Aug. 7, 1962 R. M. HARDGROVE 3,048,131

METHOD FOR BURNING FUEL

Filed June 18, 1959 5 Sheets-Sheet 1

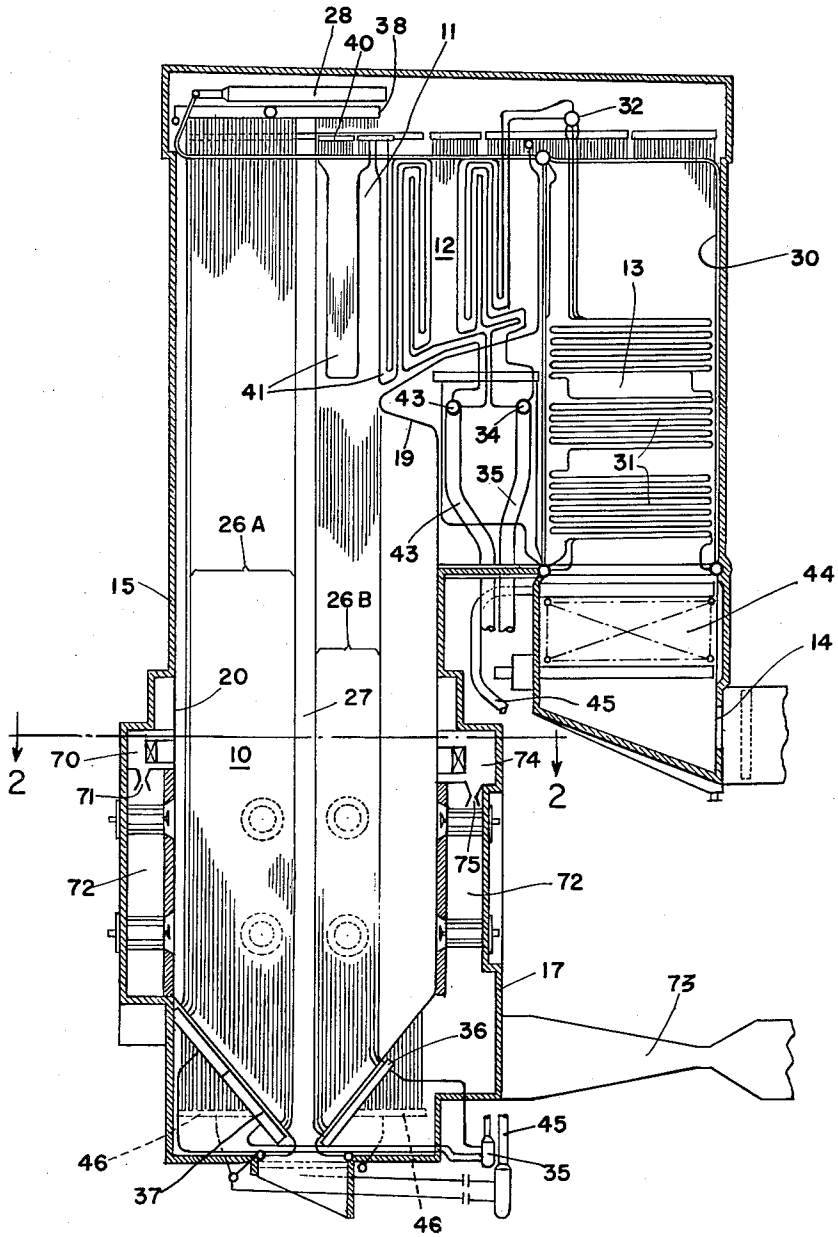


FIG. 1

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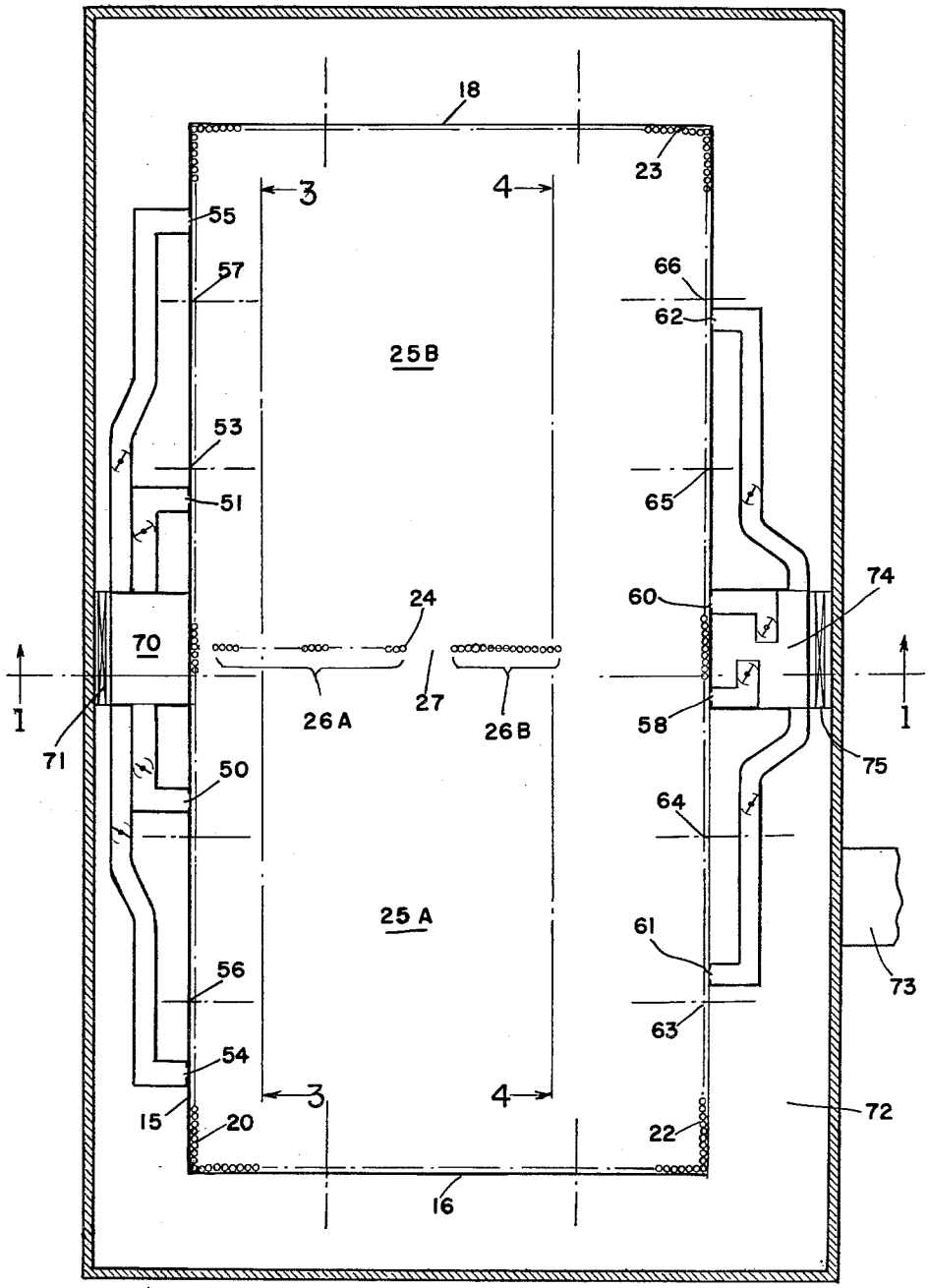


FIG. 2

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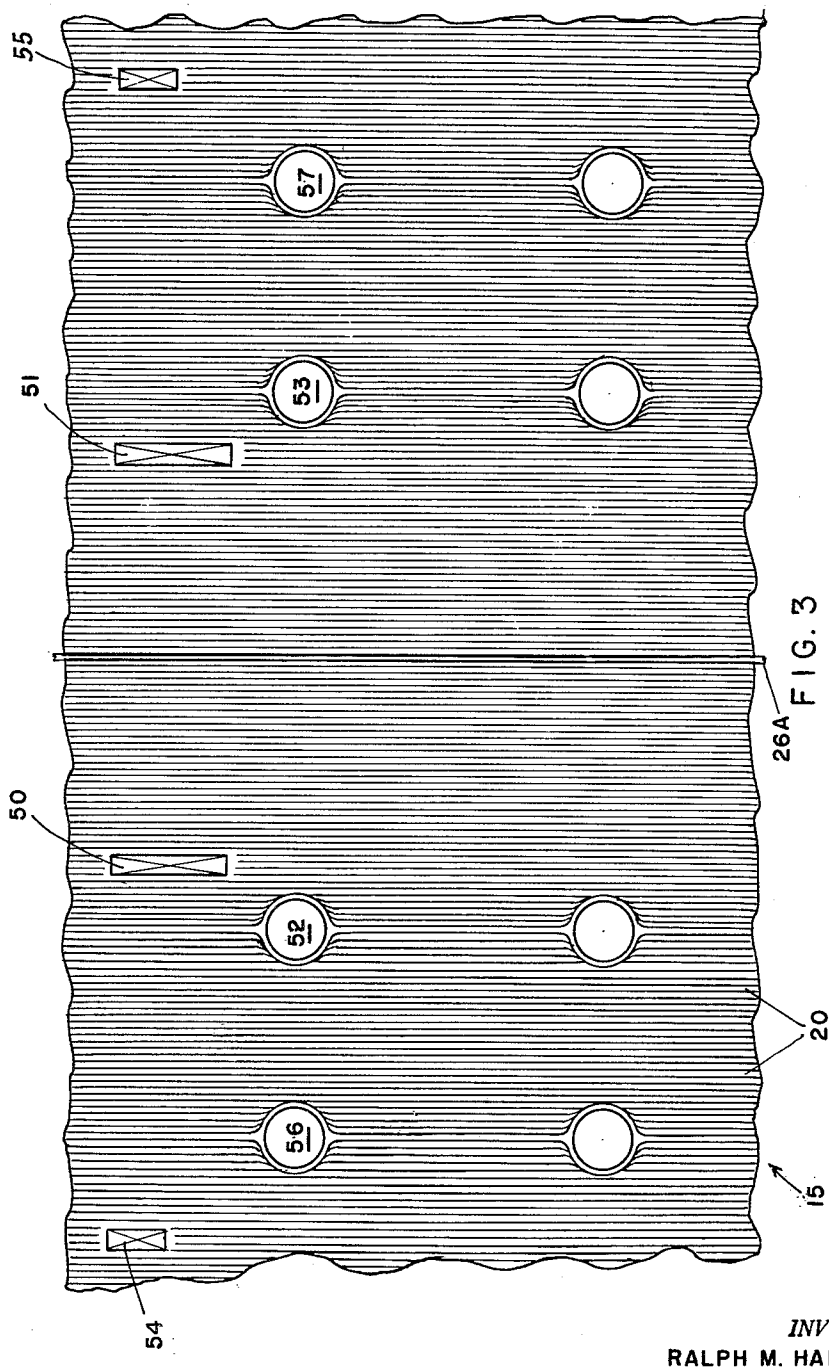


FIG. 3

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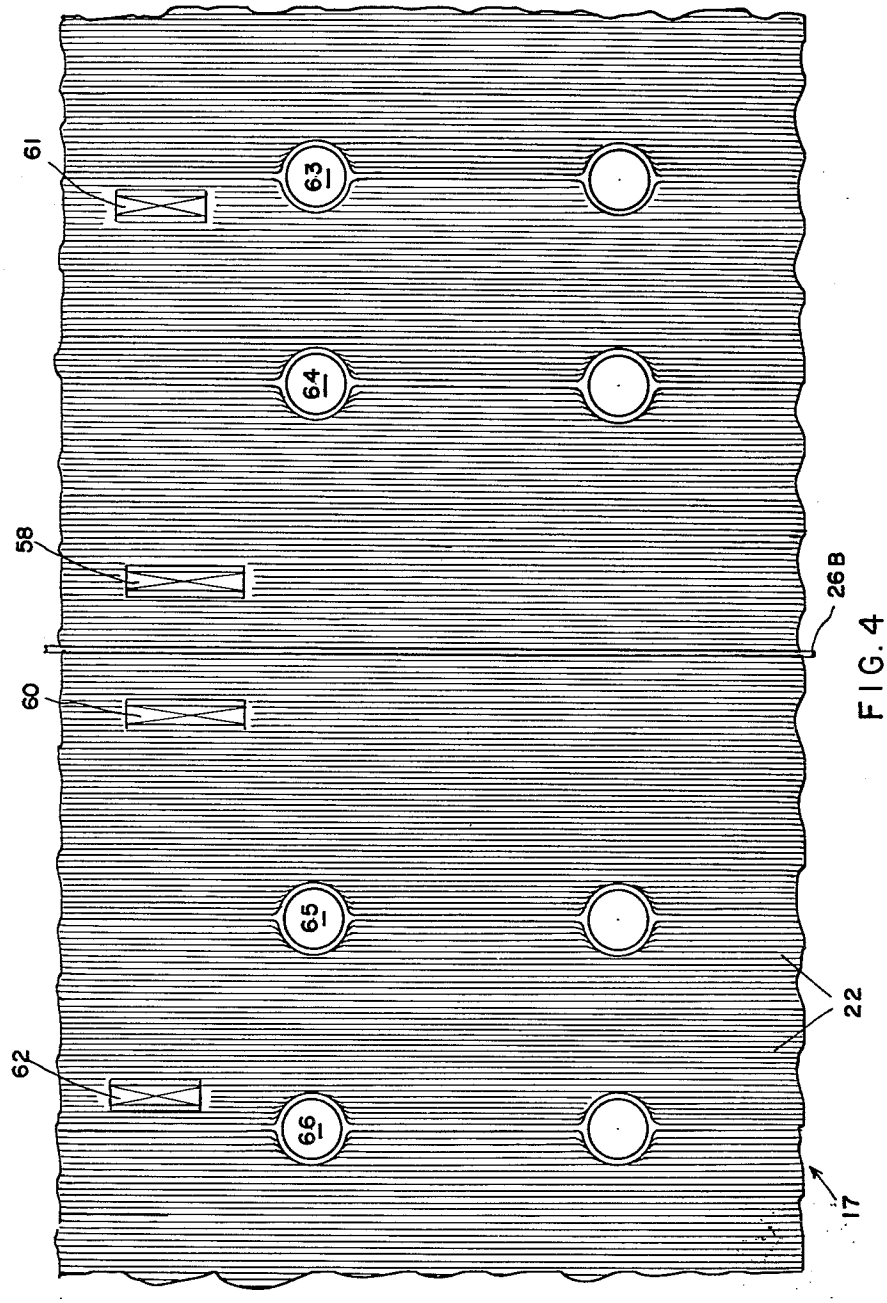


FIG. 4

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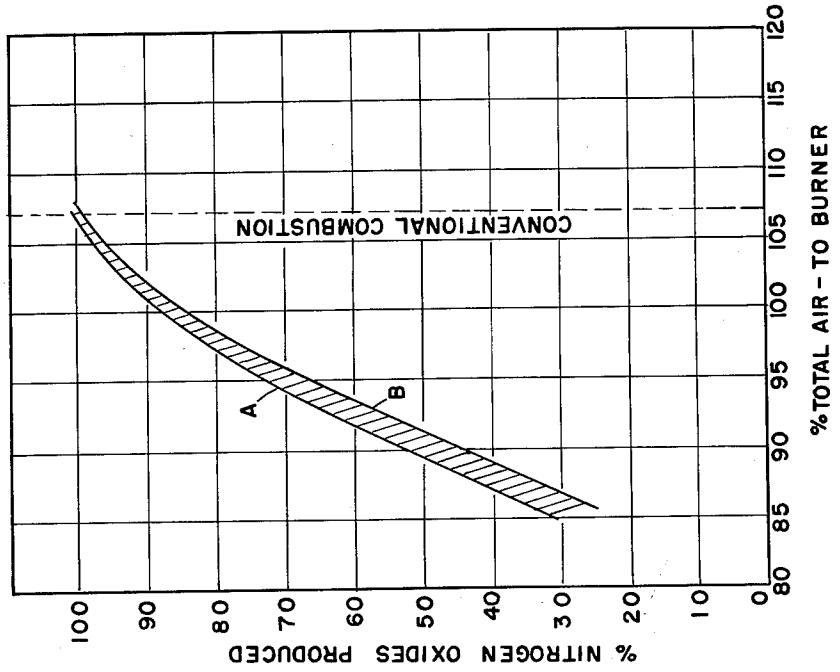


FIG. 6

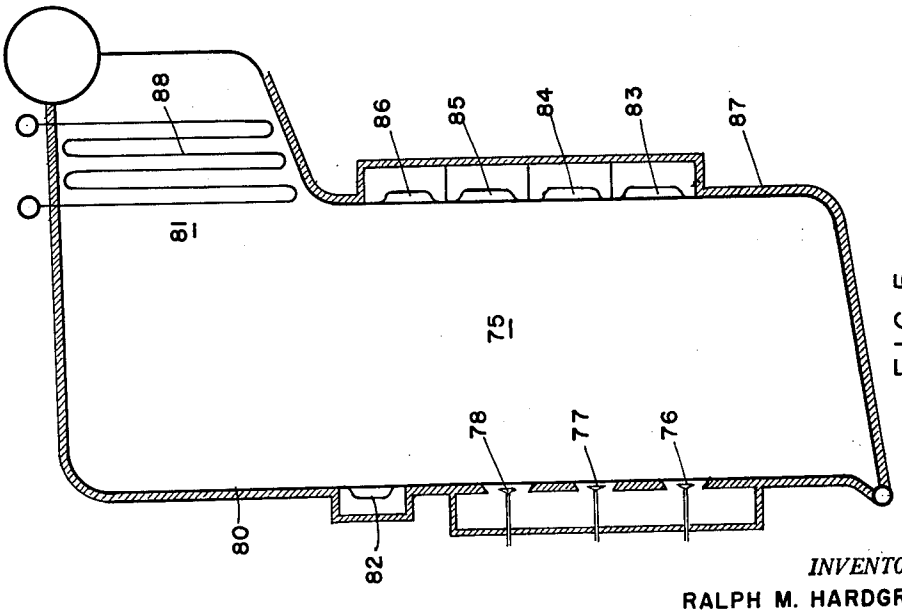


FIG. 5

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3,048,131

METHOD FOR BURNING FUEL

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2 Claims. (Cl. 110—72)

The present invention relates to a method of and apparatus for burning fuel with a consequent reduction in the quantity of nitrogen oxides formed during the combustion of the fuel, and more particularly to the regulation of the combustion air and its admission to and mixing with the fuel in a combustion space, so as to reduce the formation of nitrogen oxides in the effluent gases.

The combustion of fuels produces a quantity of nitrogen oxides in addition to the usual better known combustion products such as carbon dioxide, sulphur oxides and water vapor. Apparently, the quantity of nitrogen oxides formed during the combustion process is primarily a function of the temperature developed during the combustion of the fuel, as such temperatures are influenced by the burner characteristics and the configuration of the combustion space.

While it has been found that the quantity of nitrogen oxides formed during combustion of the common fuels, such as coal, fuel oil and natural gas, will vary to some extent with different furnace and burner arrangements, all fuels will produce some nitrogen oxides during combution. The amount of nitrogen oxides will usually lie in the range of 150 to 1500 p.p.m. (parts per million).

In recent years, it has been determined that irritating atmospheric contaminants observed during smog conditions, are primarily due to a photochemical reaction with organic materials, mostly hydrocarbons, in the presence of oxides of nitrogen. Thus, one desirable means for reducing atmospheric contamination, such as smog, is to reduce the amount of nitrogen oxides formed during the combustion of fuels and discharged into the atmosphere.

While central station power plants are operated efficiently and usually the production of nitrogen oxides is small per unit of fuel burned, the large quantities of fuel consumed is such as to make even a small reduction in the parts per million of nitrogen oxides in the effluent gases highly desirable.

It has been found that the production of nitrogen oxide in central station power plants can be reduced as much as 50% or more by operation of the combustion process in accordance with the present invention. Moreover, this reduction can be accomplished without a reduction in the efficiency of combustion or substantial adverse effects on the heat transfer within the vapor generating unit.

In the present invention, the usual fuel burner is supplied with air in an amount less than that theoretically required for complete combustion. The remainder of the combustion air is supplied to the furnace at a position spaced from the burner so that the air mixes with the burning fuel after the initial high temperature associated with the combustion process has been attained. In effect, complete combustion of the fuel is retarded to reduce the maximum temperature of the flame, while at the same time completing the combustion within the confines of the furnace. More specifically, the invention contemplates that from 80 to 95 percent of the theoretical combustion air will be introduced with or in close proximity to the fuel for burning in the furnace, while the remainder of the combustion air, including the desired excess air, will be introduced into the furnace from a position spaced from the burner or burners.

Apparently in the combustion of fuel, according to the present invention, the absence of sufficient oxygen in the hottest portion of the flame causes the available oxygen to combine with carbon, rather than with nitrogen, since carbon seems to have a stronger affinity for the oxygen. Thus, by the time the carbon of the fuel and the oxygen of the air have combined, the temperatures in the flame have been reduced. As a result, the combination of nitrogen and oxygen to form nitrogen oxides is less likely to occur and such combinations as do occur are drastically reduced in quantity. Since the formation of nitrogen oxides is at a maximum at maximum burner capacities, the divided introduction of the combustion air to the furnace, according to the present invention, is particularly useful at maximum furnace operating fuel rates, and need not be used at partial firing rates.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described a preferred embodiment of the invention.

Of the drawings:

FIG. 1 is an elevation, in section, of a high capacity, high pressure vapor generating and heating unit incorporating combustion apparatus for the performance of the present invention;

FIG. 2 is an enlarged section taken on the line 2—2 of FIG. 1;

FIGS. 3 and 4 are enlarged, partial sections taken on the lines 3—3 and 4—4, respectively, of FIG. 2;

FIG. 5 is an elevation in section, of a modified construction of a furance incorporating apparatus for the performance of the present invention; and

Fig. 6 is a graph illustrating results obtained in utilizing the present invention.

The invention is particularly useful in reducing the formation of nitrogen oxides during the combustion of fuels for the generation of power, as in central station vapor generators, and is so illustrated in the embodiments of the invention. However, it will be understood that the invention is also applicable to the combustion of fuels in other types and kinds of furnaces, and is also effective in reducing the nitrogen oxide formations without adversely influencing the completeness of the fuel combustion.

In the embodiment of the invention shown in FIGS. 1 through 4, the vapor generator is of the high capacity radiant type and is constructed to generate steam at high pressures and temperatures. The specific installation illustrated is capable of producing over two million pounds of steam per hour at a pressure of the order of 2700 p.s.i. (pounds per square inch). The unit illustrated is of the once-through type suitable for either subcritical or supercritical pressures and employs steam reheating for maximum efficiency of the power generating cycle.

As shown particularly in FIG. 1, the furnace **10** is upwardly elongated, having provisions for the introduction of fuel in the lower portion and with a gas outlet **11** in the upper portion of the furnace. The combustion gases leaving the outlet **11** from the furnace pass through a horizontally disposed passageway **12**, thence downwardly through a convection heating pass **13** on an outlet **14** at the lower end of the gas downpass **13**. As shown in FIG. 2, the walls **15**, **16**, **17** and **18** of the furnace **10** are lined by closely spaced upright fluid cooled tubes **20**, **21**, **22** and **23** which define the four walls of the furnace. As shown in FIGS. 1 and 2, the tubes **22** in the rear wall **17** are displaced forwardly into the furnace at a position downwardly adjacent the outlet **11** to form a nose baffle **19** which deflects the ascending heating gases toward the

forward portion of the furnace before the gases turn into the horizontal gas pass 12.

In the illustrated vapor generator, the furnace is divided by an upright row of fluid cooled tubes 24 which separate the furnace into two combustion spaces 25A and 25B. This is illustrated in particular in FIG. 2 of the drawings. The tubes 24 in the furnace 10 are supplied with superheated steam and serve as the final superheating stage for the unit. As shown in FIG. 2, the upright closely spaced small diameter tubes 24 are arranged in side by side relationship across the midplane of the furnace, forming two panels 26A and 26B lying in a common plane. The panels are spaced from the front and rear walls 15 and 17, respectively, of the furnace and are also spaced apart near the center of the furnace so as to form a vertically extending gap 27 between the panels. Thus, with the construction described, the tube panels 26A and 26B provide an extensive surface for heat transfer purposes within the confines of the furnace closure walls. Moreover, the wall arrangement provides for substantial equalization of furnace pressures between the two combustion spaces 25A and 25B.

The vapor generated in the wall tubes 15 to 18 of the furnace 10 is discharged into a collecting manifold 28 in the upper portion of the unit, with the fluid thereafter passed downwardly through upright tubes 30 into convection heating banks 31 which form the primary superheater of the unit. The partially heated steam from the convection banks 31 is collected in a manifold 32 and discharged into pendent type superheater elements 33 in the horizontal gas pass 12 connecting the furnace and the convection gas pass. Thereafter, the steam passes from a collecting header 34 through an exterior downcomer 35 for delivery to the inclined headers 36 and 37 positioned adjacent the lower portion of the furnace 10. The tube panels 26A and 26B receive superheated steam from the headers 36 and 37 and discharge the steam to an upper collection header 38 for delivery to a steam turbine (not shown).

Steam extracted from a lower pressure stage of the steam turbine is delivered to an inlet header 40 and passed through reheating elements 41 which are positioned in the upper portion of the furnace 10 and in the horizontal gas pass 12 adjacent the outlet 11 from the furnace. The reheated steam is thereafter passed through a collecting header 43 and discharge pipe 43' to a low pressure steam turbine (not shown).

In addition to the convection steam superheating elements 31, an economizer 44 is positioned upwardly adjacent the gas outlet 14 from the vapor generator. The feed water entering the economizer is heated by contact with the partially spent heating gases and is delivered to a downcomer 45 serving the lower headers 46 of the vapor generating wall tubes 20, 21, 22 and 23 of the vapor generator.

As shown in FIGS. 1 through 4, the furnace 10 is provided with a total of 24 burner ports arranged in the walls 15 to 18, inclusive, in two vertically spaced horizontal rows with 12 of the ports opening to each of the combustion spaces 25A and 25B. The burners positioned in the burner ports may be suitable for supplying coal, gas or oil either singly or in any combination. The burners are arranged so that each combustion space is supplied by 4 burners positioned in each of the three adjoining sides of the furnace 10. Each burner is provided with an air register 39 so that the amount of air delivered to each burner will be individually regulated.

In accordance with the present invention, burner ports and the burners therein are spaced in accordance with normal practice. Air admission ports are arranged to supply a minor portion of the total combustion air to the combustion spaces 25A and 25B from positions upwardly spaced from the burner ports. In the particular construction of vapor generator illustrated in FIGS. 1 to 4, the air admission ports are particularly arranged as hereinafter described to effect substantially uniform combustion and gas mixing in each of the combustion spaces. Air admission ports are provided only in the walls 15 and 17.

As shown particularly in FIGS. 3 and 4, the walls 15 and 17 of the combustion spaces 25A and 25B, which are at right angles to the tube panels 26A and 26B, are each provided with one air port for each of the vertically spaced pair of burner ports. In the wall 15 (see FIG. 3), the air ports 50 and 51 are symmetrically arranged on each side of the panel 26A and are positioned adjacent the upper burner ports 52 and 53, respectively. The air ports 54 and 55 in this wall are symmetrically arranged between the burner ports 56 and 57 and the furnace walls 16 and 18, respectively.

The air admission ports in the opposite wall 17 of the furnace, as shown in FIG. 4, are provided with air ports 58 and 60 symmetrically arranged and positioned closely spaced from the panel 26B. In a similar manner, the outermost air ports 61 and 62 are symmetrically arranged on opposite sides of the panel 26B and are spaced between the rows of burners 63 and 64, 65 and 66, respectively.

The distribution of air to each of the air ports is regulated by separate damper controlled air ducts, with the air ports in the wall 15 receiving air from a common distribution chamber 70 which in turn receives a measured quantity of air through a venturi 71 from the air chamber 72. The walls of the air chamber 72 enclose the lower portion of the furnace 10 and the chamber receives a controlled flow of preheated superatmospheric air from an air heater (not shown) through a duct 73 (see FIGS. 1 and 2). The air ports 61, 58, 60 and 62 likewise receive air through damper controlled ducts from a common distribution chamber 74 which is supplied by a measured quantity of combustion air through a venturi 75 opening at its lower end to the chamber 72. In addition, air is supplied to each of the burners from air chamber 72 with the air flow to individual burners controlled by the burner register assembly.

In the arrangement described, the total quantity of combustion air delivered to the chamber 72 is regulated by the flow through the duct 73, in coordination with the delivery rate of the fuel to the furnace. For example, the air delivered to the chamber 72 may be equal to 107 percent of the theoretical air required for the fuel delivered by the burners serving the furnace through the burner ports. From the chamber 72, some of the combustion air enters the furnace 10 through each of the burner ports, with the amount of air passed through each burner port regulated in accordance with the rate of fuel flow through the corresponding burner. At the same time, some of the combustion air passed through each of the air ports is also controlled so as to reduce the quantity of nitrogen oxides formed in the furnace.

With the construction described, the air port staggered arrangement is such as to provide for the introduction of supplementary air through the opposite walls 15 and 17 of the furnace with a majority of the supplementary or auxiliary combustion air introduced adjacent the panels 26A and 26B. The arrangement described insures an adequate and complete mixing of the gaseous products in the spaces 26A and 26B so that no specific wall portion of any of the walls of the furnace 10 will be overheated.

As hereinafter described in greater detail, the furnace and vapor generating unit of the FIGS. 1 through 4 construction is served by a mixture of fuel and air introduced through the burner ports with the remainder of the combustion air required for complete combustion introduced through the air admission ports. In the particular configuration illustrated approximately 90% of the theoretical air required for combustion of the fuel delivered to the furnace is admitted through the burner ports. The remainder of the combustion air, including any excess air for ensuring complete combustion, is admitted through the air ports shown in the drawings.

In the modification of the invention illustrated in FIG. 5 of the drawings, a somewhat simpler form of furnace construction is diagrammatically illustrated. In this version of the invention, the upwardly elongated furnace **75** is provided with vertically spaced burners **76**, **77** and **78** which may be constructed for the admission of oil, gas or pulverized coal. The burners are positioned in the lower portion of the furnace in the wall **80** opposite the gas exit **81** in the upper portion of the furnace. The furnace is provided with a transverse row **82** of air admission ports positioned above the burners **78** and in addition, is provided with vertically spaced rows of air admission ports **83**, **84**, **85** and **86** located in the wall **87** of the furnace opposite the burner wall. With the construction described, a portion of the combustion air required for the combustion of the fuel may be selectively introduced to the air ports **82** directly above the burners or through one or more of the air ports **83** to **86**, inclusive, positioned in the wall **87** of the furnace. Alternately, all of the air port admission positions may be in use.

As hereinafter described in more detail, the air admission ports directly above the burners are preferably used for a maximum reduction in the nitrogen oxide formation in the combustion zone of the furnace. However, it may sometimes be desirable to utilize the air admission ports in the opposite wall **87** of the furnace so as to more effectively control the temperature of the superheated steam produced in the unit, such as the steam heated in the pendent type superheater **88** shown in FIG. 5. For nitrogen oxide control, it is preferred that the air ports **82** above the burners **76** to **78**, inclusive, should be used, and the reduction in nitrogen oxide may be less if the superheated steam temperature is adequately regulated by admission of air through the air ports in the wall **87** of the furnace.

The graph of FIG. 6 shows, for various operating conditions, percentage ratio of the quantity of nitrogen oxides produced during conventional combustion procedures to the quantity of nitrogen oxides produced in accordance with the procedures of the invention over a range of total air supplied to the burner. The base, 100% nitrogen oxide production, is the result of introducing the total combustion air through the burner. It is understood that the actual nitrogen oxide production under base operation conditions (as NO and/or NO_2) may be in the order of from 150 to 1500 p.p.m.

As shown in the drawing the theoretical air required for the complete combustion of the fuel is represented by the 100% value of total air to burner. In furnaces of the general type shown in FIGS. 1 and 5, the total air delivered to the furnace for combustion purposes will be of the order of 107%, i.e. 7% excess air will be delivered so as to assure complete combustion of the fuel. It will be understood that some types of furnaces may require more or less excess air for complete combustion of the fuel. The excess air percentage will usually be determined by testing the gaseous products of the fuel combustion and the air flow regulated until the CO in the gas has been eliminated and the O_2 maintained at a minimum.

The curves A and B of FIG. 6 represent the range of test data obtained on an experimental unit fired by oil and gas fuels with different portions of the total combustion air introduced through the burner with the fuel and the remainder of the total combustion air introduced to the furnace through air ports spaced from the fuel burners. With a reduction in the proportion of the combustion air introduced into the furnace with the fuel, and an increase in the air separately introduced to the furnace, the percentage of nitrogen oxide produced in the furnace will be drastically reduced. In vapor generating units with the usual furnace construction, the minimum air introduction through the burner will normally be about 85%, as shown in FIG. 6, since any further reduction will most likely result in incomplete combustion or in combustion occurring beyond the furnace area. Either result will be adverse to efficient operation of the vapor generating unit, leading to combustible losses and/or difficulties with superheated steam temperature control, and excessive heat loss to the stack. The dimensions and wall structure of some furnaces may limit the minimum burner air flow to 90 or even 95 percent of the total combustion air required for the particular fuel burned. With 90 percent of the theoretical combustion air introduced through the burner with the fuel, the remainder of the air (17%, with 107% total air flow) is introduced through the spaced secondary air ports, spaced from the burner or burners. Under such conditions, the nitrogen oxide formation in the furnace will be reduced to approximately ½ the amount produced when all of the combustion air was introduced to the furnace with the fuel.

While in accordance with the provisions of the statutes I have illustrated and described herein the best form and mode of operation of the invention now known to me, those skilled in the art will understand that changes may be made in the form of the apparatus disclosed without departing from the spirit of the invention covered by my claims, and that certain features of my invention may sometimes be used to advantage without a corresponding use of other features.

What is claimed is:

1. The method of burning a fuel in suspension in a furnace having fluid cooled boundary walls with a minimum amount of nitrogen oxides in the combustion gases leaving the furnace which comprises introducing the fuel into the furnace through a burner port in a furnace boundary wall, introducing a major portion of the combustion air into said furnace at said burner port in furnace-mixing relationship with said fuel, regulating the amount of air supplied through said burner port to an amount within the range of 80 to 95% of the theoretical combustion air requirements for the corresponding fuel to delay the complete combustion of the corresponding fuel steam and thereby reduce the maximum flame temperature in the furnace and the formation of nitrogen oxides below the values which would occur if all of the air required for complete combustion were introduced with the fuel, and supplying the remaining amount of air required to insure complete combustion of the fuel through a furnace boundary wall at a position spaced from said burner port so as to direct the stream of the remaining amount of air in mixing relation with the burning fuel stream beyond the normal maximum flame temperature zone of the furnace to complete combustion of the fuel within the furnace with a minimum formation of nitrogen oxides in the combustion gases.

2. The method of burning a fuel in suspension in a furnace having fluid cooled boundary walls with a minimum amount of nitrogen oxides in the combustion gases leaving the furnace which comprises introducing the fuel into the furnace through spaced burner ports in a furnace boundary wall, introducing combustion air into said furnace at each of said burner ports, regulating the amount of air supplied through each burner port to an amount within the range of 80 to 95% of the theoretical combustion air requirements for the corresponding fuel stream to delay the complete combustion of the corresponding fuel stream and thereby reduce the maximum flame temperature in the furnace and the formation of nitrogen oxides below the values which would occur if all of the air required for complete combustion were introduced with the fuel, and supplying the remaining amount of air required to insure complete combustion of the fuel in a plurality of streams through the furnace boundary wall at a position spaced from said burner ports so as to direct the air streams in mixing relation with the burning fuel streams at locations beyond the maximum flame tempera-

ture zone of the furnace to complete combustion of the fuel within the furnace and without increasing the temperature of the combustion gases leaving the furnace.

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