LOW NOX BURNER HAVING SPLIT AIR FLOW

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ABSTRACT

A refractory block for a burner comprises a collection chamber that receives the nozzle of a burner. A primary combustion passage extends horizontally from the collection chamber. Also, two secondary air passages extend from the collection chamber and diverge outwardly and upwardly to provide for secondary air outlets vertically above and on either side of the main combustion outlet. By delaying complete combustion, NOx emissions are reduced.
LOW NOX BURNER HAVING SPLIT AIR FLOW

FIELD OF THE INVENTION

[0001] The present invention generally relates to industrial burners and more particularly to low emission burners for high temperature furnace applications.

BACKGROUND OF THE INVENTION

[0002] Conventional industrial burners for high temperature furnace applications are typically nozzle-mixing configured. An example is the high momentum Thermjet TJ Burner commercially available from Eclipse Inc., which is the present assignee of the instant patent application. The Thermjet TJ Burner is a nozzle-mixing burner (of the type embodied in U.S. Pat. No. 5,647,739, the entire disclosure of which is hereby incorporated by reference. This burner as described in the ’739 patent comprises a housing, gas and air inlet blocks with integrated orifices to measure air and gas flows, a rear cover with a gas passage inside, and a nozzle attached to the rear cover. The housing is mounted to the refractory block. The refractory block is usually mounted in the furnace wall and in the majority of the applications is mounted horizontally (for purposes of reference, the disclosure set forth herein will assume a horizontal mounting, although other types of mountings including different angles are intended to be covered by the claims appended hereto). The refractory block has a cylindrical combustor passage, and the burner nozzle is positioned inside the combustor passage forming an annulus gap between the nozzle’s outlet disk and the combustor’s internal passage.

[0003] In operation, all gaseous fuel flows from the rear cover passage to the nozzle’s internal volume, but the oxidant or airflow splits into two different flows including: a first flow (30% of the total) that proceeds into the nozzle through the nozzle’s mixing ports for mixing with the fuel gas contained therein; and a second flow that proceeds around the nozzle through the defined annulus gap. Thus, typically about 30% of the total air is premixed with total gaseous fuel flow inside the nozzle, and the rest of the air is gradually mixed with the gaseous fuel flow inside the combustor and further in the open flame outside of the refractory block. Because of an air staging design and intensive furnace flue gas recirculation back to the root of the high momentum flame, the nitric oxide (NOx) emissions in the furnace is relatively low, and not higher than 45-55 ppm for up to a 2000°F furnace temperature.

[0004] The carbon monoxide (CO) emissions at cold furnace conditions is high, but at temperatures over 1200°F and having excessive oxygen in the furnace atmosphere, carbon monoxide will burn out to form carbon dioxide. Due to this, the burner is assigned for high temperature applications predominantly in industrial furnaces.

[0005] With this being said, new stringent requirements for emissions outputs require differently adjusted method of air and fuel gas mixing both inside the burners combustion and outside within the furnace chamber. Thus, improvements are desired.

[0006] For further purposes of reference, other attempts and discussions about reducing emissions can be had with reference to U.S. Pat. No. 5,542,839 entitled “Temperature Control Low Emissions Burner”; U.S. Pat. No. 6,471,508 entitled “Burner For Non-Symmetrical Combustion and Method”; and WO 01/35022 entitled “Air Staged Low NOx Burner.”

BRIEF SUMMARY OF THE INVENTION

[0007] It is an object of the present invention to provide a burner that obtains certain emissions levels that are lower under certain environmental working conditions than those disclosed in the foregoing Eclipse ’739 patent.

[0008] It is a further object of the present invention to maximize air and fuel entrainment with products of combustion through means of a burner configuration that minimizes nitric oxides (NO+NO2) formation.

[0009] The above objects can be accomplished with a novel refractory block for a burner that comprises a body formed at least in part from aggregated granular material in which the refractory block body has an inlet side and an outlet side. A recess is formed in the inlet side to provide for a collection chamber for receipt of air or other such suitable forms of oxidant. The refractory block also defines a combustion passage extending from the collection chamber, through the body to the outlet side to provide for a combustion outlet. Additionally, first and second oxidant passages are provided that extend from the collection chamber to the outlet side to provide at least first and secondary oxidant outlets. These first and second oxidant outlets are disposed vertically above the combustion outlet and on opposed sides of the combustion outlet.

[0010] It is a further aspect of the present invention that the refractory block is positioned over a nozzle of an industrial burner, which may generally be of the type disclosed in the aforementioned ’739 patent. The mixing nozzle is preferably received at least partly into the recess on the inlet side of the refractory block.

[0011] According to another aspect of the present invention, an apparatus is provided for mounting to a furnace that is adapted for burning the gaseous fuel with oxidant while providing for low emissions. The apparatus includes a burner generally of the type disclosed in the aforementioned ’739 Eclipse patent, but that also includes, according to the general principles of the present invention, an apparatus comprising a burner airflow divider that includes a collection chamber in communication with the mixing nozzle of a burner. The flow divider includes (a) A main combustion passage generally aligned with a mixing nozzle, in which the combustion passage extends from the collection chamber to a combustion outlet; and (b) at least first and secondary oxidant passages that are also connected to the collection chamber and have secondary oxidant passage outlets disposed vertically above and horizontally spaced on opposed sides of the combustion outlet.

[0012] Other aspects, objectives and advantages of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is a cross section of a refractory block mounted to an industrial burner, oriented in a typical horizontal orientation (e.g. with the main combustion passage
axis coincident with the horizontal plane), according to a preferred embodiment of the present invention.

FIG. 2 is a top view of the refractory block and industrial burner combination as illustrated in FIG. 1.

FIG. 3 is a side profile view of the refractory block and industrial burner combination shown in FIG. 1.

FIG. 4 is an outlet end view of the refractory block and burner combination shown in the previous figures.

FIG. 5 is a downstream isometric view of the refractory block and burner combination shown in the previous figures.

FIG. 6 is an outlet end view of the refractory block with hidden lines provided to show angles of the secondary air passages projected on a vertical plane that is perpendicular to the main combustion passage.

FIG. 7 is a side view of the refractory block with hidden lines being indicated to show angles of the secondary air passages being projected on a vertical plane parallel and coincident with the main combustion axis;

FIG. 8 is a top view of the refractory block with the relative angles of the secondary air passages being projected on a horizontal plane that is coincident with the combustion axis.

FIG. 9 is a cross section of the refractory block taken along a plane that is coincident with the axis running through a secondary air passage to illustrate the true angle relative to a horizontal plane of the refractory block.

While the invention will be described in connection with certain preferred embodiments, there is no intent to limit it to those embodiments. On the contrary, the intent is to cover all alternatives, modifications and equivalents as included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

For purposes of illustration, an embodiment of the present invention has been shown in the drawings as a refractory block 10 and an industrial burner 12 combination, which is particularly suited for mounting to a furnace. As shown in the drawings, the burner has been oriented horizontal with the main burner or combustion axis 14 coincident with the horizontal plane. This horizontal orientation is used herein and throughout as the basis for comprehending the disclosure and invention, although it will be understood that the industrial burner 12 and refractory block 10 can be mounted at different orientations other than true horizontal depending on the particular configuration and shape of a particular furnace and furnace wall, all of which is to be covered by the claims appended hereto (e.g. the main burner axis of any burner can be aligned horizontally for purposes of evaluation).

To facilitate furnace mounting, the apparatus includes a mounting flange 16 with bolt holes which receive bolts to fasten the apparatus to a furnace wall. As can be seen, the mounting flange 16 is generally disposed intermediate the refractory block 10 and the industrial burner 12 such that the substantial portion of the industrial burner is typically external to the furnace while the refractory block 10 is typically substantially internal the furnace and/or partially inside the wall of a furnace.

Turning to the details of the industrial burner 12, many of the details can be generally gathered from the assignee’s previous patent U.S. Pat. No. 5,647,739. However, burner structural details and disclosure will be provided herein for ready reference.

With reference to FIG. 1, the burner includes a generally cylindrical body or burner housing 20 to include an endplate 22 closing off the upstream end of the burner housing 20. The burner housing generally includes a gaseous fuel inlet port 24 and an air inlet port 26 for the receipt of suitable combustion oxidant such as air. Disposed within the burner housing 20 and integral with the endplate 22 is a mixing nozzle 28 projecting downstream in the burner housing generally concentric about the burner axis 14.

The mixing nozzle defines an internal gaseous fuel passage way 30 connected to the gaseous fuel inlet port 24. At the end of the gaseous fuel passage way 30 is the nozzle outlet 32. Near the nozzle outlet 32 are provided air mixing ports 34 which are disposed radially around the nozzle and are arranged and positioned to draw a portion of the combustion air into the nozzle for mixing with the gaseous fuel to facilitate the flame. Between the mixing nozzle 28 and the burner housing 20 is defined an annular air chamber 36 which acts as an airflow passageway to deliver and convey combustion air from the air inlet port 26 to the nozzle mixing ports 34 and also to the inlet side of the refractory block 10.

In operation and with the refractory block configuration, ordinarily between about 40-60% (and typically about 50%) of the combustion air will be drawn in through the mixing ports 34 and the nozzle for mixing with the fuel internal to the nozzle before being discharged and ignited into a flame near the nozzle outlet 32. To facilitate flame ignition, an igniter 38 is provided which extends through the burner endplate 22 and into the nozzle’s inlet 27 for the purposes of igniting a fuel/oxidant mixture.

Referring in greater detail to the refractory block 10, in FIG. 1 it can be seen that the refractory block 10 generally includes a body 40 formed at least in part from aggregated granular material. Such aggregated granular material for refractory blocks is known in the art and capable of withstanding high temperature furnace applications. The body 40 generally includes an upstream inlet side 42 which is adjacent the industrial burner 12 and a downstream outlet side 44 which faces the inside of the furnace when installed (this is sometimes referred to as the “hot side”). A recess 46 is formed into the inlet side 42 that is preferably circular or otherwise symmetrical about an axis 48 (see e.g., FIG. 6) that is offset vertically above the central burner axis 14. The recess 46 is preferably circular and large enough to provide for full communication with the annular air chamber 36 defined by the burner housing. As shown in FIG. 1, the mixing nozzle 28 of the burner extends at least partly and preferably all the way through the recess 46. The recess 46 forms an air collection chamber 50 disposed generally between the mounting flange 16 and the refractory block body 40. The collection chamber extends vertically above the burner air chamber 36.

The refractory block body 10 also comprises a primary combustion passage 52 that is coaxially aligned
with and that may partially receive the end of the mixing nozzle 28. The combustion passage 52 is concentric about the burner axis 14 and extends from the collection chamber 50 (or recess 46) to and through the outlet side 44 to form a combustion outlet 54. As can readily be seen in FIG. 1, the diameter of the combustion outlet is substantially smaller than a combustion passage entrance 56, which is formed at the intersection between the recess 46 and the combustion passage 52. The combustion passage entrance 56 is generally cylindrical and has a diameter substantially complementary to the inner cylindrical diameter of the burner housing (although a slight taper both in the combustion outlet 54 and the combustion passage entrance 56 are typically provided). To reduce the diameter of the combustion passage 52 as it extends from the combustion passage entrance 56 to the combustion outlet 54, the combustion passage 52 includes a necked down region 58. That reduces the diameter of the combustion passage 52 typically by more than half as shown.

[0031] Turning to other structural features of the refractory block 10, the body 40 thereof further defines at least two and preferably only two secondary air passages 60. The secondary air passages 60 extend from the collection chamber 50 through the refractory block body 40 to and through the outlet side 44 to form a corresponding pair of secondary outlets 62. The secondary air outlets 62 are disposed vertically above and on opposed sides of the combustion outlet 54 preferably in symmetrical relation. The secondary air passages 60 convey combustion air or other such suitable oxidant from the collection chamber to a point vertically above and spaced horizontally offset from the combustion outlet 54 to dump further oxidant such as air over both sides of the flame, which projects from the combustion outlet 54 and rises upward to insert secondary air jets.

[0032] As shown in figures, the secondary air passages 60 preferably extend along and may be generally coaxial about secondary axis 64. Preferably, the secondary air passages 60 intersect the collection chamber 50 at a point vertically above the combustion passage entrance 56 to form secondary air entrances 66. The fact that the collection chamber 50/recess 46 is symmetrically offset above the combustion passage helps facilitate air flow into the secondary air passages 60 (typically between 40-60% of the air flow).

[0033] Additionally, the secondary air passages 60 diverge outward and vertically upward relative to the combustion passage 52. The divergence can be constant such that the secondary air passages 60 are straight.

[0034] There are several different preferred numerical ranges for the refractory block arrangement described herein. In particular, the axes of the secondary passages were preferably formed in angle A when projected on a horizontal plane of between about 22° and about 28° as shown for example in FIG. 8. Preferably either of the axes of the secondary air passages 60 form an angle B with the combustion axis 14 when projected on a vertical plane that is generally parallel to the combustion passage axis 14 of between about 10° and 15° as shown for example in FIG. 7. Preferably the axes of the secondary air passages 60 form an angle C when projected on a vertical plane that is generally perpendicular to the combustion passage axis 14 as shown in FIG. 6 that is preferably between about 85° and about 95°. Finally, the true angle of the secondary air passages (FIG. 9) measured by the secondary air passage axis 64 relative to a horizontal plane coincident with the combustion passage axis 14 forms an angle E that is between about 16° and about 20°.

[0035] Additionally, it is preferable that only two of the secondary air passages 60 are provided, although an alternative embodiments may be provided.

[0036] In terms of diameters, the combustion outlet 54 diameter “D” in respect to the secondary air passage outlet 62“d” may be between about 1.25-1.35 (e.g. D/d, such that the combustion outlet diameter is 1.25-1.35 times bigger than that of one of the secondary air passage outlets). See FIG. 6. As an example, the combustion outlet diameter may be about 54 millimeters, and a secondary air port outlets may be of about 41 millimeters. Additionally, a distance F is defined between a combustion outlet and a secondary air passage outlet with respect to a combustion outlet diameter D measured in the block outlet cross section is F/D which is equal to between about 3.2 and about 3.4. Finally a distance G between two secondary air passages with respect to the combustion outlet diameter D measured in the block outlet cross section is G/D is between about 3.7 and about 3.9.

[0037] In operation, introduction of the inlet cavity/collection chamber 50 in the refractorially blocked body 40 allows for a divide of the total combustion air flow. The first part of the flow is directed through the nozzle to the combustor and it comprises about 40-60% of the total flow. The second part is directed through the secondary air passages and it comprises about 60-40% of the total flow. The primary air starts to mix with all of the gas flow in a nozzle and then in a combustor, and further continues to mix and burn in the open burning jet flame outside the block. The flame formed has a rich structure and generates nitric oxide levels (NOx) of between about 22 and about 28 ppm at 1800-2200°F furnace temperatures. This is approximately twice as less as for conventional high momentum burners. In the example provided, if the primary air flow is higher than 60%, the next levels will start to deteriorate up to 30 ppm and higher, which may be suitable for certain applications; but if it is less than 40%, the burner will start to lose stability allowing the flame to be blown off from the burners outlet.

[0038] The rich flame forms low NOX and very high CO emissions in the furnace chamber. To burn out the CO gas, the secondary air jet passages 60 which form secondary air jets are directed forward under a compound diverging angle and this produces the air mixing with the unburned combustion products further away from the refractory block’s combustion outlet 54. This approach allows the transformation of CO to CO2 and keeps low NOx and CO levels in the furnace exhaust.

[0039] According to preferred arrangements described herein, if an angle ‘A’ is larger than 25 degrees, ‘B’—15, ‘C’—95, and ‘E’—20, the secondary air jets meet with a flame body further from the block outlet, thus reducing the intensity of mixing with unburned combustion products and resulting in an increase of CO emission. If an angle ‘A’ is smaller than 25 degrees, ‘B’—10, ‘C’—85, and ‘E’—16, the secondary air jets meet with a flame earlier and closer to the block outlet. This increases the flame temperature in the end of the flame and promotes a chemical reaction of NOX formation. Thus, the NOX emission increases.
If the ratio \( D/d \) of a combustor outlet diameter \( D \) to a secondary air outlet diameter \( d \) is larger than 1.35, the NOx emission will grow up to 30 ppm and higher levels. If the ratio is smaller than 1.25, not enough air goes to the combustor to support combustion and form a stable flame.

If \( F/D \) ratio is larger than 3.4 and \( G/D \) ratio is larger than 3.9, the CO emission increases above minimum acceptable level of 50 ppm due to the secondary air jets meet with a flame further from the block outlet, thus reducing the intensity of mixing with unburned combustion products. If \( F/D \) ratio is smaller than 3.2 and \( G/D \) ratio is smaller than 3.7, the secondary air jets meet with a flame earlier and closer to the block outlet increasing the flame temperature in the end of the flame. Temperature elevation promotes a chemical reaction of NOx formation. Thus, the NOx emission increases.

The burner can operate at preheated combustion air. For that the housing and rear cover internals needs to be insulated to keep the surface temperature cooler. The refractory block design for this application stays the same.

All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

The use of the terms “a” and “an” and “the” and similar references in the context of describing the invention (especially in the context of the following claims) is to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

What is claimed is:

1. A refractory block for a burner, comprising:
   - a body formed at least in part from aggregated granular material, the body having an inlet side and an outlet side;
   - a recess in the inlet side forming a collection chamber;
   - a combustion passage extending from the collection chamber through the body to the outlet side to provide a combustion outlet; and
   - first and second oxidant passages extending from the collection chamber to the outlet side to provide at least first and second secondary oxidant outlets, the first and second oxidant outlets being disposed vertically above the combustion outlet, the first and second oxidant outlets being on opposed sides of the combustion outlet.

2. The refractory block of claim 1, wherein the combustion passage extends along a combustion passage axis, and wherein the first and second oxidant passages diverge outwardly and vertically upward relative to the combustion passage axis along first and second secondary axes, respectively.

3. The refractory block of claim 2, wherein the axes of the oxidant passages form an angle \( A \) when projected on a horizontal plane of between about 22 and about 28 degrees.

4. The refractory block of claim 2, wherein either of the axes of the oxidant passages form an angle \( B \) with the combustion axis when projected on a vertical plane that is generally parallel to the combustion passage axis of between about 10 and about 15 degrees.

5. The refractory block of claim 2, wherein the axes of the oxidant passages form an angle \( C \) when projected on a vertical plane that is generally perpendicular to the combustion passage axis of between about 85 and about 95 degrees.

6. The refractory block of claim 2, wherein an angle \( E \) between each of the oxidant passages and a horizontal plane through the combustion passage is between about 16 and about 20 degrees.

7. The refractory block of claim 2, wherein the axes of the oxidant passages form an angle \( A \) when projected on a horizontal plane through the combustion passage of between about 22 and about 28 degrees, wherein either of the axes of the oxidant passages form an angle \( B \) with the combustion axis when projected on a vertical plane that is generally parallel to the combustion passage axis of between about 10 and about 15 degrees, wherein the axes of the oxidant passages form an angle \( C \) when projected on a vertical plane that is generally perpendicular to the combustion passage axis of between about 85 and about 95 degrees, wherein an angle \( E \) between each of the oxidant passages and the horizontal plane through the combustion passage is between about 16 and about 20 degrees.

8. The refractory block of claim 1, wherein only two oxidant passages are provided including only the first and second oxidant passages.

9. The refractory block of claim 8, wherein the combustion passage is generally cylindrical about a combustion axis, the combustion passage including a necked down section between a combustion passage entrance at the combustion chamber and the combustion outlet, such that the combustion outlet is of a substantially smaller diameter than the combustion passage entrance.
10. The refractory block of claim 9, wherein the collection chamber is symmetrical about a center point that is offset vertically above the combustion axis.

11. A refractory block and burner apparatus for mounting to a furnace for burning a fuel with an oxidant, comprising:

a burner including a burner housing, a gas inlet for receipt of fuel, an oxidant inlet for receipt of combustion oxidant, a nozzle for mixing of the oxidant and the fuel, a oxidant flow passage between the oxidant inlet and the nozzle, a fuel passage between the fuel inlet and the nozzle, and an igniter arranged proximate to the nozzle adapted to ignite the oxidant and the fuel;

a refractory block positioned over the nozzle, the refractory block including:

(i) a body formed at least in part from aggregated granular material, the body having an inlet side and an outlet side;

(ii) a recess in the inlet side forming a collection chamber, the nozzle of the burner being received into the recess;

(iii) a combustion passage extending from the collection chamber through the body to the outlet side to provide a combustion outlet; and

(iv) first and second oxidant passages extending from the collection chamber to the outlet side to provide at least first and second secondary oxidant outlets, the first and second oxidant outlets being disposed vertically above the combustion outlet, the first and second oxidant outlets being on opposed sides of the combustion outlet.

12. The refractory block of claim 11, wherein the combustion passage extends along a combustion passage axis, and wherein the first and second oxidant passages diverge outwardly and vertically upward relative to the combustion passage axis along first and second secondary axes, respectively.

13. The refractory block of claim 12, wherein the axes of the oxidant passages form an angle C when projected on a horizontal plane of between about 22 and about 28 degrees.

14. The refractory block of claim 12, wherein either of the axes of the oxidant passages form an angle B with the combustor axis when projected on a vertical plane that is generally parallel to the combustion passage axis of between about 10 and about 15 degrees.

15. The refractory block of claim 12, wherein the axes of the oxidant passages form an angle C when projected on a vertical plane that is generally perpendicular to the combustion passage axis of between about 85 and about 95 degrees.

16. The refractory block of claim 12, wherein an angle E between each of the oxidant passages and a horizontal plane through the combustion passage is between about 16 and about 20 degrees.

17. The refractory block of claim 12, wherein the axes of the oxidant passages form an angle A when projected on a horizontal plane through the combustion passage of between about 22 and about 28 degrees, wherein either of the axes of the oxidant passages form an angle B with the combustor axis when projected on a vertical plane that is generally parallel to the combustion passage axis of between about 10 and about 15 degrees, wherein the axes of the oxidant passages form an angle C when projected on a vertical plane that is generally perpendicular to the combustion passage axis of between about 85 and about 95 degrees, wherein an angle E between each of the oxidant passages and the horizontal plane through the combustion passage is between about 16 and about 20 degrees.

18. The refractory block of claim 11, wherein only two oxidant passages are provided including only the first and second oxidant passages.

19. The refractory block of claim 18, wherein the combustion passage is generally cylindrical about a combustion axis, the combustion passage including a necked down section between a combustion passage entrance at the combustion chamber and the combustion outlet, such that the combustion outlet is of a substantially smaller diameter than the combustion passage entrance.

20. The refractory block of claim 19, wherein the collection chamber is symmetrical about a center point that is offset vertically above the combustion axis.

21. An apparatus for mounting to a furnace adapted for burning an oxidant and fuel, comprising:

a burner including a burner housing, a gas inlet for receipt of fuel, an oxidant inlet for receipt of combustion oxidant, a nozzle for mixing of the oxidant and the fuel, a oxidant flow passage between the oxidant inlet and the nozzle, a fuel passage between the fuel inlet and the nozzle, and an igniter arranged proximate to the nozzle adapted to ignite the oxidant and the fuel;

a flow divider having an inlet side and an outlet side, the flow divider including a collection chamber in communication with the nozzle, the flow divider further including:

(i) a main combustion passage generally aligned with the nozzle projecting from the collection chamber to a combustion outlet;

(ii) at least first and second secondary oxidant passages connected to the collection chamber and having secondary oxidant passage outlets disposed vertically above and horizontally spaced on opposed sides of the combustion outlet.

22. The apparatus of claim 21, wherein each secondary air passage generally diverges vertically upward and outwardly relative to the combustion passage to form secondary air passage outlets.

23. The apparatus of claim 21, wherein the combustion passage intersects the collection chamber at a combustion passage entrance, wherein the combustion passage is generally cylindrical about a combustion axis, the combustion passage including a necked down section between a combustion passage entrance at the combustion chamber and the combustion outlet, such that the combustion outlet is of a substantially smaller diameter than the combustion passage entrance.

24. The apparatus of claim 23, wherein the collection chamber is symmetrical about a center point that is offset vertically above the combustion axis.

25. The apparatus of claim 21, wherein only two oxidant passages are provided including only the first and second oxidant passages.

26. The apparatus of claim 21, wherein the flow divider comprises a refractory block formed from aggregated granular material.