A method and apparatus are disclosed for use in furnaces such as those used in steam cracking. The apparatus includes a burner tube having a downstream end and an upstream end for receiving fuel and flue gas, air or mixtures thereof, with a burner tip being mounted on the downstream end of the burner tube adjacent a first opening in the furnace, so that combustion of the fuel takes place downstream of the burner tip. The burner includes at least one passageway having a first end at a second opening in the furnace and a second end adjacent the upstream end of the burner tube, the passageway having a cross-sectional area and shape sufficient to permit a total FGR (flue gas recycle) ratio of greater than 10%. In addition, the burner includes a means for drawing flue gas from the furnace through the passageway in response to an inspirating effect created by uncombusted fuel flowing through the burner tube.
BURNER EMPLOYING FLUE-GAS RECIRCULATION SYSTEM WITH ENLARGED CIRCULATION DUCT

RELATED APPLICATIONS

[0001] This patent application claims priority from Provisional Application Serial No. 60/365,234, filed on Mar. 16, 2002, the contents of which are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] This invention relates to an improvement in a burner such as those employed in high temperature furnaces in the steam cracking of hydrocarbons. More particularly, it relates to the use of flue gas recirculation of reduced temperature in a burner of novel configuration to achieve a reduction in NOx emissions.

BACKGROUND OF THE INVENTION

[0003] As a result of the interest in recent years to reduce the emission of pollutants from burners used in large industrial furnaces, burner design has undergone substantial change. In the past, improvements in burner design were aimed primarily at combustion efficiency and effective heat transfer. Increasingly stringent environmental regulations have shifted the focus of burner design to the minimization of regulated pollutants. As may be appreciated, the reduction of burner emissions and the maximization of burner efficiency are desirable goals, which, however, are at odds with one another.

[0004] Oxides of nitrogen (NOx) are formed in air at high temperatures. These compounds include, but are not limited to, nitrogen oxide and nitrogen dioxide. Reduction of NOx emissions is a desired goal to decrease air pollution and meet government regulations. In recent years, a wide variety of mobile and stationary sources of NOx emissions have come under increased scrutiny and regulation.

[0005] A strategy for achieving lower NOx emission levels is to install a NOx reduction catalyst to treat the exhaust stream. This strategy, known as Selective Catalytic Reduction (SCR), is very costly and, although it can be effective in meeting more stringent regulations, represents a less desirable alternative to improvements in burner design.

[0006] Burners used in large industrial furnaces may use either liquid fuel or gas. Liquid fuel burners mix the fuel with steam prior to combustion to atomize the fuel to enable more complete combustion, and combustion air is mixed with the fuel at the zone of combustion.

[0007] Gas fired burners can be classified as either premix or raw gas, depending on the method used to combine the air and fuel. They also differ in configuration and the type of burner tip used.

[0008] Raw gas burners inject fuel directly into the air stream, and the mixing of fuel and air occurs simultaneously with combustion. Since airflow does not change appreciably with fuel flow, the air register settings of natural draft burners must be changed after firing rate changes. Therefore, frequent adjustment may be necessary, as explained in detail in U.S. Pat. No. 4,257,763. In addition, many raw gas burners produce luminous flames.

[0009] Premix burners mix some or all of the fuel with some or all of the combustion air prior to combustion. Since premixing is accomplished by using the energy present in the fuel stream, airflow is largely proportional to fuel flow. As a result, therefore, less frequent adjustment is required. Premixing the fuel and air also facilitates the achievement of the desired flame characteristics. Due to these properties, premix burners are often compatible with various steam cracking furnace configurations.

[0010] Floor-fired premix burners are used in many steam crackers and steam reformers primarily because of their ability to produce a relatively uniform heat distribution profile in the tall radiant sections of these furnaces. Flames are non-luminous, permitting tube metal temperatures to be readily monitored. Therefore, a premix burner is the burner of choice for such furnaces. Premix burners can also be designed for special heat distribution profiles or-flame shapes required in other types of furnaces.

[0011] In gas fired industrial furnaces, NOx is formed by the oxidation of nitrogen drawn into the burner with the combustion air stream. The formation of NOx is widely believed to occur primarily in regions of the flame where there exist both high temperatures and an abundance of oxygen. Since ethylene furnaces are amongst the highest temperature furnaces used in the hydrocarbon processing industry, the natural tendency of burners in these furnaces is to produce high levels of NOx emissions.

[0012] One technique for reducing NOx, that has become widely accepted in industry is known as combustion staging. With combustion staging, the primary flame zone is deficient in either fuel (fuel rich) or fuel (fuel lean). The balance of the air or fuel is injected into the burner in a secondary flame zone or elsewhere in the combustion chamber. As is well known, a fuel-rich or fuel-lean combustion zone is less conducive to NOx formation than an air-fuel ratio closer to stoichiometry. Combustion staging results in reducing peak temperatures in the primary flame zone and has been found to alter combustion kinetics in a way that reduces NOx. Since NOx formation is exponentially dependent on gas temperature, even small reductions in peak flame temperature dramatically reduce NOx emissions. However this must be balanced with the fact that radiant heat transfer decreases with reduced flame temperature, while CO emissions, an indication of incomplete combustion, may actually increase as well.

[0013] In the context of premix burners, the term primary air refers to the air premixed with the fuel; secondary, and in some cases tertiary, air refers to the balance of the air required for proper combustion. In raw gas burners, primary air is the air that is more closely associated with the fuel; secondary and tertiary air are more remotely associated with the fuel. The upper limit of flammability refers to the mixture containing the maximum fuel concentration (fuel-rich) through which a flame can propagate.

[0014] U.S. Pat. No. 2,813,578, the contents of which are incorporated by reference in their entirety, discloses a heavy liquid fuel burner, which mixes the fuel with steam for inspiration prior to combustion. The inspirating effect of the fuel and steam draws hot furnace gases into a duct and into the burner block to aid in heating the burner block and the fuel and steam passing through a bore in the block. This arrangement is disclosed as being effective to vaporize
liquid fuel and reduce coke deposits on the burner block and also to prevent any dripping of the oil.

[0015] U.S. Pat. No. 2,918,117 discloses a heavy liquid fuel burner, which includes a venturi to draw products of combustion into the primary air to heat the incoming air stream to therefore completely vaporize the fuel.

[0016] U.S. Pat. No. 4,004,875, the contents of which are incorporated by reference in their entirety, discloses a low NOx burner, in which combusted fuel and air is cooled and recirculated back into the combustion zone. The recirculated combusted fuel and air is formed in a zone with a deficiency of air.

[0017] U.S. Pat. No. 4,230,445 discloses a fluid fuel burner that reduces NOx emissions by supplying a flue gas/air mixture through several passages. Flue gas is drawn from the combustion chamber through the use of a blower.

[0018] U.S. Pat. No. 4,575,332, the contents of which are incorporated by reference in their entirety, discloses a burner having both oil and gas burner lances, in which NOx emissions are reduced by discontinuously mixing combustion air into the oil or gas flame to decelerate combustion and lower the temperature of the flame.

[0019] U.S. Pat. No. 4,629,413 discloses a low NOx premix burner and discusses the advantages of premix burners and methods to reduce NOx emissions. The premix burner of U.S. Pat. No. 4,629,413 lowers NOx emissions by delaying the mixing of secondary air with the flame and allowing some cooled flue gas to recirculate with the secondary air.

[0020] U.S. Pat. No. 4,708,638, the contents of which are incorporated by reference in their entirety, discloses a fluid fuel burner in which NOx emissions are reduced by lowering the flame temperature. A venturi in a combustion air supply passage, upstream of a swirl, induces the flow of flue gas into the combustion air supply passage from ducts opening into the furnace. A swirler is located at the free end of a fluid pipe and mixes the flue gas with the primary combustion air.

[0021] U.S. Pat. No. 5,092,761 discloses a method and apparatus for reducing NOx emissions from premix burners by recirculating flue gas. Flue gas is drawn from the furnace through a pipe or pipes by the aspirating effect of fuel gas and combustion air passing through a venturi portion of a burner tube. The flue gas mixes with combustion air in a primary air chamber prior to combustion to dilute the concentration of O2 in the combustion air, which lowers flame temperature and thereby reduces NOx emissions. The flue gas recirculating system may be retrofitted into existing premix burners or may be incorporated in new low NOx burners.

[0022] A drawback of the system of U.S. Pat. No. 5,092,761 is that the staged-air used to cool the FGR duct must first enter the furnace firebox, traverse a short distance across the floor, and then enter the FGR duct. During this passage, the staged-air is exposed to radiation from the hot flue-gas in the firebox. Analyses of experimental data from burner tests suggest that the staged-air may be as hot as 700°F when it enters the FGR duct. Further, analysis of burners of the type described in U.S. Pat. No. 5,092,761 has indicated the flue-gas-recirculation (FGR) ratio is generally in the range 5-10% where FGR ratio is defined as:

\[ \text{FGR ratio (\%) = 100 \% \left( \frac{G}{F + A} \right) } \]

[0023] where G=Flue-gas drawn into venturi, (lb)

[0024] F=Fuel combusted in burner, (lb), and

[0025] A=Air drawn into burner, (lb).

[0026] The contents of all of the above U.S. patents are incorporated herein by reference in their entirety.

[0027] Despite these advances in the art, a need exists for a highly efficient burner design for industrial use to meet increasingly stringent NOx emission regulations. In particular, there is a need for a burner for the combustion of fuel which enables higher flue gas recirculation ratios (FGR) to be utilized, thereby yielding further reductions in NOx emissions, e.g., by lowering flame temperature and oxygen levels.

SUMMARY OF THE INVENTION

[0028] The present invention is directed to a method and apparatus for use in burners of furnaces such as those used in steam cracking.

[0029] The apparatus of the present invention relates to a burner for the combustion of fuel in a furnace, said burner comprising: (a) a burner tube having a downstream end, and having an upstream end for receiving fuel, and flue gas, air and mixtures thereof, and burner tip being mounted on the downstream end of said burner tube adjacent a first opening in the furnace, so that combustion of the fuel takes place downstream of the burner tip; (b) at least one passageway, e.g., a flue gas recirculation (FGR) duct, having a first end at a second opening in the furnace for admitting flue gas and a second end adjacent the upstream end of said burner, said passageway having a cross-sectional area and shape sufficient to permit a total FGR Ratio of greater than 10%; and (c) means for drawing flue gas from said furnace through said passageway in response to an inspiring effect created by uncombusted fuel flowing through said burner tube from its upstream end towards its downstream end.

[0030] In one embodiment of the present invention, the cross-section of the FGR duct is substantially rectangular, typically with a major dimension and a minor dimension ranging from 30% to 100% of the major dimension.

[0031] In another embodiment of the present invention, the cross-sectional area of the FGR duct can range from about 5 square inches to about 12 square inches/MBTU/hr burner capacity.

[0032] In still another embodiment of the present invention, the FGR ratio is greater than 10% to 20%.

[0033] In yet another embodiment of the present invention, the FGR ratio is 15% to 20%.

[0034] In still another embodiment of the present invention, the burner comprises a passageway, e.g., FGR duct, which can accommodate a mass flow rate of at least 100 pounds per hour, per million (MM) Btu/hr burner capacity.

[0035] In still yet another embodiment of the present invention, the burner comprises a passageway, e.g., FGR duct, which can accommodate a mass flow rate of at least 130 pounds per hour, per MMBTU/hr burner capacity.

[0036] In another embodiment of the present invention, the burner comprises a passageway, e.g., FGR duct, which
can accommodate a mass flow rate of at least 200 pounds per hour, per MMBtu/hr burner capacity.

[0037] In still another embodiment, said means for drawing flue gas from the furnace comprises a venturi portion in said burner tube.

[0038] In yet another embodiment, the burner comprises a primary air chamber, wherein the at least one passageway comprises a duct having a first end and a second end, said first end extending into a second opening in the furnace, and said second end extending into the primary air chamber.

[0039] Conveniently, the burner further comprises at least one adjustable damper in fluid communication with the primary air chamber to restrict the amount of ambient air entering into the primary air chamber, thereby providing a vacuum to draw flue gas from the furnace.

[0040] In another embodiment, the burner is a premix burner.

[0041] In yet another embodiment, the burner is a flat flame burner.

[0042] In still yet another embodiment, the burner is a pencil flame burner.

[0043] In still another embodiment, the burner is utilized in a steam cracking furnace.

[0044] The present invention further relates to a method for combusting fuel in a burner of a furnace, comprising the steps of: combining fuel and flue gas, air or mixtures thereof at a predetermined location; combusting the fuel at a combustion zone downstream of the predetermined location; and drawing a stream of flue gas from the furnace through a flue gas recirculation (FGR) duct in response to the inspiring effect of uncombusted fuel flowing towards the combustion zone, said duct having 1) a first end at an opening in the furnace, 2) a second end adjacent the predetermine location, and 3) a cross-sectional area and shape sufficient to permit a total FGR Ratio of greater than 10%.

[0045] The present method can be carried out with or without steam, and with or without an inspiring assist from steam.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] The invention is further explained in the description that follows with reference to the drawings illustrating, by way of non-limiting examples, various embodiments of the invention wherein:

[0047] FIG. 1 is an elevation partly in section of a burner according to one embodiment of the present invention;

[0048] FIG. 2 is an elevation partly in a section rotated 90 degrees from FIG. 1;

[0049] FIG. 3 is a plan view of the burner of said one embodiment, along line 3-3 of FIG. 1;

[0050] FIG. 4 is an elevation partly in section of a flat-flame burner according to a further embodiment of the present invention; and

[0051] FIG. 5 is an elevation partly in section of the burner of FIG. 4 taken along line 5-5 of FIG. 4.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0052] Reference is now made to the embodiments illustrated in FIGS. 1-5 wherein like numerals are used to designate like parts throughout.

[0053] Although the present invention is described in terms of a burner for use in connection with a furnace or an industrial furnace, it will be apparent to one of skill in the art that the teachings of the present invention also have applicability to other process components such as, for example, boilers. Thus, the term furnace herein shall be understood to mean furnaces, boilers and other applicable process components.

[0054] A burner 10 includes a freestanding burner tube 12 located in a well in a furnace floor 14. Burner tube 12 includes an upstream end 16, a downstream end 18 and a venturi portion 19. Burner tip 20 is located at downstream end 18 and is surrounded by an annular tile 22. A fuel orifice which may be contained within gas spud 24 is located at upstream end 16 and introduces fuel into burner tube 12.

[0055] Fresh or ambient air is introduced into primary air chamber 26 as further described to mix with the fuel at upstream end 16 of burner tube 12. Combustion of the fuel and fresh air occurs downstream of burner tip 20.

[0056] A plurality of air ports 30 originate in secondary air chamber 32 and pass through furnace floor 14 into the furnace. Fresh air enters secondary air chamber 32 through adjustable dampers 34 and passes through staged air ports 30 into the furnace to provide secondary or staged combustion as described in U.S. Pat. No. 4,629,413.

[0057] In order to recirculate flue gas from the furnace to the primary air chamber, flue gas recirculation duct 36 extends from opening 40, in the floor of the furnace to opening 44, via primary air chamber 26. Flue gas is drawn through flue gas recirculation duct 36 by the inspiring effect of fuel, which effect may be supplemented with steam (see steam injection tubes 15) passing through venturi portion 19 of burner tube 12. In this manner, the primary air and flue gas are mixed in primary air chamber 26, which is prior to the zone of combustion. Therefore, the amount of inert material mixed with the fuel is raised, thereby reducing the flame temperature and, as a result, reducing NOx emissions. This is in contrast to a liquid fuel burner, such as that of U.S. Pat. No. 2,813,578, in which the combustion air is mixed with the fuel at the zone of combustion, rather than prior to the zone of combustion.

[0058] Unmixed low temperature ambient air (primary air), is introduced through angled primary air ducts 37 and 38, each having a first end comprising an orifice 37a and 38a, controlled by damper 37b, and a second end comprising an orifice 37c and 38e which communicates with the flue gas recirculation duct 36. The ambient air so introduced is mixed directly with the recirculated flue gas in duct 36. The primary air is drawn through primary air ducts 37 and 38, by the inspiring effect of the fuel passing through the fuel orifice, contained within gas spud 24. The ambient air may be fresh air as discussed above.
A sight and lighting port 50 is provided in the burner 10, both to allow inspection of the interior of burner 10, and to provide access for lighting of the burner 10. The burner plenum may be covered with mineral wool insulation 52 and wire mesh screening (not shown) to provide insulation therefor.

In addition to the use of flue gas as a diluent, another technique to achieve lower flame temperature through dilution is through the use of steam injection. Steam can be injected in the primary air or the secondary air chamber. Steam may be injected through one or more steam injection tubes 15, as shown in FIG. 1, or one or more steam injection tube 184, as shown in FIG. 4. Preferably, steam is injected upstream of the venturi.

The enlarged flue gas recirculation duct disclosed herein can alternatively be applied in flat-flame burners, as will now be described by reference to FIGS. 4 and 5.

A burner 110 includes a freestanding burner tube 112 located in a well in a furnace floor 114. Burner tube 112 includes an upstream end 116, a downstream end 118 and a venturi portion 119. Burner tip 120 is located at downstream end 118 and is surrounded by a peripheral tile 122. A fuel orifice, which may be located within gas spud 124, is located at upstream end 116 and introduces fuel gas into burner tube 112. Fresh or ambient air may be introduced into primary air chamber 126 through damper 137b to mix with the fuel gas at upstream end 116 of burner tube 112. Combustion of the fuel gas and fresh air occurs downstream of burner tip 120. Fresh secondary air enters secondary chamber 132 through dampers 134.

In order to recirculate flue gas from the furnace to the primary air chamber, a flue gas recirculation passageway 176 drawn from furnace opening 200 is connected to primary air chamber 126, so that flue gas is mixed with fresh air drawn into the primary air chamber from damper 137b. Primary air and flue gas are mixed in passageway 176 and introduced into primary air chamber 126, which is prior to the zone of combustion.

As with the previous embodiment, unmixed low temperature ambient air (primary air), can be mixed directly with the recirculated flue gas through angled primary air ducts 137 and 138 each having a first end comprising an orifice 137a and 138a, respectively, and opening into ambient air and controlled by damper 137b and a second end comprising an orifice 137c and 138c, respectively, which communicate with the flue gas recirculation duct 176. The primary air is drawn through primary air ducts 137 and 138 into flue gas recirculation duct 176, by the inspiratory effect of the fuel passing through the fuel orifice contained within gas spud 124.

In the embodiments described above, the cross-section of the FGR duct 176 is substantially rectangular, typically with its minor dimension ranging from 30% to 100% of its major dimension. Conveniently, the cross sectional area of the FGR duct 176 ranges from about 5 square inches to about 12 square inches/million (MM) Btu/hr burner capacity and, in a practical embodiment, from 34 square inches to 60 square inches. In this way the FGR duct 176 can accommodate a mass flow rate of at least 100 pounds per hour per MMBtu/hr burner capacity, preferably at least 130 pounds per hour per MMBtu/hr burner capacity, and still more preferably at least 200 pounds per hour per MMBtu/hr burner capacity. Moreover, FGR ratios of greater than 10% and up to 15% or even up to 20% can be achieved.

It will also be understood that the teachings described herein also have utility in traditional raw gas burners and raw gas burners having a pre-mix burner configuration wherein flue gas alone is mixed with fuel gas at the entrance to the burner tube. In fact, it has been found that the pre-mix, staged-air burners of the type described in detail herein can be operated with the primary air damper door closed, with very satisfactory results.

**EXAMPLES**

**Example 1**

In order to demonstrate the benefits of the present invention, computational fluid dynamics, CFD, were used to evaluate the configurations described below. A CFD analysis solves fundamental controlling equations and provides fluid velocity, species, combustion reactions, pressure, heat transfer and temperature values, etc. at every point in the solution domain. FLUENT™ software from Fluent Inc. was used to perform the analysis. (Fluent, Inc., USA, 10 Cavendish Court, Centerra Resource Park, Lebanon, N.H., 03766-1442).

**Example 2**

In Example 2, detailed material and energy balance were calculated using the FLUENT computational fluid dynamics software and showed that with a larger FGR duct of 4.75 inches (12.1 cm) by 9 inches (22.9 cm) (total 43 square (277 square centimeters)), the mass flow rate through the FGR duct rises to 920 pounds per hour. This can be expected to increase the FGR rate by about 50% to a total of about 15%. Such FGR rate increase is expected to reduce the NOx emissions of the burner.

**Example 3**

As may be appreciated by those skilled in the art, the present invention can be incorporated in new burners or can be retrofitted into existing burners by alterations to the burner surround.

**Example 4**

Although illustrative embodiments have been shown and described, a wide range of modification, change and substitution is contemplated in the foregoing disclosure and in some instances, some features of the embodiment may be employed without a corresponding use of other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the embodiments disclosed herein.
What is claimed is:

1. A burner for the combustion of fuel in a furnace, said burner comprising:
   (a) a burner tube having a downstream end, and having an upstream end for receiving fuel and flue gas, air or mixtures thereof, a burner tip being mounted on the downstream end of said burner tube adjacent a first opening in the furnace, so that combustion of the fuel takes place downstream of said burner tip;
   (b) at least one passageway having a first end at a second opening in the furnace for admitting flue gas and a second end adjacent the upstream end of said burner tube, said at least one passageway having a cross-sectional area and shape sufficient to permit a total FGR Ratio of greater than 10%;
   (c) means for drawing flue gas from said furnace through said at least one passageway in response to an inspirating effect created by uncombusted fuel flowing through said burner tube from its upstream end towards its downstream end.

2. The burner according to claim 1, wherein said cross-sectional area of said passageway is substantially rectangular.

3. The burner according to claim 1, wherein said cross-sectional area ranges from about 5 square inches/MMBtu/hr to about 12 square inches/MMBtu/hr.

4. The burner according to claim 1, wherein said cross-sectional area comprises a major dimension and a minor dimension ranging from 30% to 100% of said major dimension.

5. The burner according to claim 1, wherein said burner is a pre-mix burner.

6. The burner according to claim 1, wherein said burner is a flat-flame burner.

7. The burner according to claim 1, wherein said fuel comprises fuel gas.

8. The burner according to claim 1, wherein said burner further comprises at least one steam injection tube.

9. The burner according to claim 1, further comprising a fuel orifice located adjacent the upstream end of said burner tube, for introducing fuel into said burner tube.

10. The burner according to claim 9, wherein said fuel orifice is located within a gas spud.

11. The burner according to claim 9, wherein said means for drawing flue gas from said furnace through said passageway in response to said inspirating effect is created by uncombusted fuel exiting the fuel orifice.

12. The burner according to claim 9, wherein said FGR ratio is greater than 10% to about 20%.

13. The burner according to claim 9, wherein said FGR ratio is about 15% to about 20%.

14. The burner according to claim 9, wherein said passageway can accommodate a mass flow rate of at least about 100 pounds per hour, per MMBtu/hr burner capacity.

15. The burner according to claim 9, wherein said passageway can accommodate a mass flow rate of at least about 130 pounds per hour per MMBtu/hr burner capacity.

16. The burner according to claim 9, wherein said passageway can accommodate a mass flow rate of at least about 200 pounds per hour per MMBtu/hr burner capacity.

17. The burner according to claim 1, further comprising a primary air chamber, wherein said at least one passageway comprises a duct having a first end and a second end, said first end extending into a second opening in the furnace, and said second end extending into said primary air chamber.

18. The burner according to claim 17, further comprising at least one adjustable damper in fluid communication with said primary air chamber to restrict the amount of air entering into said primary air chamber, thereby providing a vacuum to draw flue gas from the furnace.

19. The burner according to claim 1, wherein the furnace is a steam cracking furnace.

20. A method for combusting fuel in a burner of a furnace, comprising the steps of:
   a) combining fuel and flue gas, air or mixtures thereof at a predetermined location;
   b) combusting the fuel at a combustion zone downstream of the predetermined location;
   c) drawing a stream of flue gas from the furnace through a flue gas recirculation (FGR) duct in response to the inspirating effect of uncombusted fuel flowing towards the combustion zone, said duct having 1) a first end at an opening in the furnace, 2) a second end adjacent the predetermined location, and 3) a cross-sectional area and shape sufficient to permit a total FGR Ratio of greater than 10%.

21. The method according to claim 20, wherein said cross-sectional area is substantially rectangular.

22. The method according to claim 21, wherein said substantially rectangular cross-sectional area ranges from about 5 square inches/MMBtu/hr to about 12 square inches/MMBtu/hr, with a major dimension and a minor dimension ranging from 30% to 100% of said major dimension.

23. The method according to claim 20, wherein said FGR ratio is greater than 10% to about 20%.

24. The method according to claim 20, wherein said FGR ratio is about 15% to about 20%.

25. The method according to claim 20, wherein said duct can accommodate a mass flow rate of at least about 100 pounds per hour per MMBtu/hr burner capacity.

26. The method according to claim 20, wherein said duct can accommodate a mass flow rate of at least about 130 pounds per hour per MMBtu/hr burner capacity.

27. The method according to claim 20, wherein said duct can accommodate a mass flow rate of at least about 200 pounds per hour per MMBtu/hr burner capacity.

28. The method according to claim 20, wherein said burner is a pre-mix burner.

29. The method according to claim 20, wherein said burner is a flat-flame burner.

30. The method according to claim 20, wherein said fuel comprises fuel gas.

31. The method according to claim 20, wherein the burner further comprises at least one steam injection tube.

32. The method according to claim 20, wherein the furnace is a steam cracking furnace.