The invention provides systems and methods for multi-stage burners. The burner may accept a variable input fuel stream, which may be divided into a plurality of output fuel streams. The fuel stream may be divided by a pressure-actuated flow separator that may distribute an increasing amount of fuel to a secondary flow stream as the input flow rate of the input fuel stream increases. One or more of the output streams may be conditioned to provide a desired flame characteristic. The multi-stage burners may be decorative burners, and may be used for theatrical displays or other fire displays.
FIG. 1A
FIG. 1B
FIG. 1C
FIG. 5

- Burner outer tube: 502
- Burner inner tube: 500
- Laminizer: 520
- Diffuser core: 518
- Burner base: 512
- Insulating disk: 514
- Relief spring: 524
- Relief needle: 522
- Relief plug: 526
- Inline filter: 528
- Reducing coupler: 530
- Proportional valve: 504
- Manifold: 506
- Pilot tube: 510
- Pilot base: 508
MULTI-STAGE DECORATIVE BURNER

CROSS-REFERENCE

[0001] This application claims the benefit of U.S. Provisional Application No. 61/443,222, filed Feb. 15, 2011, which application is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates in general to gaseous fuel burners. More particularly this invention may relate to gaseous fuel burners for decorative applications with regulated air entrainment that produce a luminous, smokeless flame.

BACKGROUND OF THE INVENTION

[0003] In the field of special effects, real flames are often employed to achieve a powerful visual impact on live audiences. Devices called flame projectors emit flames that often exceed 30 feet in height in sequence with musical transitions or other dramatic events. Flame effects currently available for theatrical applications are capable of producing flames that are either on or off, but not variable. Other theatrical equipment, such as directional lights and LEDs can vary the intensity of their output over a wide range, allowing a much greater variety of visual impressions, images and moving patterns than would be possible with binary on/off control of these devices. In order to generate more powerful visual effects using fire, an improved flame effect is needed to vary its output over a wide range similar to lighting devices. A further need exists for flame effects with widely variable outputs that could generate images and patterns with enhanced richness and variety as compared to on/off flame effects currently available.

[0004] Atmospheric burners, including those used in flame effects, sometimes pre-mix fuel with some air and introduce the mixture into a combustion region where additional ambient air mixes with the fuel and the mixture burns in a stable manner. Practically, traditional decorative flame effects are limited to emitting fuel-rich flammable mixtures in order to generate luminous flames that contain light-radiating carbon particles. However, a flame that is excessively rich will also produce unsightly black smoke and heightened levels of CO, an undesirable pollutant. Therefore, a need exists for a burner for a practical flame effect that produces a fuel-air mixture with a fuel-air ratio that lies within a narrow acceptable range.

[0005] Turbulence aids the mixing of fuel and air in an atmospheric combustion region, which reduces the amount of pre-mixed air that is necessary to avoid creating visible smoke.

[0006] Emitting gas to the combustion region at higher velocities generates greater turbulence. Consequently, the desirable fuel-air premix ratio for a flame effect changes depending on the velocity of gasses exiting the burner. For a burner with a fixed cross-sectional area at its outlet, if the fuel throughput increases, the velocity also increases. Accordingly, a need exists for a variable-output flame effect that is capable of varying either the fuel-air ratio of the mixture it emits, or the cross-sectional area of the burner exit, or both, in response to the varying throughput to maintain soot-free, luminous combustion.

[0007] Therefore there is a clear and persistent need for a burner that can produce a flame that is stable, soot-free and luminous over a wide range of sizes.

SUMMARY OF THE INVENTION

[0008] The invention provides systems and methods for multi-stage decorative burners. Various aspects of the invention described herein may be applied to any of the particular applications set forth below or for any other types of flame effects. The invention may be applied as a standalone system or method, or as part of an integrated display package, such as a theatrical fire display, or any other fire display. It shall be understood that different aspects of the invention can be appreciated individually, collectively, or in combination with each other.

[0009] In accordance with an aspect of the invention, a burner for a decorative flame effect may be provided that can accept a wide range of fuel throughput rates while maintaining a luminous, smokeless flame.

[0010] In some embodiments, a burner for a decorative flame effect may support a fully-attached, stable flame with a widely-variable flame height.

[0011] A burner that produces a luminous smokeless flame over a wide range of output rates may comprise a proportioning system that can divide the input fuel into two or more output streams, one or more passages that can introduce air into one or more of the fuel output streams, and a burner outlet geometry that may combine the multiple output streams to form a single flame.

[0012] The separate flow paths may be constructed to condition the fluid streams flowing through them to improve the aesthetic properties of the flame such as, by reducing turbulence, increasing flow uniformity, or controlling velocity. By separating the fuel flow into multiple streams, and conditioning each stream separately, using flow path geometry, a designer can manipulate the characteristics of the flame at various heights with greater flexibility than would be possible using a single flow path. The geometry of each fuel flow path may be designed to achieve specific air/fuel ratios, flow velocities and turbulence levels.

[0013] The proportioning system can be designed to send a greater fraction of the total flow to a certain flow path as the total flow increases. Thus, the flame properties may be increasingly dominated by the flow characteristics of that certain fuel stream as the total flow increases. Conversely, the flame properties may be dominated by the flow characteristics of a different fuel stream as the total flow decreases. This progressive blending of two or more fluid streams with different flow properties can be used to build a burner capable of maintaining a flame with desirable aesthetic properties over a wide range of flame sizes.

[0014] Other goals and advantages of the invention will be further appreciated and understood when considered in conjunction with the following description and accompanying drawings. While the following description may contain specific details describing particular embodiments of the invention, this should not be construed as limitations to the scope of the invention but rather as an exemplification of preferable embodiments. For each aspect of the invention, many variations are possible as suggested herein that are known to those of ordinary skill in the art. A variety of changes and modifi-
All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

FIG. 1A is a high-level depiction of a multi-stage burner with two stages provided in accordance with an embodiment of the invention.

FIG. 1B is a high-level depiction of a multi-stage burner with more than two stages provided in accordance with an embodiment of the invention.

FIG. 1C is a high-level depiction of another possible configuration for a multi-stage burner with more than two stages provided in accordance with an embodiment of the invention.

FIG. 2 is a block diagram of a multi-stage burner.

FIG. 3 is a cross-sectional view of a multi-stage burner in accordance with an embodiment of the invention.

FIG. 4 is an additional cross-sectional view of a multi-stage burner.

FIG. 5 provides an exploded view of a multi-stage burner provided in accordance with an embodiment of the invention.

FIG. 6 shows an example of a flame element provided in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

While preferred embodiments of the invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention.

A multi-stage burner may be provided in accordance with an embodiment of the invention. The multi-stage burner may be a luminous, smokeless gas burner. The burner may be used for a decorative flame effect, and may accept a wide range of fuel throughput rates while maintaining a luminous, substantially smokeless flame. The burner may support a fully-attached, stable flame with a widely-variable flame height. The burner may allow the flame height to vary rapidly. In some embodiments, the burner may be used for theatrical effects, or other fire displays.

FIG. 1A is a high-level depiction of a multi-stage burner with two stages provided in accordance with an embodiment of the invention. The multi-stage burner may include one or more of the following: a fuel supply 100, a fuel rate control 101, a flow separator 102, a primary flow path 103a, a secondary flow path 103b, and a flame combination region 104.

Fuel may flow from the fuel supply 100. The fuel supply may have a finite amount of fuel, or may have a relatively unlimited supply of fuel. In some embodiments, the fuel supply may be a tank or other container. In other embodiments, the fuel supply may be a utility or may be conveyed from a very large fuel source. In some embodiments the fuel may be propane, natural gas, hydrogen, acetylene, alcohol, gasoline, diesel, oil, or other flammable fuel. The fuel may be a gaseous fuel, liquid fuel, or any other fluid fuel.

In some embodiments a fuel rate control 101 may be provided that may control the fuel flow rate from the fuel supply 100. In some embodiments, the fuel rate control may be a proportional valve. The fuel rate control may control the overall flow of fuel from the fuel supply. The fuel rate control may vary or maintain the fuel flow rate of the fuel input stream to the burner. The fuel rate control may be located locally or remotely from the fuel supply. In some embodiments, the fuel rate control may control the amount of fuel flowing from the fuel supply, while in other embodiments, the fuel rate control may only control whether fuel is flowing from the fuel supply or not.

A flow separator 102 may be in fluid communication with the fuel rate control 101 and/or the fuel supply 100. The flow separator may separate the fuel into two or more separate flow paths. In some embodiments, the flow separator may separate the fuel into a primary flow path 103a and a secondary flow path 103b. In some embodiments, both the primary and secondary flow paths may convey fuel to the combustion region 104. In some embodiments, the flow separator may be a relief valve. The flow separator may separate the fuel depending on total fuel flow rates. For example, in some embodiments, the primary flow path may convey more of the fuel for low total fuel flow rates. The secondary flow path may carry a progressively greater portion of the total fuel as the total fuel flow rate increases. The secondary flow path may convey more of the fuel for high total fuel flow rates. Thus, the properties of the flame may be dominated by the primary stream when the flame is small, but transition to being dominated by the secondary stream as the flame gets larger. Thus, in some embodiments, depending on the total fuel flow rate, the fraction of fuel distributed between the primary and secondary flow paths may change. The fraction of fuel distributed to the secondary flow path versus the primary flow path may increase as the total fuel flow rate increases. A flow separator may separate a fuel input stream into multiple output streams, wherein a first output stream carries the majority of the fuel output flow for a first range of input flow rates, and a second output stream carries the majority of the fuel output flow for a second range of input flow rates.

FIG. 1B is a high-level depiction of a multi-stage burner with more than two stages provided in accordance with an embodiment of the invention. The multi-stage burner may include one or more of the following: a fuel supply 110, a fuel rate control 111, a flow separator 112, a first flow path 113a, a second flow path 113b, a third flow path 113c, up to any number of flow paths 113x and a flame combination region 114.

A flow separator 112 may be in fluid communication with the fuel rate control 111 and/or the fuel supply 110. The flow separator may separate the fuel into two, three, four or more separate flow paths. A flow separator may separate fuel
into N separate flow paths, where N is a whole number greater than 1. The separate flow paths are preferably not in fluid communication with one another after the flow separation.

[0033] In some embodiments, the flow separator 112 may separate the fuel into a first flow path 113a, a second flow path 113b, a third flow path 113c, and possible additional flow paths 113d. In some embodiments, all of the flow paths (e.g., first, second, and third flow paths) may convey fuel to the combustion region 114. In some embodiments, the flow separator may be a relief valve. In some embodiments, a single flow separator may be used to separate the fuel into multiple flow paths. Alternatively, a plurality of flow separators may be used to separate the fuel into multiple flow paths.

[0034] The flow separator may separate the fuel depending on total fuel flow rates. For example, in some embodiments, the first flow path may convey more of the fuel for low total fuel flow rates. The second flow path may carry a progressively greater portion of the total fuel as the total fuel flow rate increases. The third flow path may carry a progressively greater portion of the total fuel as the total fuel flow rate increases even further. For instance, the second flow path may carry a progressively greater portion of the total fuel when the total fuel flow rate approaches or exceeds a first threshold, and the third flow path may carry a progressively greater portion of the total fuel when the total fuel flow rate approaches or exceeds a second threshold that is higher than the first threshold. Thus, the properties of the flame may be dominated by the first stream when the flame is small, but transition to being dominated by the second stream as the flame gets larger, and transition to being dominated by the third stream as the flame gets larger still. This may be true for any number of flow paths with each subsequent flow path receiving a greater portion of the total fuel as the total fuel rate goes higher and higher. Thus, in some embodiments, depending on the total fuel flow rate, the fraction of fuel distributed between flow paths may change. The fraction of fuel distributed to the second flow path versus the first flow path may increase as the total fuel flow rate increases. The fraction of fuel distributed to the third flow path versus the second or first flow path may increase as the total fuel flow rate increases further. This may occur for any subsequent flow paths.

[0035] FIG. 1C is a high-level depiction of another possible configuration for a multi-stage burner with more than two stages provided in accordance with an embodiment of the invention. The multi-stage burner may include one or more of the following: a fuel supply 120, a fuel rate control 121, a first flow separator 122a, a second flow separator 122b, a first flow path 123a, a second flow path 123b, and a flame combination region 124.

[0036] A first flow separator 122a may be in fluid communication with the fuel rate control 121 and/or the fuel supply 120. The first flow separator may separate the fuel into two or more separate flow paths. For example, a first flow separator may separate the fuel into a first flow path 123a and fuel that is further separated by a second flow separator 122b. The second flow separator may separate the fuel received into two or more separate flow paths. In one example, the second flow may separate the fuel into a second flow path 123b and a third flow path. In another example, the second flow separator may separate the fuel into a second flow path and fuel that is further separated by a third flow separator. In a burner assembly, N-1 flow separators may be provided that may separate fuel into N separate flow paths, where N is a whole number greater than 1. Any number of flow separators may be daisy chained to create any number of separate flow paths. The separate flow paths are preferably not in fluid communication with one another after the flow separation.

[0037] In some embodiments, all of the flow paths (e.g., first, second, and third flow paths) may convey fuel to the combustion region 124. In some embodiments, the one or more flow separators may be a relief valve. In some embodiments, a plurality of flow separators may be used to separate the fuel into multiple flow paths.

[0038] The flow separators may separate the fuel depending on total fuel flow rates. For example, in some embodiments, the first flow path may convey more of the fuel for low total fuel flow rates. The second flow path may carry a progressively greater portion of the total fuel as the total fuel flow rate increases. The third flow path may carry a progressively greater portion of the total fuel when the total fuel flow rate approaches or exceeds a first threshold, and the third flow path may carry a progressively greater portion of the total fuel when the total fuel flow rate approaches or exceeds a second threshold that is higher than the first threshold. A first flow separator may apportion a greater amount or fraction of total fuel to a second flow path over the first flow path as the total fuel flow rate increases. In some embodiments, a second flow separator may apportion a greater amount or fraction of fuel to a third flow path over the second flow path. This may or may not affect the amount of fuel apportioned to the first flow path. Thus, the properties of the flame may be dominated by the first stream when the flame is small, but transition to being dominated by the second stream as the flame gets larger, and transition to being dominated by the third stream as the flame gets larger still. This may be true for any number of flow paths with each subsequent flow path receiving a greater portion of the total fuel as the total fuel rate goes higher and higher. Thus, in some embodiments, depending on the total fuel flow rate, the fraction of fuel distributed between flow paths may change. The fraction of fuel distributed to the third flow path versus the second or first flow path may increase as the total fuel flow rate increases further. This may occur for any subsequent flow paths.

[0039] The total fuel flow may be divided into any number of fuel flow paths. The fuel may be divided at one point, or may be divided in multiple stages in a daisy-chained fashion, or any combination thereof. Any description herein of a two-stage burner may also be applied to multi-stage burners with any number of flow paths, and vice versa.

[0040] FIG. 2 is a block diagram of a multi-stage burner. A multi-stage burner assembly may include one or more of the following: a fuel supply, a proportional valve, a relief valve, a primary flow path, a secondary flow path, and a combining outlet. In some embodiments, the primary flow path may include an inspirator with an air inlet. In some embodiments, the secondary flow path may include a diffuser and a laminator.

[0041] In some embodiments, a proportional valve may determine the amount of fuel flow from the fuel supply. A proportional valve can be adjusted to control whether any fuel is flowing, or the degree of fuel flow. The proportional valve may control the total rate of fuel flow from the fuel supply.
A relief valve may be in fluid communication with fuel that flows past the proportional valve. The relief valve may separate the total fuel into two or more separate flow paths. For example, the relief valve may separate the total fuel into a primary flow path and a secondary flow path. The primary and secondary flow paths are preferably not in fluid communication with one another after the flow separation. Alternatively, they may be brought into fluid communication. The primary and secondary flow paths may be combined in a common atmospheric combustion zone.

In some embodiments, the relief valve may separate the fuel depending on total fuel flow rates. For example, in some embodiments, the primary flow path may convey more of the fuel for low total fuel flow rates. The secondary flow path may carry a progressively greater portion of the total fuel as the total fuel flow rate increases. In some embodiments, when the total fuel flow rate is beneath a particular threshold, all or most of the fuel may be directed to the primary flow path with none or very little of the fuel being directed to the secondary flow path. Thus, the properties of the flame may be dominated by the primary stream when the flame is small, but transition to being increasingly dominated by the secondary stream as the flame gets larger.

Thus, depending on the total fuel flow rate, the fraction of fuel distributed between the primary and secondary flow paths may change. The fraction of fuel distributed to the secondary flow path versus the primary flow path may increase as the total fuel flow rate increases. In some embodiments, the fraction of fuel distributed to the secondary flow path may be zero until the total fuel flow rate exceeds a threshold value. The fraction of the fuel distributed to the secondary flow path may be zero until pressure exerted on the relief valve exceeds a threshold pressure. Once the total fuel flow rate exceeds the threshold, increasing amounts of fuel may flow to the secondary flow path. In some embodiments, the amount of fuel that flows to the secondary flow path may or may not have a linear relationship with the increase in the total fuel flow rate. Alternatively, the secondary flow path may have any other relationship with the total fuel flow rate. In some alternate embodiments, there is no threshold value, and there may be a positive fraction of fuel in the secondary path as long as there is total fuel flow.

The primary or secondary flow path may be conditioned to obtain desired flame properties at different input flow rates. One or more stream may be conditioned to affect whether the flow is laminar or turbulent, speed of output stream, air to fuel content of the stream, or any other property. In one example, a primary flow path may be conditioned to have different flame properties than a secondary flow path.

In some embodiments, the primary flow path may preferably have an inspirator with one or more air inlets. The air may be able to mix with the fuel in the primary flow. Alternatively, there may be no air inlet in the primary flow path. In some embodiments there is no air inlet for the secondary flow path. Alternatively, there may be an air inlet for the secondary flow path.

In some embodiments, the secondary flow path may preferably have a diffuser and a laminizer. The diffuser and laminizer may be positioned in series. For example, the fuel may first flow through the diffuser and then through the laminizer. The diffuser may reduce the non-uniformities in fluid velocity, thereby resulting in a more even flame. The laminizer may reduce the turbulence of the stream, which may slow the mixing with air in the combustion region, resulting in a taller, and therefore more visually prominent flame.

FIG. 3 is a cross-sectional view of a multi-stage burner in accordance with an embodiment of the invention. The multi-stage burner may include a pilot, a primary passage, and a secondary passage. In some embodiments, fuel may be provided to the burner through a gas inlet. The fuel may be distributed to a manifold body. The manifold body may accept the fuel through the gas inlet.

An interior of a pilot may be in fluid communication with the manifold body. In some embodiments, a fuel channel or any other passageway may connect the manifold with the interior of a pilot base. A pilot base may be connected to a pilot fuel/air passage via a pilot orifice. In some embodiments, the pilot orifice may be a channel or passageway. The pilot orifice may have a smaller cross-sectional area than the interior of the pilot base. In some embodiments, a pilot air passage may be provided downstream of the pilot orifice. The pilot air passage may permit air to enter the pilot fuel/air passage. This may allow fuel and air to mix. In some embodiments, the pilot fuel/air passage may be a tube. The pilot fuel/air passage may have any cross-sectional shape which may include, but is not limited to a circular shape, elliptical shape, triangular shape, quadrilateral shape, pentagonal shape, hexagonal shape, octagonal shape, or any other shape.

In some embodiments, a primary passage may be provided, surrounded by a secondary passage. In one example, the primary and secondary passages may form concentric passages with the primary passage in the interior and the secondary passage as the surrounding passage, or vice versa. In some embodiments, the primary and secondary passages may be formed as tubes (e.g., primary tube within the secondary tube). Alternatively, they may have any cross-sectional shape which may include, but is not limited to a circular shape, annular shape, elliptical shape, triangular shape, quadrilateral shape, pentagonal shape, hexagonal shape, octagonal shape, or any other shape. They may have the same shape as one another or different shapes. In alternate embodiments, the primary and secondary passages need not be within one another and may be adjacent to one another, partially surrounded by one another, or spaced apart from one another.

The primary passage may be slightly longer than the secondary passage. In some embodiments, the primary passage may extend beyond the secondary passage. The primary passage may extend by any amount. For example, the primary passage may extend more than, less than, or about 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 1 cm, 1.5 cm, 2 cm, 2.5 cm, 3 cm, 4 cm, 5 cm, 10 cm, or 20 cm further than the secondary passage. The outlet of the primary passage may be slightly higher than the outlet for the secondary passage. The primary and secondary passages may be oriented vertically. Alternatively, they may be oriented horizontally or at any angle relative to vertical. The primary and secondary passages may be oriented so that the outlet for the primary and secondary passages is upward or at a higher elevation than the manifold body. In alternate embodiments, the primary passage may extend to the same amount as the secondary passage, or the secondary passage may extend past the primary passage.

A primary fuel/air passage may be in fluid communication with the manifold body. In some embodiments, fuel may flow to the primary passage via a primary orifice. In some embodiments, the primary orifice may be a channel
or passageway. The primary orifice may have a smaller cross-sectional area than the interior of the primary fuel-air passage.

In some embodiments, a primary air passage 6 may be provided downstream of the primary orifice. The primary air passage may permit air to enter the primary fuel/air passage. This may allow fuel and air to mix. In some embodiments, a primary air passage may include one air inlet, while in other embodiments, the primary air passage may include a plurality of air inlets. In some embodiments, a plurality of air inlets may be arranged in a radially symmetrical fashion (e.g., two air inlets 180 degrees from one another, three air inlets 120 degrees from one another, four air inlets 90 degrees from one another). The air inlets may be located at or near the bottom of the primary fuel/air passage. The primary air passage may be located upstream of the primary fuel/air passage or most of the primary fuel/air passage. In some embodiments, the primary passage outlet may be angled upward. In some embodiments, the fuel/air mixture may travel up the primary passage.

A secondary passage 8 may or may not be in fluid communication with the manifold body 2. In some embodiments, the secondary passage may be in fluid communication with the manifold body at some times and may not be in fluid communication with the manifold body at other times. The secondary passage may have a default of not being in fluid communication with the manifold body and may be brought into fluid communication with the manifold body under certain conditions. In some alternate embodiments, the secondary passage may have a default in being in fluid communication with the manifold body so that a very small amount of fluid may flow to the secondary passage, and may be brought into greater fluid communication with the manifold body under certain conditions. The secondary passage may be brought into or out of fluid communication with the manifold body. The secondary passage may be brought into or out of greater fluid communication with the manifold body.

In some embodiments, fuel may flow to a secondary tube 8 via a secondary fuel passage 21. In some embodiments, the secondary fuel passage may be a channel or passageway. The secondary fuel passage may have a smaller cross-sectional area than the interior of the secondary tube. The secondary fuel passage may pass through a manifold—burner interface 11.

In some embodiments, unlike the primary fuel/air passage 7, no air is entrained into the secondary stream 8. No air entrainment is needed in this embodiment because the secondary passage only conveys substantial flow when the primary is already imparting sufficient turbulence and premixed air to the flame to prevent the formation of smoke.

The secondary tube may include a diffuser core 10 in the interior. In order to increase uniformity of the flame when the secondary stream is active (for higher flow rates) the secondary flow path may include a converging/diverging section that may form the diffuser core. The converging/diverging section may first accelerate the fuel by reducing cross-sectional area of the secondary passage, and then slow the flow by gradually increasing the cross-sectional area. This converging/diverging section may greatly reduce the non-uniformities in fluid velocity introduced by smaller discrete supply channels opening into a larger passage. In some embodiments, the converging/diverging section of the diffuser core may be formed by a shaped feature on an interior surface of the secondary passage, an exterior surface of the primary passage, or any combination thereof.

The secondary tube may also include a laminizer 9. In some embodiments, the laminizer may be formed of one or more laminizer fins. In some embodiments, the secondary flow path may include a series of veins or fins that may divide the single large secondary passageway into several smaller passageways or channels to reduce the hydraulic diameter of the fluid stream, thereby reducing the turbulence of the stream. This has the advantage of slowing the mixing with air in the combustion region. This may result in a taller, and therefore more visually prominent flame, which will be further explained in greater detail below.

In some embodiments, a laminizer 9 may be provided downstream of the diffuser core 10. In some embodiments, a laminizer may include one laminizer fin, while in other embodiments, the primary air passage may include a plurality of laminizer fins. Two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen or more laminizer fins. In some embodiments, a plurality of laminizer fins may be arranged in a radially symmetrical fashion (e.g., two fins 180 degrees from one another, three fins 120 degrees from one another, four fins 90 degrees from one another, five fins 75 degrees from one another, six fins 60 degrees from one another, or n fins 360/n degrees from one another). The laminizer fins may or may not be evenly spaced from one another. The laminizer may be located at or near the top of the secondary passage. The laminizer may be located downstream of the manifold body, the secondary fuel passage and/or the diffuser core. The laminizer may be located upstream of the secondary passage outlet. In some embodiments, the secondary passage outlet may be angled upward. In some embodiments, the fuel may travel up the secondary passage through the diffuser core and the laminizer. Preferably, the fuel may first pass through the diffuser core and then through the laminizer. In alternate embodiments, the fuel may pass through a laminizer before passing through the diffuser core.

A combustion region 20 may be provided at or near the outlet of the primary passage 7 and the secondary passage 8. The combustion region may be provided above the outlet of the primary and secondary passages. A flame effect may be provided by the merging of the flames provided by the primary and secondary passages. The flame characteristics may be determined by the relative fuel flow to the primary and secondary passages. For example, if more fuel flows through the primary passage, the flame characteristics may be dominated by the primary passage. If more fuel flow through the secondary passage, the flame characteristics may be dominated by the secondary passage.

A flow separator may determine how fuel gets distributed from the manifold body 2 to the primary passage 7 and/or the secondary passage 8. In some embodiments, the flow separator may be implemented as a spring-loaded relief valve. This may include a movable relief plunger 15 that may form a seal, or a near seal, against a stationary valve seat 18. In some embodiments, a relief O-ring 17 may assist with forming the seal or near seal against the valve seat. A relief spring 14 may push the plunger 15 against the valve seat 18 to maintain the seal. In other embodiments, other mechanisms, such as elastics, deforming pieces, flexible pieces, or tension mechanisms may be used, and any description of a spring may also apply to such mechanisms. The spring or other mechanism may rest on a relief plug 13. The primary fuel/air
passage 7 is connected directly to the burner’s fuel supply, upstream of the relief valve. The secondary passage 8 lies downstream of the relief valve, and is therefore substantially blocked from receiving fuel by the plunger 15 sealing against the seat 18.

[0062] In a preferable embodiment, a small bypass hole 16 through the plunger may allow a small amount of fuel through to the secondary passage 8 while the relief is closed. Having some fuel flow in the secondary passageway, even for low fuel flow rates, may be beneficial by allowing some resistance to wind because of the fuel eddy behind a protruding primary tube. In other embodiments, a bypass hole is not provided and when the relief is closed fuel does not flow to the secondary passage.

[0063] The flow separator may divert substantially all of the fuel to the primary flow path until the fuel throughput reaches a high enough rate that the pressure presented at the surface of the relief plunger 15 is sufficient to overcome the force of the spring 14 or other mechanism holding the plunger against the seat 18. Once the fuel throughput reaches the rate required to lift the relief plunger 15, most additional fuel flow may be diverted to the secondary flow path 8. This may be a threshold condition that may permit an increasing amount of fuel flow to the secondary flow path. The flow separator may be a pressure-driven flow separator where an increased amount of fuel is permitted to flow to the secondary flow path as the amount of total fuel to the manifold is increased past a threshold. The ratio of fuel provided to the secondary flow path relative to the primary flow path may increase as the total fuel to the manifold is increased. In some instances, a total fuel flow rate may reach a point where the flow separator reaches a maximum open position, after which the ratio of fuel provided to the secondary flow path relative to the primary flow path may stabilize.

[0064] At low flow rates in quiescent air, there may be little or no turbulence in the flame, meaning smoke is more likely to be observed. To eliminate visible smoke at low flow rates, the primary flow path may include an inspirator with a primary air passage 6, which entrains some air into the fuel stream through several air inlets. After the inspirator, a length of channel 7 may be provided to allow the air to mix with the fuel before the primary outlet into the combustion region 20.

[0065] The cross-sectional area of the primary flow path 7 may be small in order to sustain a greater fluid velocity at lower flow rates. In some embodiments, the cross-sectional area may be about 0.1", 0.2", 0.25", 0.3", 0.4", 0.5", 0.7", or 1.0". The greater exit velocity may allow the primary flow path to support a more stable flame at its outlet for very low flow rates, and may also impart momentum to the secondary stream at greater flow rates.

[0066] For high total fuel flow rates, most of the fuel may be directed to the secondary flow path 8. Therefore, the secondary fuel stream may dominate the characteristics of the flame for larger flames. To maintain a fully-attached flame at higher flow rates, the secondary flow path may have a much larger cross-sectional area at its outlet than the primary flow path 7. In some embodiments, the cross-sectional area of the secondary flow path may be about 0.5", 0.75", 1", 1.25", 1.5", 2", 3", or 5". In some embodiments, the ratio of cross-sectional area for the secondary flow path to the cross-sectional area for the primary flow path may be greater than, less than, or equal to about 1:1, 1.2:1, 1.3:1, 1.4:1, 1.5:1, 1.6:1, 1.7:1, 1.8:1, 1.9:1, 2:1, 2.1:1, 2.2:1, 2.3:1, 2.4:1, 2.5:1, 2.6:1, 2.7:1, 2.8:1, 2.9:1, 3:1, 3.1:1, 3.2:1, 3.3:1, 3.4:1, 3.5:1, 3.6:1, 3.7:1, 3.8:1, 3.9:1, or 4:1. This larger area may result in a lower fuel-exit velocity. The velocity of the fuel exiting the burner may preferably be below the flame speed at the burner exit for the flame to remain attached.

[0067] FIG. 4 is an additional cross-sectional view of a multi-stage burner. The multi-stage burner may have a pilot 400, primary flow path 402, and secondary flow path 404. As previously discussed, fuel may be provided from a fuel supply and the total fuel flow rate may be controlled by a proportional valve.

[0068] A multi-stage burner may have a proportional valve outlet 406 that may accept the fuel supply and controlled by the proportional valve. The proportional valve outlet may direct the fuel into a manifold 408. Fuel may flow from the manifold through a pilot noise reduction orifice 410 to a pilot flow path. The fuel may flow through a pilot fuel orifice 412 within the pilot and may encounter one or more pilot air passages 414. The pilot air passages may allow air to enter the pilot and mix with the fuel. The fuel-air mixture may travel up the pilot 400.

[0069] Fuel may also flow from the manifold 408 through a primary fuel orifice 416 into a primary flow path 402. The fuel may encounter one or more primary air passages 418. The primary air passages may allow air to enter the primary flow path and mix with the fuel. The fuel-air mixture may travel up the primary flow path.

[0070] Fuel may also flow through the manifold 408 and encounter a relief valve. At a default position, a relief needle 420 may block the fuel from flowing to the secondary flow path 404. A relief spring 422 may bias the relief needle against a seat. When sufficient fuel throughput is provided, the pressure from the fuel may be sufficient to overcome the spring and may cause the relief needle to retract. When the relief needle retracts, fluid connection to the secondary flow path may be provided. As the relief needle retracts further, an increased fluid connection to the secondary flow path may be provided. A flow passageway in fluid communication with a secondary fuel passage 424 may be provided in accordance with any embodiment of the invention. The secondary fuel passage may have a smaller cross-sectional area than the overall secondary flow path. In some embodiments, one, two, or more secondary fuel passages may be provided to convey fuel to the secondary flow path. The secondary flow path may include a diffuser core 426 and one, two, or more laminator fins 428. In some embodiments, the fuel may first encounter the diffuser core, and may then pass between the laminator fins. The fuel may travel up the secondary flow path.

[0071] In some embodiments, one or more O-rings or other similar features may be used to assist with sealing various parts of the multi-stage burner. For example, a relief O-ring may be provided at the relief needle, to assist with sealing the relief needle against the valve seat. In another example, an O-ring may be provided at the manifold-burner interface. This may assist with keeping the manifold-burner interface sealed as fuel may flow from the manifold to the flow paths.

[0072] In some embodiments, an electrically insulating disk 430 may be provided between the manifold-burner interface and the manifold 408. The insulating disk may electrically insulate the burner from the manifold.

[0073] In some embodiments, the multi-stage burner may be arranged with the primary flow path running up the center of the secondary flow path. The primary flow path may be provided within a primary tube, and a secondary flow path may be provided within a secondary tube. The primary tube may terminate about 1/2" (or any other distance mentioned...
elsewhere herein) above the termination of the secondary tube so that the smaller primary tube extends slightly past the secondary tube.

[0074] This configuration may be advantageous for a number of reasons. First, the primary and secondary fuel streams may be uniformly combined with respect to the axis of both streams, creating a flame that looks uniform from all viewing angles in still air. For example, both the primary and secondary fuel streams may have the same axis. The axis may be located at or near the center of the tubes. In some embodiments, the axis may be a vertical axis. Alternatively, the axis may be a horizontal or angled axis. Co-axial primary and secondary fuel streams may permit the fuel streams to be visually combined.

[0075] Second, for higher flow rates when the secondary fuel stream is flowing a substantial amount of gas, the slower, laminar secondary flow may shield the faster, more turbulent primary flow from air for a substantial distance above the burner outlet. This may slow the mixing of the fuel with air by reducing the turbulence at the fuel-air interface, which may provide a taller flame than would be realized otherwise.

[0076] Third, for low and intermediate flow rates, the secondary fuel stream may release a small amount of slowly-flowing gas in an even pattern around the primary outlet. In wind, this slow-moving gas may be pushed away from the upwind side of the secondary outlet and towards the downwind side, which is partially shielded by the protruding primary tube. This collection of secondary fuel in the lee of the primary may help the burner maintain a flame in higher winds than would be realized in other arrangements.

[0077] FIG. 5 provides an exploded view of a multi-stage burner provided in accordance with an embodiment of the invention. The multi-stage burner may have a first fuel passage passing through a burner inner tube 500 and a second fuel passage passing through a burner outer tube 502. In one example, the first fuel passage may have a circular cross-section while the second fuel passage may have an annular cross-section.

[0078] A proportional valve 504 may deliver fuel to a manifold 506 of the burner. A pilot base 508 may be connected to the manifold. In some instances, the pilot base may screw into the manifold. The pilot base may be welded, locked, clamped, adhered, or attached to the manifold in any other manner known in the art. A pilot tube 510 may be connected to a pilot base. In some embodiments, a pilot tube may slide over a portion of the pilot base. The pilot tube may be a separate or separable piece from the pilot base. Alternatively, the pilot tube may optionally be integrally formed of a single piece with the pilot base.

[0079] In some embodiments, a third fuel passage may be provided in the pilot to aid in the creation of the flame. Fuel may be supplied to this passage from the manifold 506. Fuel may be supplied to the pilot from the same manifold as the inner burner. A very small channel in the manifold may convey fuel to a chamber between the threaded pilot base 508 and the manifold. This small channel may serve to slow the flow of fuel to the pilot, thereby reducing the noise that the pilot produces. Next, the pilot fuel may flow through a pilot orifice in the pilot base. Air may be introduced to the pilot stream just past the orifice, and the mixture may flow up the pilot tube to where it exits near the main burner exit. An inspirator for the pilot may be constructed to produce a mixture that has a much lower fuel-air ratio than the primary stream, and which is nearly stoichiometric. This mixture ratio may be beneficial in that it may be easily ignited by an electric spark.

[0080] A burner base 512 may be connected to the manifold 506. In some embodiments, an insulating disk 514 may be provided between the burner base and the manifold. The insulating disk may electrically insulate the burner from the manifold.

[0081] The burner base 512 may also have several machined features that may assist with the operation of the burner. A small hole in the center may serve as an orifice for an inspirator that may draw air into a primary stream. Air passages 516 may convey air to the primary stream just downstream of the orifice, thus forming the inspirator, which may reduce smoke production. In some instances, any number of radial air passages may be provided (e.g., 1, 2, 3, 4, 5, 6 or more). Secondary fuel passages may be drilled axially in locations that alternate with the aforementioned air passages. For example, if three air passages are provided, three secondary fuel passages may be provided. These fuel passages may transmit fuel from an annular region between the manifold 506 and the burner base, through the burner base, to the annular region between the burner inner 500 and outer 502 tubes.

[0082] One, two or more circumferential grooves in the burner interface may retain o-rings. In one embodiment, the smaller of two o-rings may separate primary and secondary flow paths. The larger of the two o-rings may separate the secondary flow path from the atmosphere at the burner manifold interface. These two o-rings and the insulating disk that rests between the burner base and the manifold may serve to electrically insulate the burner assembly from the manifold, while maintaining a positive fluidic seal. This may permit the burner assembly to be used as a flame detection sensor terminal.

[0083] A burner inner tube 500 may be connected to the burner base 512. In some embodiments, the burner inner tube may fit into a lower inner part of the burner base. In some embodiments, the interior of the inner tube may be in fluid communication with a central portion of the burner base without being in fluid communication with a peripheral portion of the inner tube. In some embodiments, the interior of the inner tube may retain a uniform cross-section. For example, the interior of the inner tube may be straight. In other embodiments, the interior of the inner tube may vary along the length of the tube.

[0084] The inner tube may also include a diffuser core 518 and one or more laminator fins 520. The diffuser core may be formed on an outer surface of the inner tube. The diffuser core may bulge outward from the outer surface of the inner tube. In some embodiments, the diffuser core may be a separate piece that fits over the inner tube. Alternatively, the diffuser core may be integrally formed of a single piece from the inner tube. The interior of the diffuser core may be solid or hollow. The laminator fins may protrude from the surface of the inner tube. The laminator fins may have a parallel orientation with respect to an axis of the inner tube. For example, if an inner tube is oriented vertically the laminator fins may also be oriented vertically. The laminator fins may extend outward in a radial fashion from the inner tube. The laminator fins may be separate or separable pieces attached to the inner tube, or may be integrally formed on the inner tube.

[0085] A burner outer tube 502 may fit over a burner inner tube 500. The burner outer tube may cover a diffuser core 518 and/or laminator fins 520 of the burner inner tube. The burner
outer tube may contact or connect to the burner base 512. In some instances, the burner outer tube may fit over a portion of the burner base. The interior of the burner outer tube may be in fluid communication with a peripheral portion of the burner base without being in fluid communication with a central portion of the burner base. When assembled, in some embodiments, the burner inner tube may extend past the burner outer tube.

[0086] The construction of a burner may comprise a burner base, the burner outer tube that conveys the secondary flow to the burner outlet, the burner inner tube that conveys the primary flow to the burner outlet, a diffuser core encircling the burner inner tube and laminizer fins attached to the burner inner tube. The inner and burner outer tubes may be co-axial so that the primary stream (e.g., inner stream) flows up the center of the secondary stream (e.g., outer stream). The burner base may provide the structural support for both tubes at their bases.

[0087] A relief needle 522, relief spring 524, and relief plug 526 may be connected to the manifold. The relief needle may retract when a sufficient pressure is exerted on the relief needle. When the relief needle is in an unretracted or closed state, fluid communication may be provided between the manifold 506 and the burner inner tube 500 without fluid communication or with extremely little fluid communication being provided between the manifold and the burner outer tube 502. When the relief needle is in a retracted or open state, the fluid communication may be provided between the manifold and the burner inner tube with fluid communication or with an increased amount of fluid communication being provided between the manifold and the burner outer tube. The relief needle may have a varying range of retraction in the open state. The relief needle degree of openness may be continuously variable.

[0088] The relief needle may be capable of being retracted or unretracted at a rapid rate. The flame characteristics may be able to rapidly vary corresponding to the rapid variation in distribution of fuel to one or more different output flow paths based on the relief valve. The flame characteristics may be able to vary widely in a short amount of time.

[0089] An inline filter 528 may be provided. The inline filter may connect to the manifold 506. In some embodiments, the inline filter may screw into the manifold. The inline filter is useful for reducing debris that may stop the valve or flame effect from operating properly.

[0100] A reducing coupler 530 may be connected to the inline filter 528. In some embodiments, the reducing coupler may screw into the inline filter. The reducing coupler may adapt the plumbing to the correct size.

[0101] A quick connect filter 532 may be connected to the reducing coupler 530. The quick connect filter may screw into the reducing coupler. The quick connect filter may allow for easy connection and disconnection of the fuel supply.

[0102] FIG. 6 shows an example of a flame element provided in accordance with an embodiment of the invention. A flame element may include a multi-stage burner that may be in communication with a fuel inlet 600. The multi-stage burner may include a manifold 602, a main burner 604, a pilot burner 606, and an igniter 608. The multi-stage burner may have one or more of the characteristics described elsewhere herein. A gas inlet may provide fuel to the manifold of the burner. The manifold may distribute fuel to the pilot and the main burner.

[0103] A valve 610 may be connected to the manifold 602. The valve may be useful for controlling the flow of fuel into the manifold. The valve may be a proportional solenoid valve, a pilot operated valve, a servo-actuated valve, a muscle wire actuated valve, or any type of valve that permits variable control of fuel flow to the manifold.

[0094] A circuit board 612 (e.g., printed circuit board—PCB) may be provided. The circuit board may be connected to one or more electrical connectors 614. The electrical connectors may provide power to the circuit board. Alternatively, the flame element may have an internal power source. The circuit board may include processors, tangible computer readable media, logic, code, instructions, or memory that may assist with controlling the burner. The circuit board may provide one or more signals to an igniter which may ignite a flame. The circuit board may provide one or more signals to the valve, which may control the flow of fuel from the gas inlet to the manifold 602. The valve may control the flow rate of fuel from the gas inlet to the manifold. In some embodiments, the flow rate of the fuel may be varied at a rapid rate. For example, the flow rate may be varied up to about 1000 times per second (1 KHz), 2000 times per second (2 KHz), 3000 times per second (3 KHz), 4000 times per second (4 KHz).

[0095] The flame element may be enclosed or partially enclosed within a housing 616. The housing may enclose the circuit board 612, valve 610, and a portion of the gas inlet 600. The housing may enclose a portion of the manifold 602. The housing 616 may be extended from the housing. In some instances, the housing may extend from the top of the housing.

[0096] The housing 616 may include a bottom cap 618. In some instances, the bottom cap may be screwed into the housing, or attached in any other way known in the art. The bottom cap may include one or more openings that may permit a gas inlet and/or electrical connections to pass to the exterior of the housing. Alternatively, a local fuel source and/or power source may be provided within the housing of the flame element, so openings may not be required.

[0097] It should be understood from the foregoing that, while particular implementations have been illustrated and described, various modifications can be made thereto and are contemplated herein. It is also not intended that the invention be limited by the specific examples provided within the specification. While the invention has been described with reference to the aforementioned specification, the descriptions and illustrations of the preferable embodiments herein are not meant to be construed in a limiting sense. Furthermore, it shall be understood that all aspects of the invention are not limited to the specific depictions, configurations or relative proportions set forth herein which depend upon a variety of conditions and variables. Various modifications in form and detail of the embodiments of the invention will be apparent to a person skilled in the art. It is therefore contemplated that the invention shall also cover any such modifications, variations and equivalents.

What is claimed is:

1. A multi-stage burner with variable output, comprising: a fuel input stream; a proportioning system that divides the fuel input stream into multiple fuel output streams; a passage that introduces air into at least one of the fuel output streams; and an outlet that combines the fuel output streams in a common atmospheric combustion zone.
2. The burner of claim 1 wherein the proportioning system changes the relative proportions of fuel flowing in the fuel output streams with respect to the total fuel flowing through the burner.

3. The burner of claim 2 wherein the fuel output streams include a primary fuel output stream and a secondary fuel output stream, and the proportioning system diverts an increasing proportion of the total fuel to the secondary with increasing total fuel flow.

4. The burner of claim 3 wherein the proportioning system comprises a spring-loaded relief that blocks fuel from flowing to the secondary fuel output stream until a threshold upstream pressure is exceeded, thereby causing the relief to open, permitting fuel to enter the secondary stream.

5. The burner of claim 3 wherein the proportioning system comprises a spring-loaded relief movable between (a) a closed position that blocks most fuel from flowing to the secondary fuel output stream, and (b) an open position that permits an increased amount of fuel to flow to the secondary fuel output stream, and a channel that circumvents the relief to allow fuel to flow to the secondary fuel output stream when the relief is in the closed position.

6. The burner of claim 3 further comprising an inspirator that is configured to draw air into the primary fuel output stream through an air passage.

7. The burner of claim 3 wherein the outlet is configured such that the primary fuel output stream exits through a smaller cylindrical tube that is co-axial with a larger cylindrical tube that conveys the secondary fuel output stream.

8. The burner of claim 7 wherein the smaller cylindrical tube extends past the plane of the larger cylindrical tube.

9. The burner of claim 3 further comprising a third pilot stream that is used to ignite the flame fed by the primary and secondary fuel output streams.

10. The burner of claim 3 further comprising a diffuser in the secondary fuel output stream to uniformly slow the fluid flow.

11. The burner of claim 3 further comprising a laminizer configured to divide the secondary fluid output stream into a series of smaller channels.

12. The burner of claim 3 wherein the secondary fuel output stream has a larger cross-sectional area at its outlet than the primary fuel output stream at its outlet.

13. A method for producing a flame comprising the following steps:
   * controlling an input flow rate of a fuel input stream;
   * separating the flammable gas input stream into multiple output streams, wherein a first output stream carries the majority of the fuel output flow for a first range of input flow rates and a second output stream carries the majority of the fuel output flow for a second range of input flow rates;
   * conditioning at least one output stream to obtain desired flame properties at different input flow rates; and
   * introducing the first and second output streams into a common atmospheric combustion region.

14. The method of claim 13 wherein the conditioning of the at least one output stream includes using a diffuser to uniformly slow the fluid flow.

15. The method of claim 13 wherein the conditioning of the at least one output stream includes using one or more laminizer to divide the at least one output stream into a series of smaller channels.

16. The method of claim 13 wherein said separating is performed by a spring-loaded relief that is in a first position for the first range of input flow rates and in a second position for the second range of input flow rates.

17. A method for producing a flame comprising the following steps:
   * controlling the flow rate of a flammable gas input stream;
   * diverting some of the flammable gas input stream through an orifice to a primary output stream;
   * sending remaining flammable gas from the flammable gas input stream to a secondary output stream via a relief valve that opens when the pressure upstream of the relief valve is above a specific design pressure; and
   * introducing both streams into a common atmospheric combustion region.

18. The method of claim 17 further comprising entraining air into the primary output stream using an inspirator.

19. The method of claim 17 further comprising conditioning the secondary output stream to be a substantially uniform, laminar flow.

20. The method of claim 17 wherein the secondary output stream surrounds the primary output stream.