral gas and air into the fuel gas in advance of the liberation of the fuel gas into the furnace and in amount to produce substantially the same stream velocity in the said streams, and a rate of flame propagation corresponding to the stream velocity to complete the combustion of the carbon and other constituents of the fuel gas substantially at the edge of the material from whence the exhaust products are exhausted.

16. The method of controlling flame propagation which consists in forming air and fuel gas into substantially parallel juxtaposed streams, the air stream substantially covering the fuel gas stream, introducing a mixture of air and a substantially neutral gas into the fuel gas stream in proportions that vary from zero to maximum in either case, the amount of the neutral gas varying according to the velocity of the fuel gas stream and the amount of air varying according to the ignition rate of the fuel gas and the amount of the said mixture being such as to produce the same stream velocity in the gas stream as that of the air stream to maintain a constant flame length.

17. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel, juxtaposed streams and introducing a gas other than fuel gas into the fuel gas in quantities less than that which would produce an inflammable mixture and in amount to produce at the point of introduction of the fuel gas into the heating chamber of the furnace a fuel gas stream velocity substantially the same as that of the air stream.

18. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel, juxtaposed streams and introducing air into the fuel gas stream in advance of the introduction of the fuel gas into the heating chamber of the furnace in amount to produce substantially the same stream velocity in the said stream and less than that which would produce an inflammable mixture.

19. The method of controlling flame propagation in furnaces for heating materials which consists in introducing air and fuel gas into the heating chamber of the furnace in substantially parallel, juxtaposed streams and introducing a mixture of a neutral gas and air into the fuel gas in advance of the liberation of the fuel gas and in a total amount to produce substantially the same stream velocity in the said streams, and in amount such that the air of the mixture is less than that which would produce an inflammable mixture.

FRANZ G. SCHWALBE.