US 20180224120A1

(19) United States

(12) Patent Application Publication

Cheng et al.

(10) Pub. No.: US 2018/0224120 A1

(43) Pub. Date: Aug. 9, 2018

(54) **BURNER PLATES AND BURNER APPARATUS**

(71) Applicant: **The Regents of the University of California**, Oakland, CA (US)

(72) Inventors: **Robert K. Cheng**, Kensington, CA (US); **Peter Therkelsen**, Oakland, CA (US); **Darren Sholes**, Baden-Württemberg (DE); **Vi Rapp**, Berkeley, CA (US)

(21) Appl. No.: **15/942,915**

(22) Filed: **Apr. 2, 2018**

Related U.S. Application Data

(63) Continuation-in-part of application No. PCT/US2016/056301, filed on Oct. 10, 2016.

(60) Provisional application No. 62/239,804, filed on Oct. 9, 2015, provisional application No. 62/249,890, filed on Nov. 2, 2015, provisional application No. 62/329,938, filed on Apr. 29, 2016.

Publication Classification

(51) **Int. Cl.**

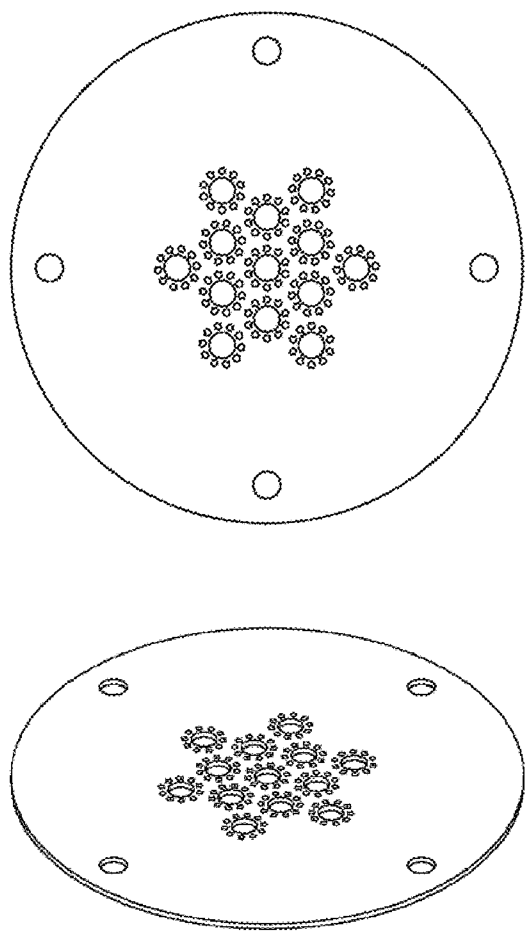
F23D 14/62	(2006.01)
F23D 14/46	(2006.01)
F23D 14/70	(2006.01)
F24C 3/08	(2006.01)

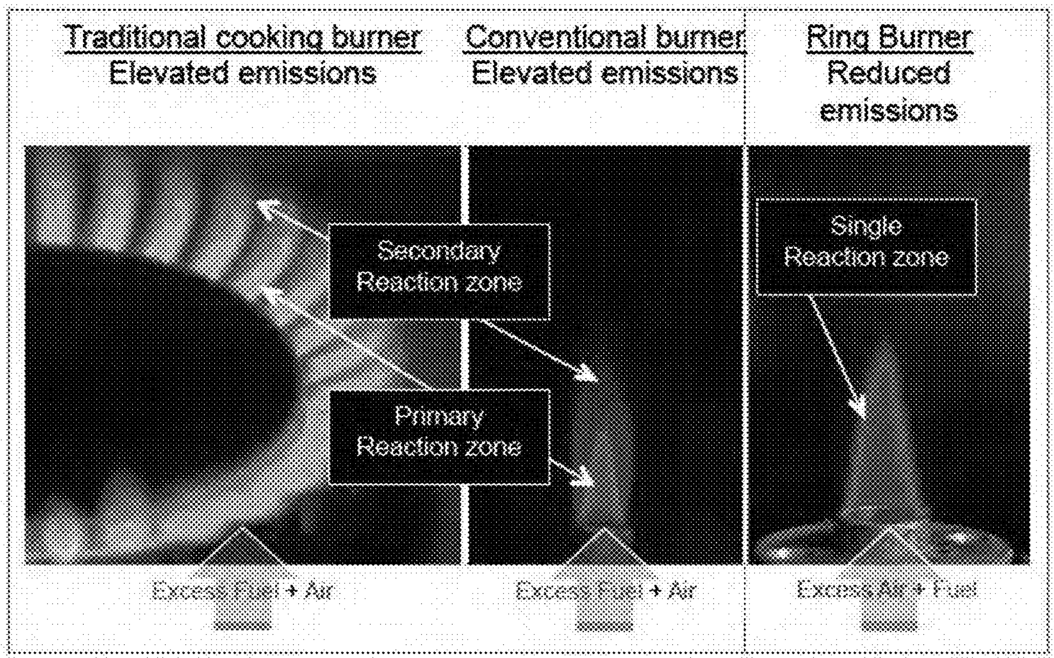
(52) **U.S. Cl.**

CPC ***F23D 14/62*** (2013.01); ***F24C 3/08*** (2013.01); ***F23D 14/70*** (2013.01); ***F23D 14/46*** (2013.01)

(57) **ABSTRACT**

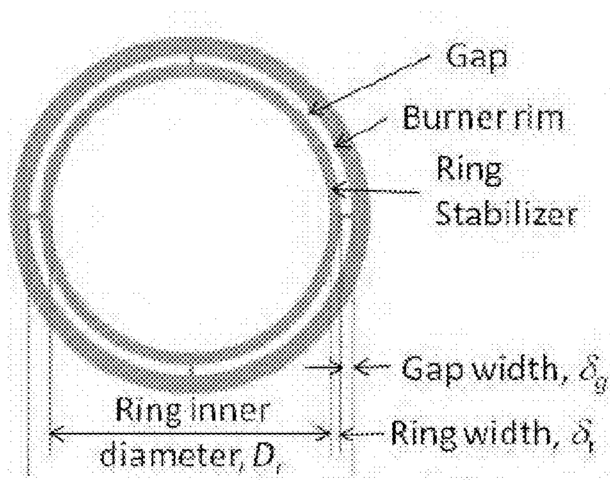
This disclosure provides systems, methods, and apparatus related to burners. In one aspect, an apparatus includes a burner body, an inlet to the burner body, a divider disposed in the burner body, and a burner plate. The inlet is operable for delivery of a fuel/air mixture to the burner body. The divider forms a first section and a second section in the burner body. The divider defines a plurality of interior ports between the first section and the second section. The burner plate defines a combustion surface for the fuel/air mixture. The burner plate forms a surface of the burner body and in part defines the second section. The burner plate defines a plurality of primary ports. The burner plate further defines a plurality of secondary ports surrounding each primary port of the plurality of primary ports.





PRIOR ART

Figure 1A Figure 1B Figure 1C



$$D_p = D_r + \delta_r + \delta_g$$

Figure 2

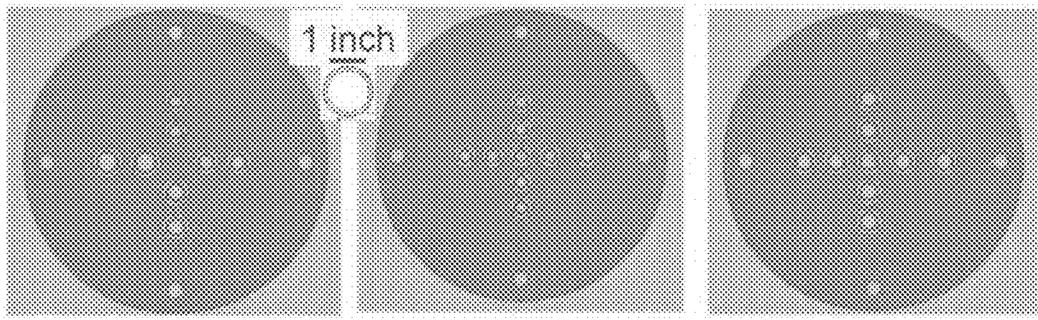


Figure 3A Figure 3B Figure 3C

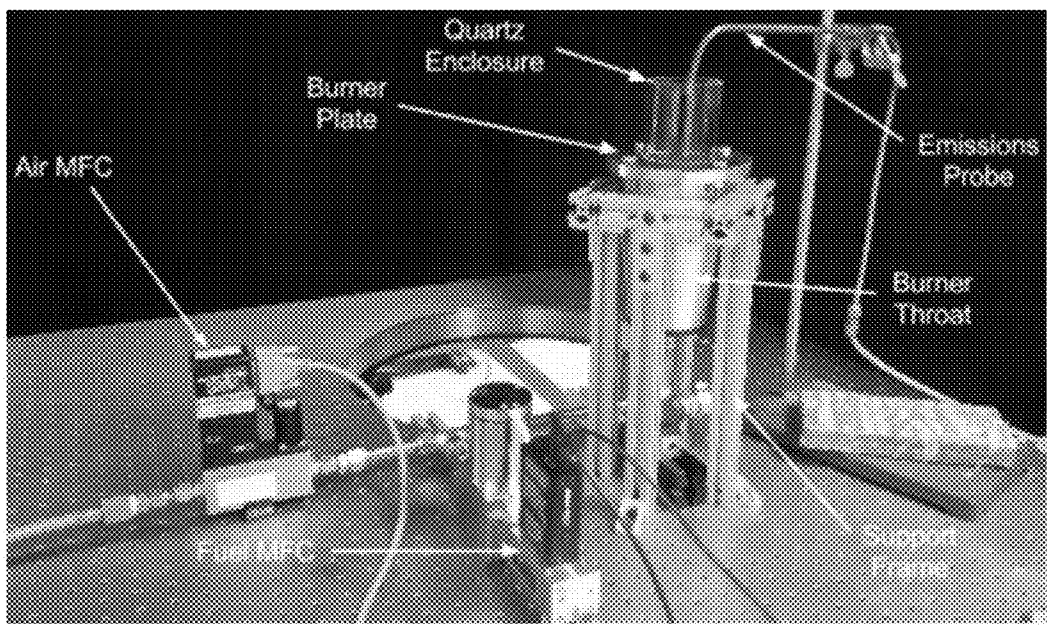


Figure 4

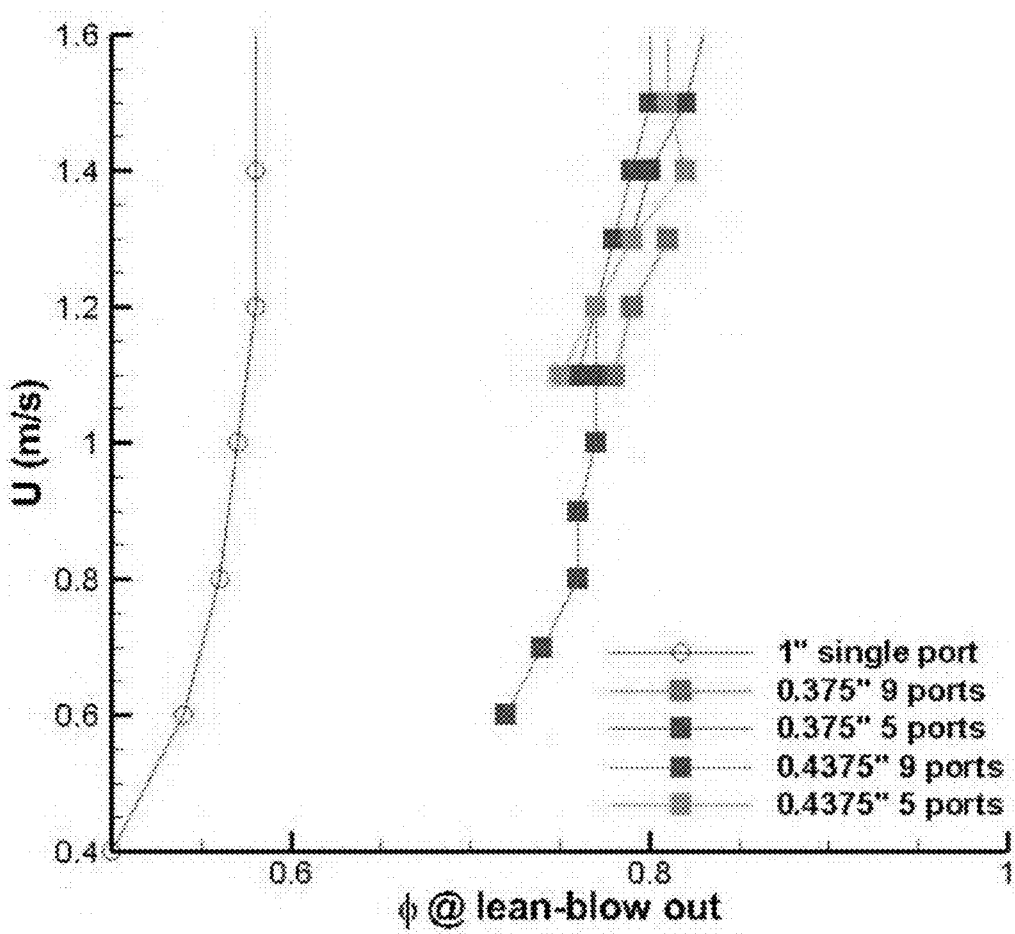

1.6
1.4
1.2
1
0.8
0.6
0.4
U (m/s)
0.6
0.8
1
ϕ @ lean-blow out
1" single port
0.375" 9 ports
0.375" 5 ports
0.4375" 9 ports
0.4375" 5 ports

Figure 5

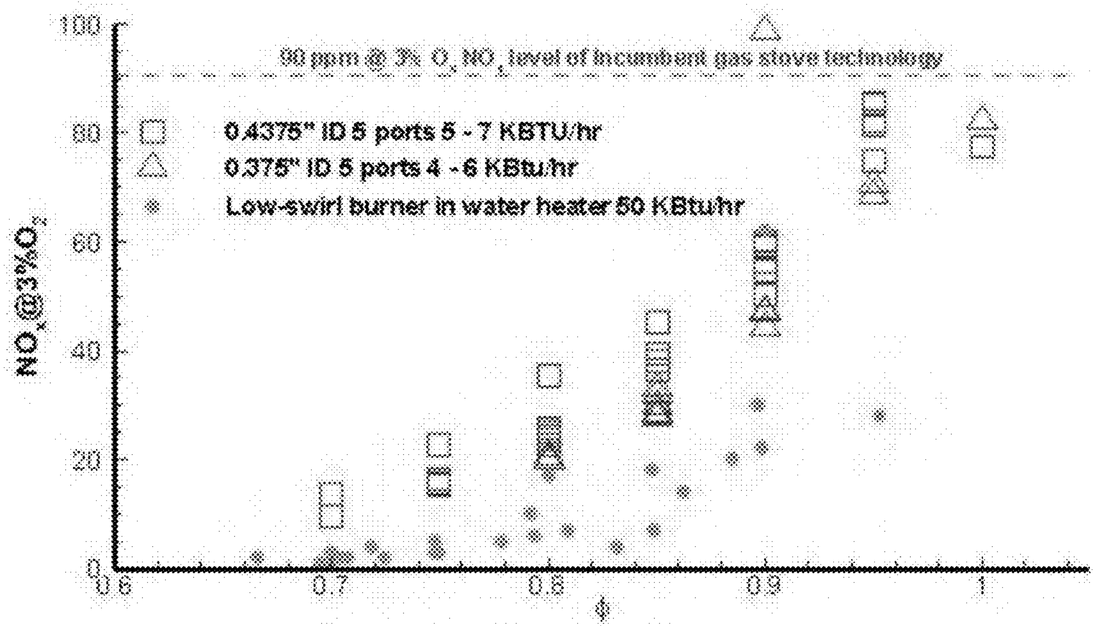


Figure 6

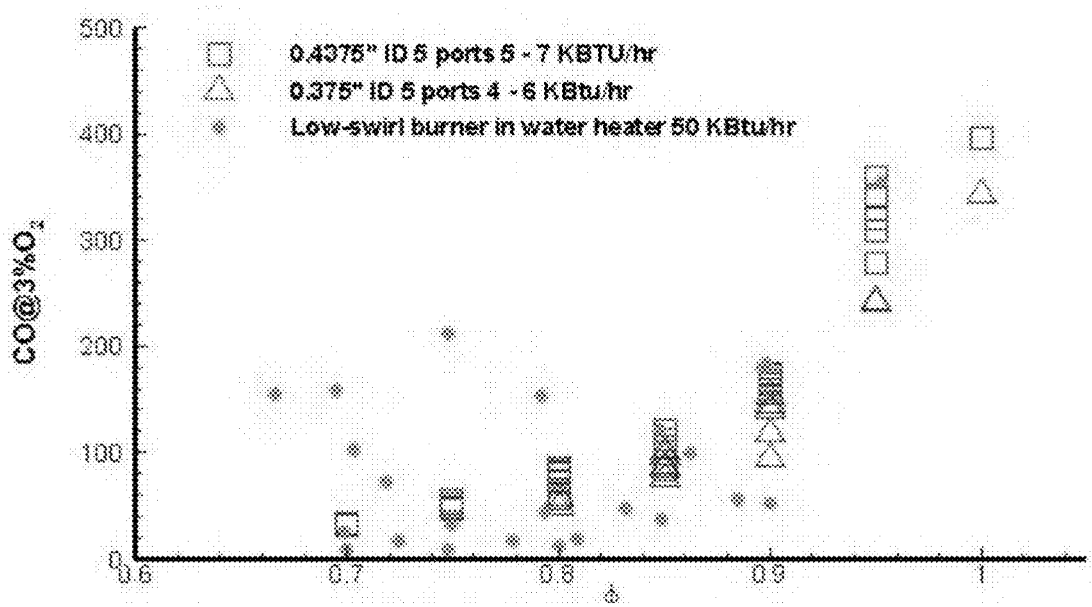


Figure 7

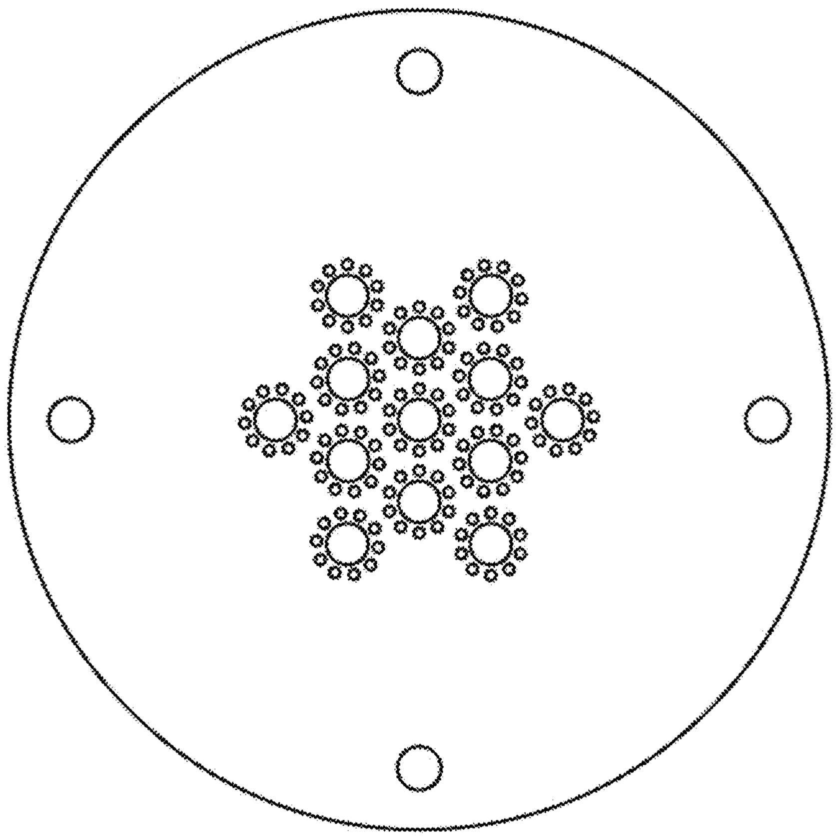


Figure 8A

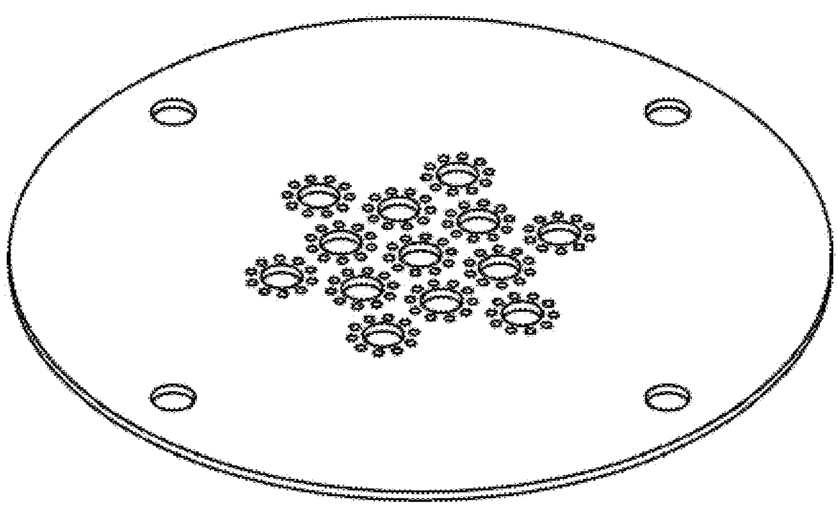


Figure 8B

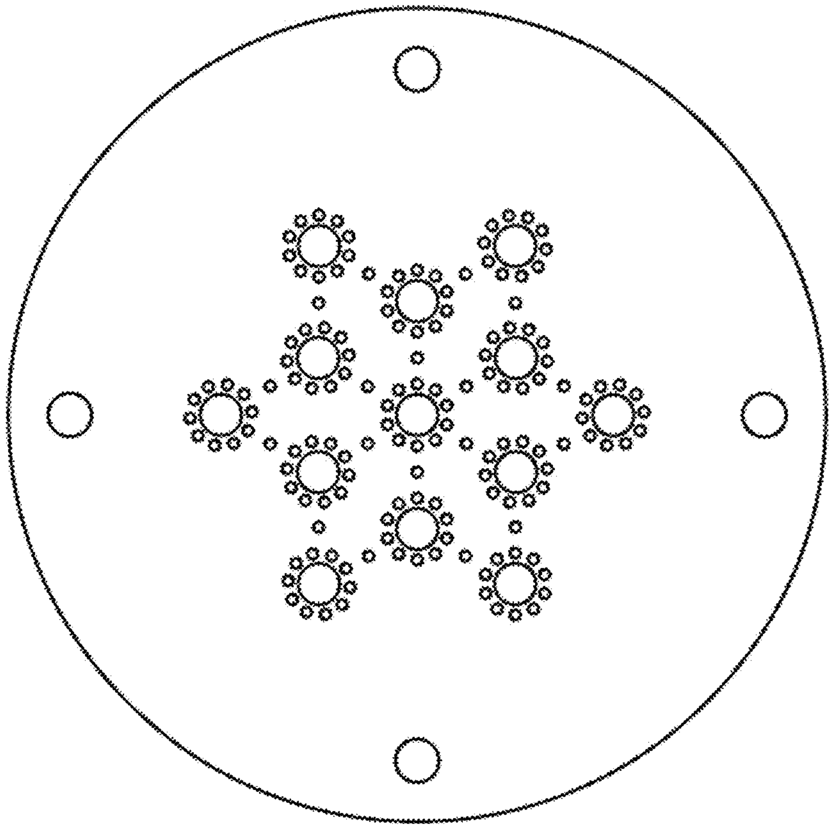


Figure 8C

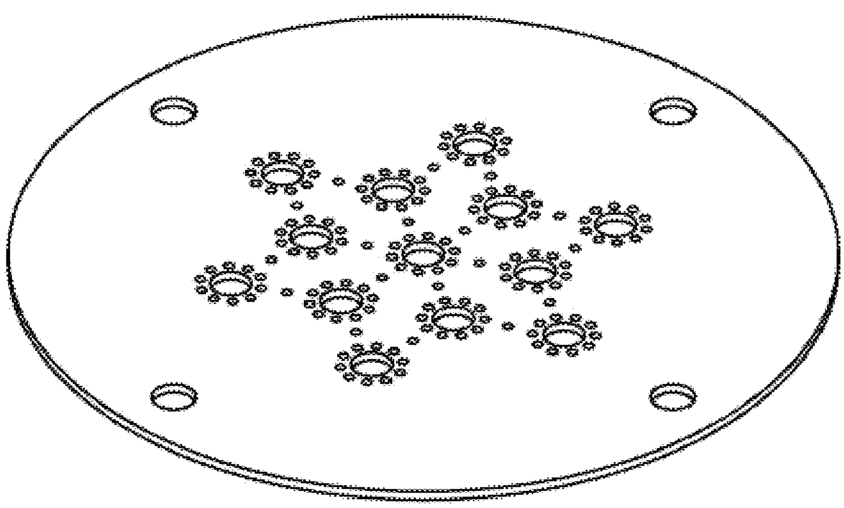


Figure 8D

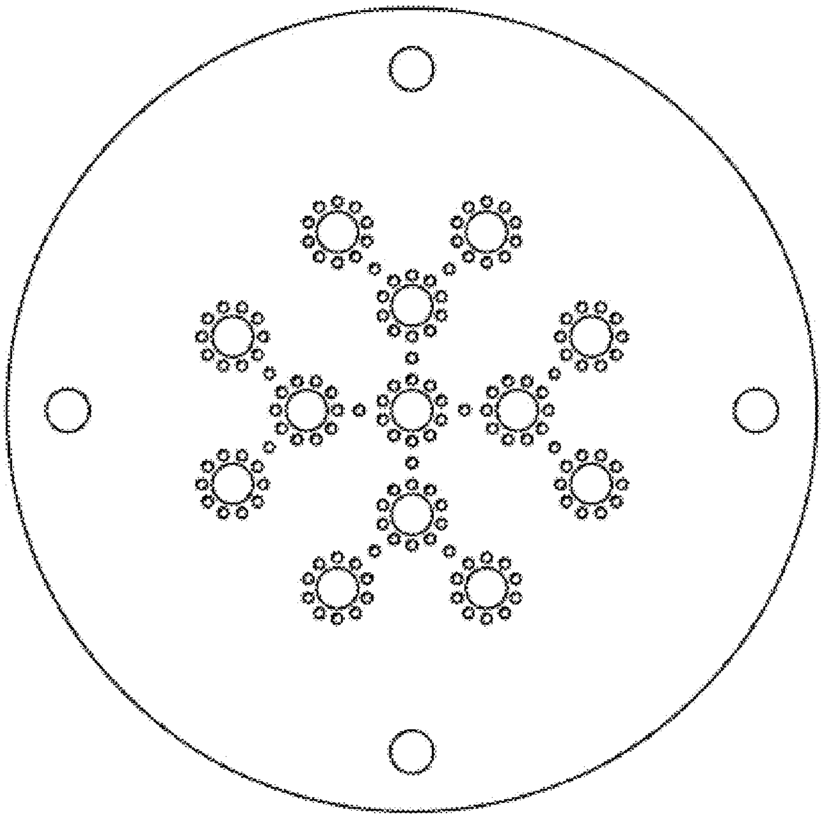


Figure 8E

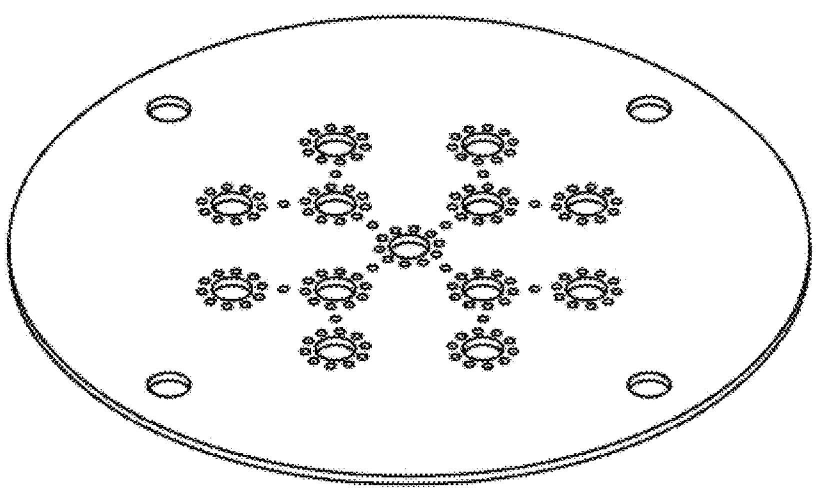


Figure 8F

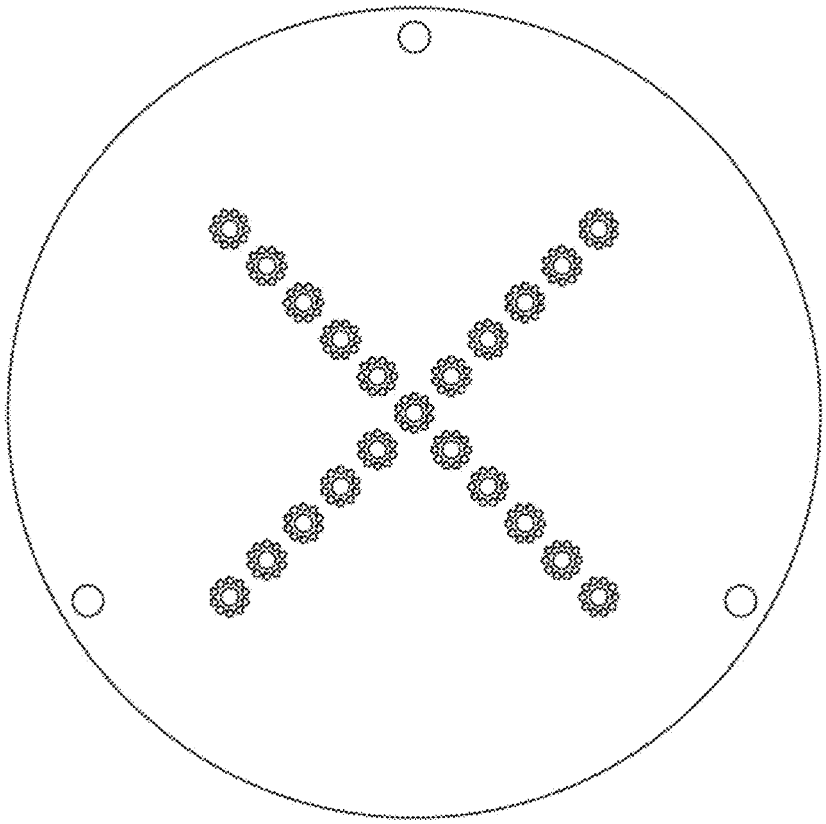


Figure 8G

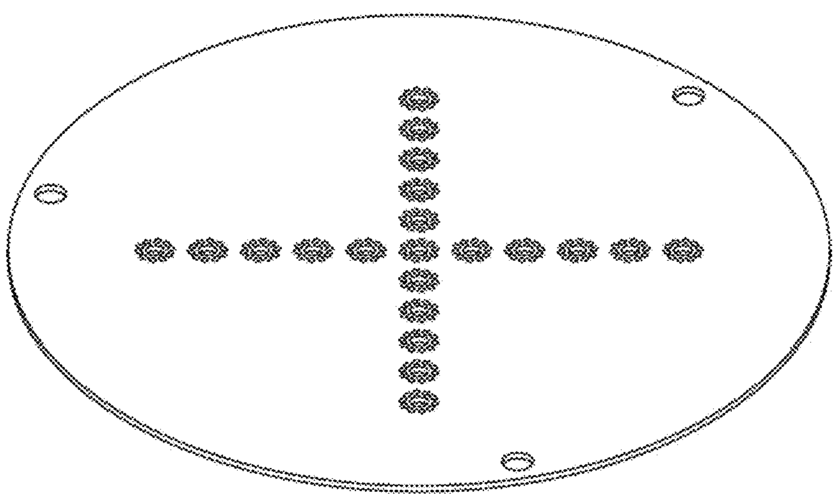


Figure 8H

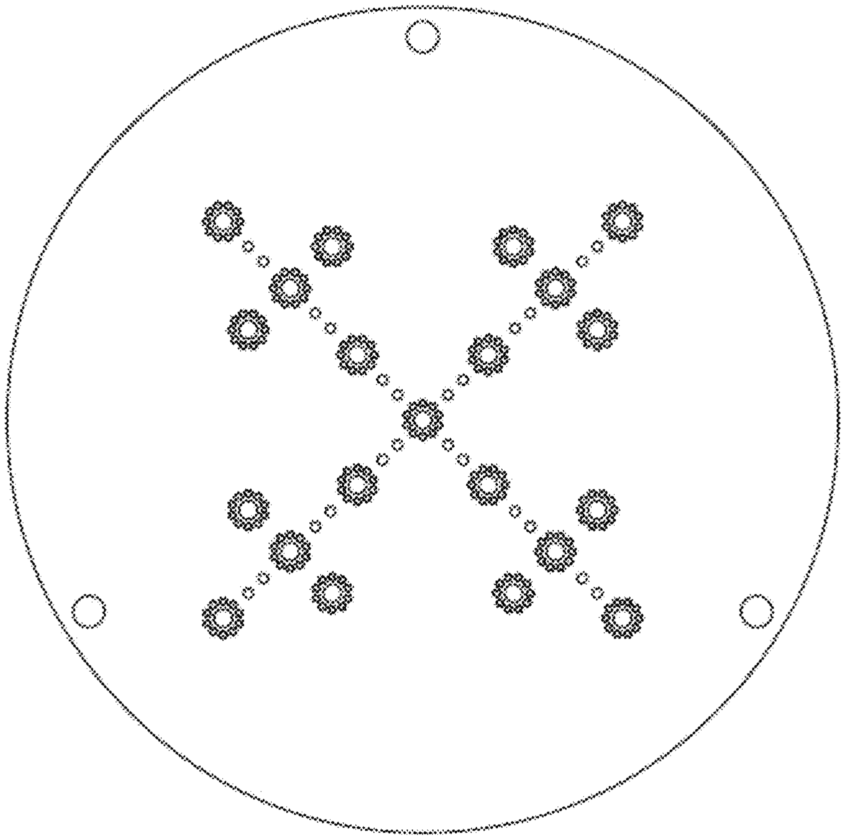


Figure 8I

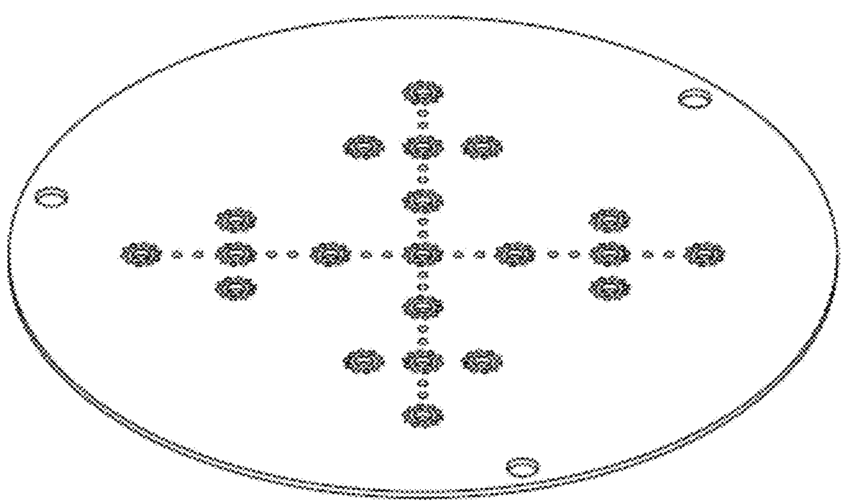


Figure 8J

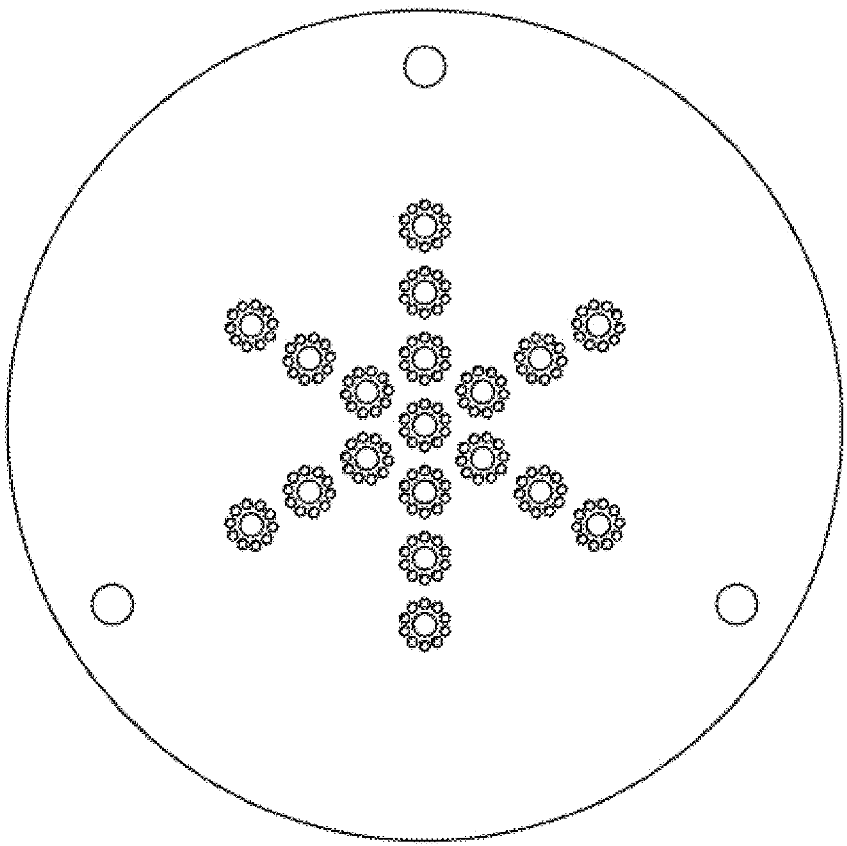


Figure 8K

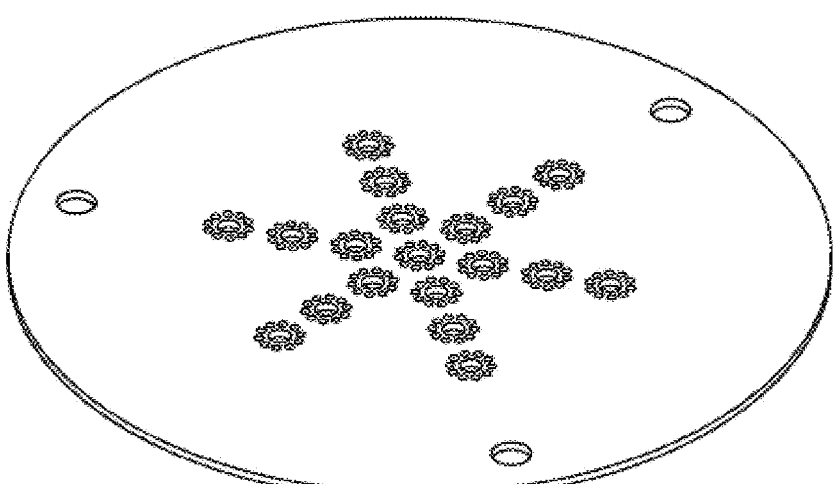


Figure 8L

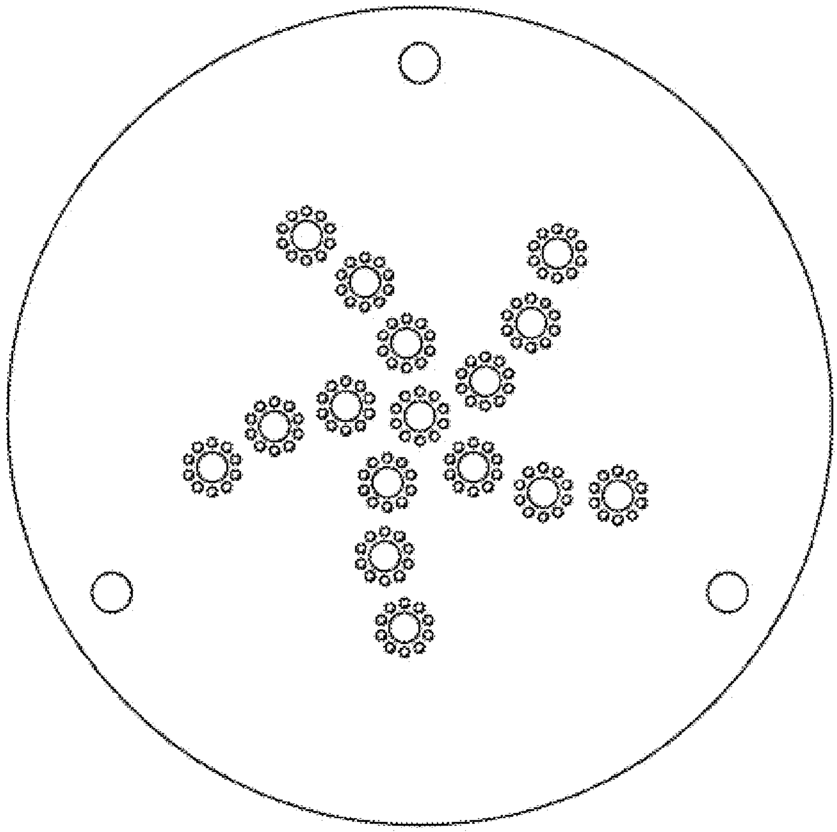


Figure 8M

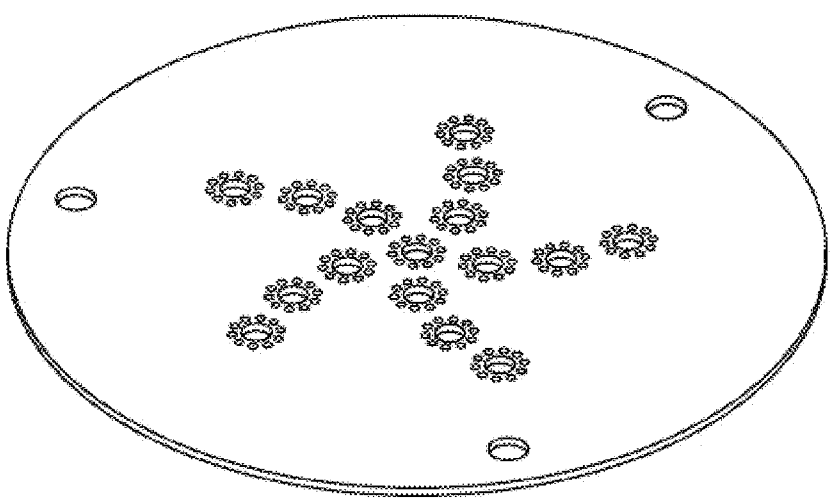


Figure 8N

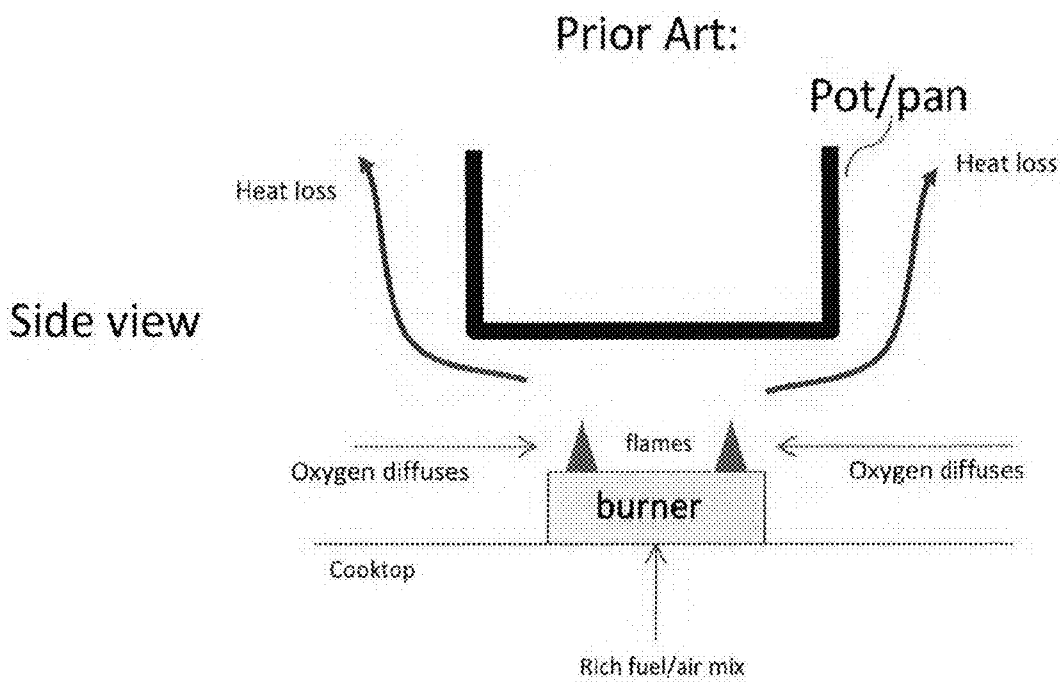


Figure 9A

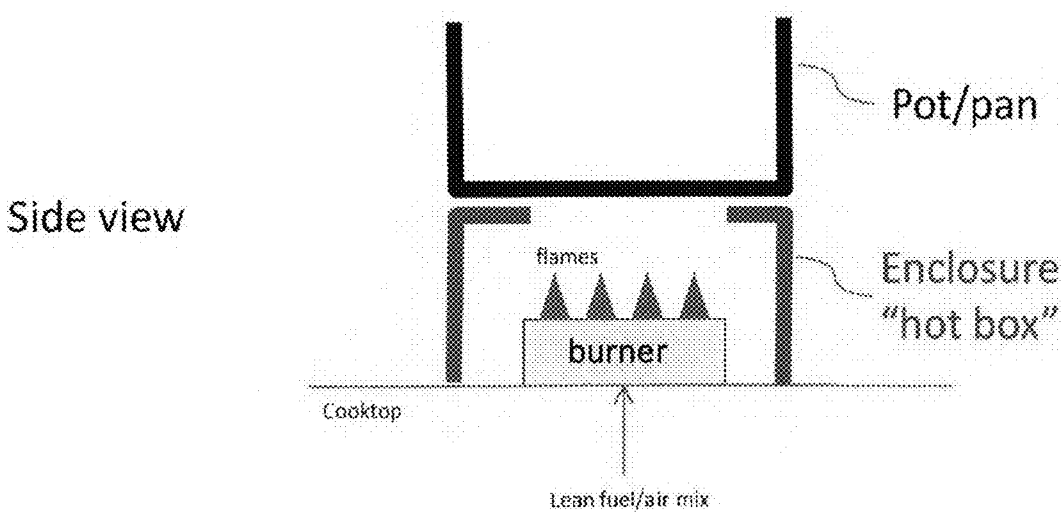


Figure 9B

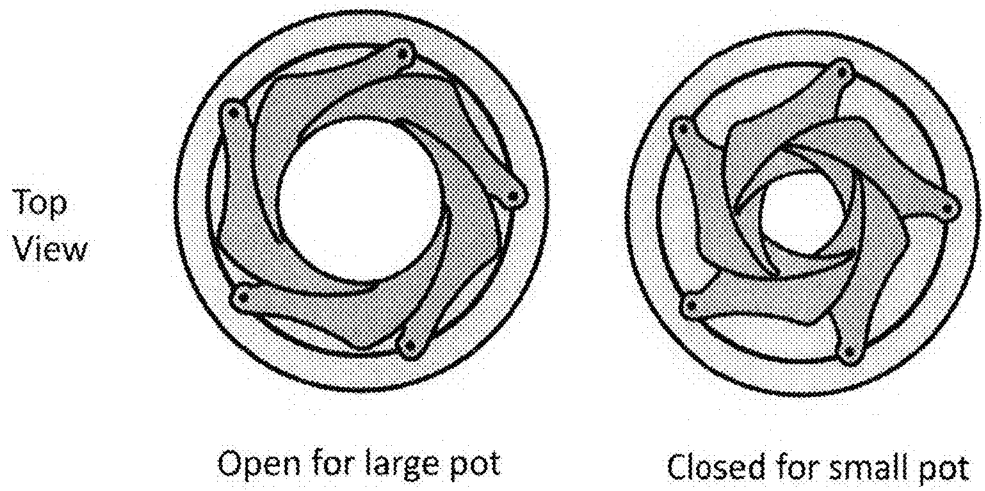


Figure 10A **Figure 10B**

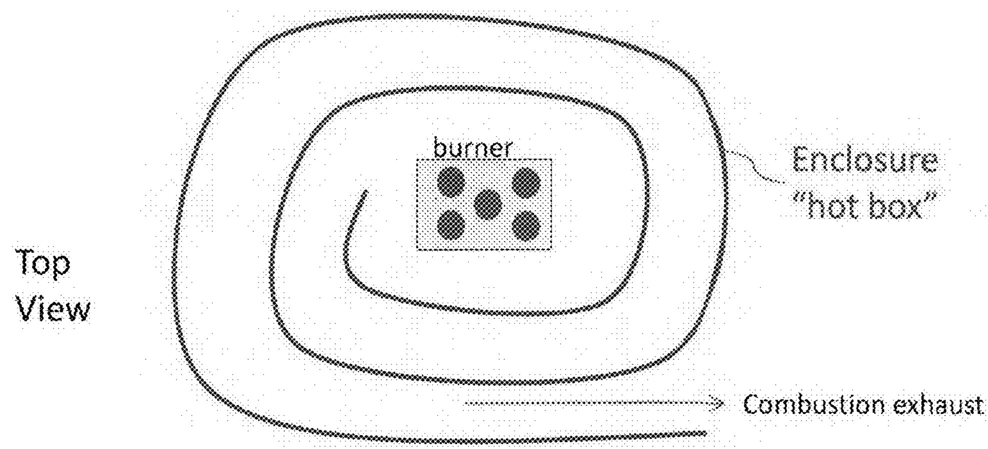


Figure 11

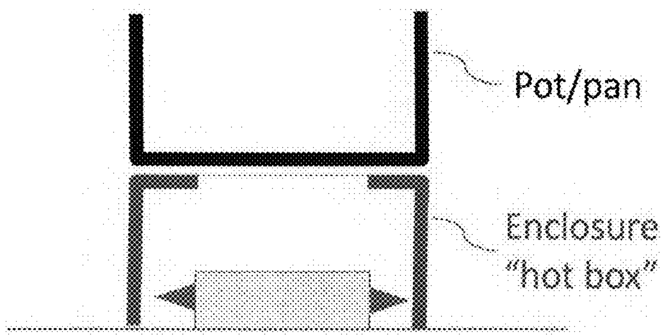


Figure 12A

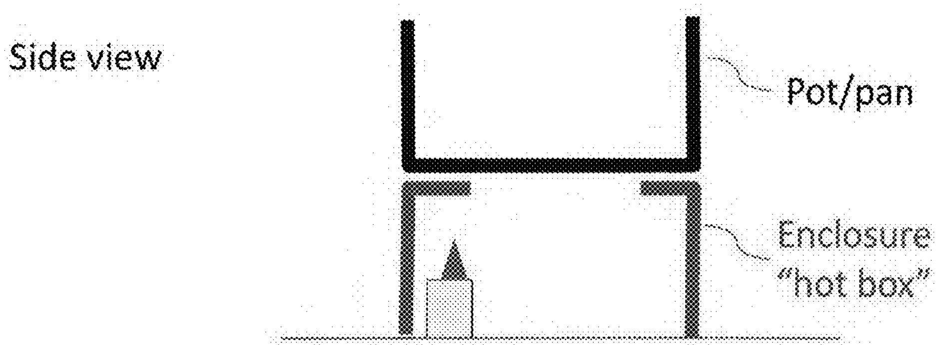


Figure 12B

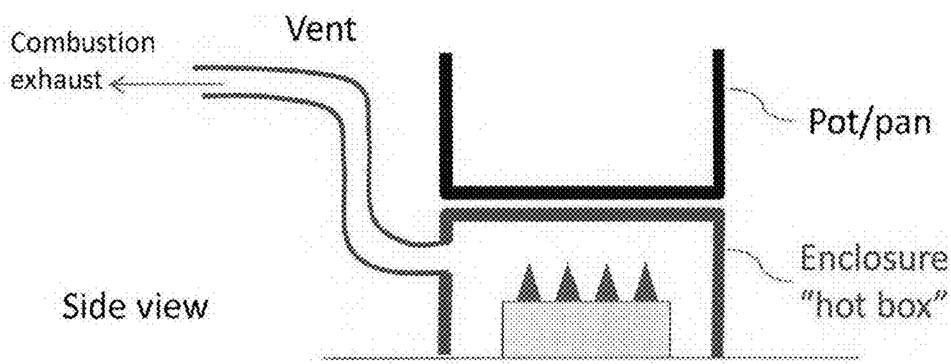


Figure 13

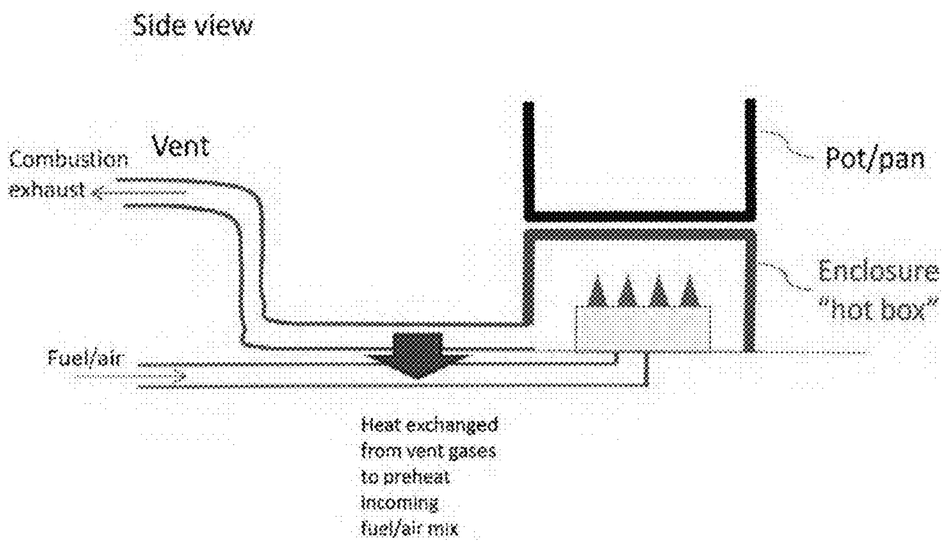


Figure 14

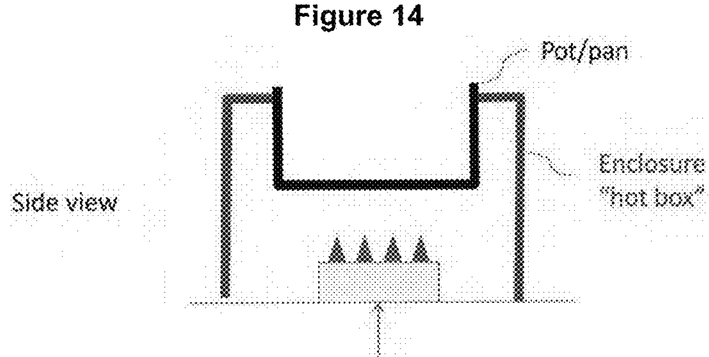


Figure 15

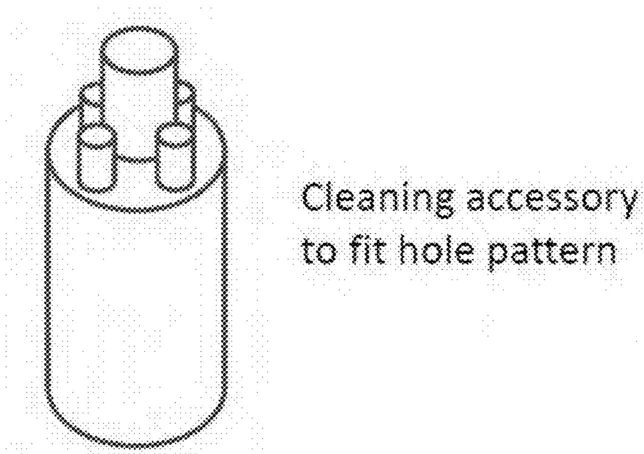


Figure 16A

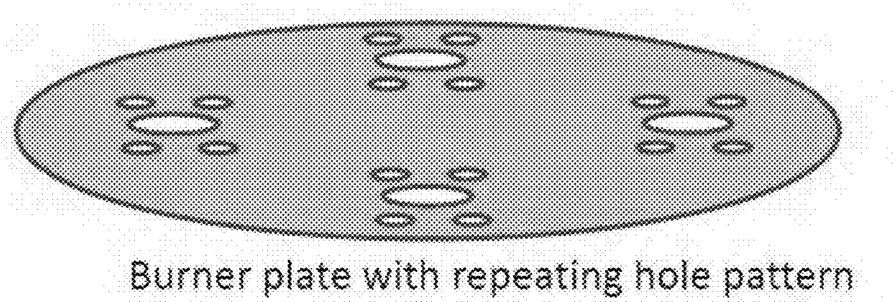
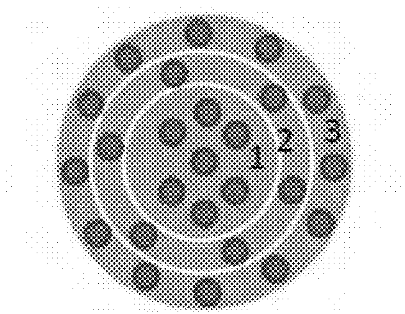


Figure 16B



Burner port sets 1,2,3, can be turned on/off independently

Figure 17

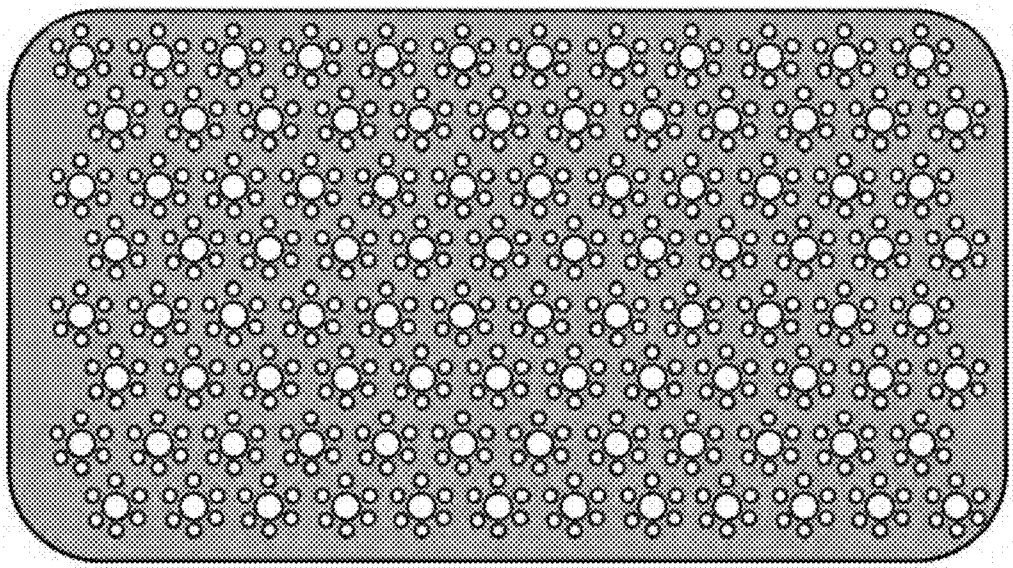
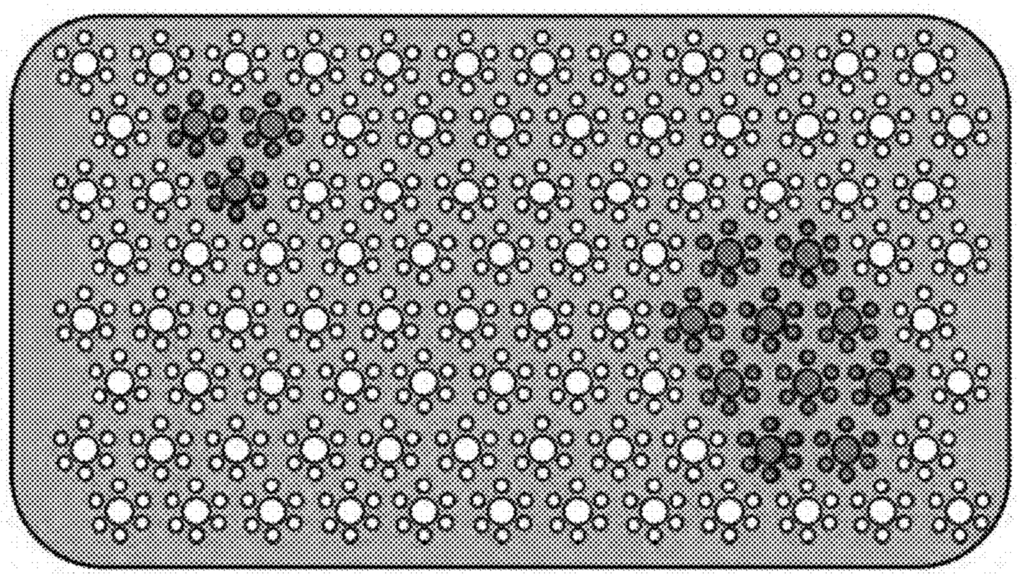


Figure 18A



Subsets ignited for a small pot (upper left) and larger pot (lower right)

Figure 18B

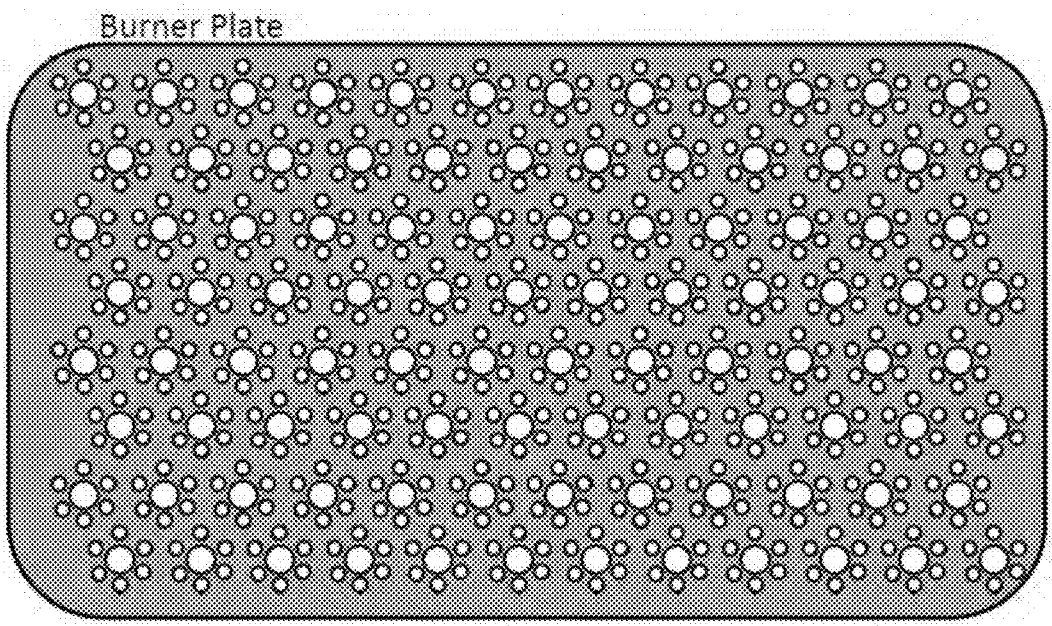


Figure 19A

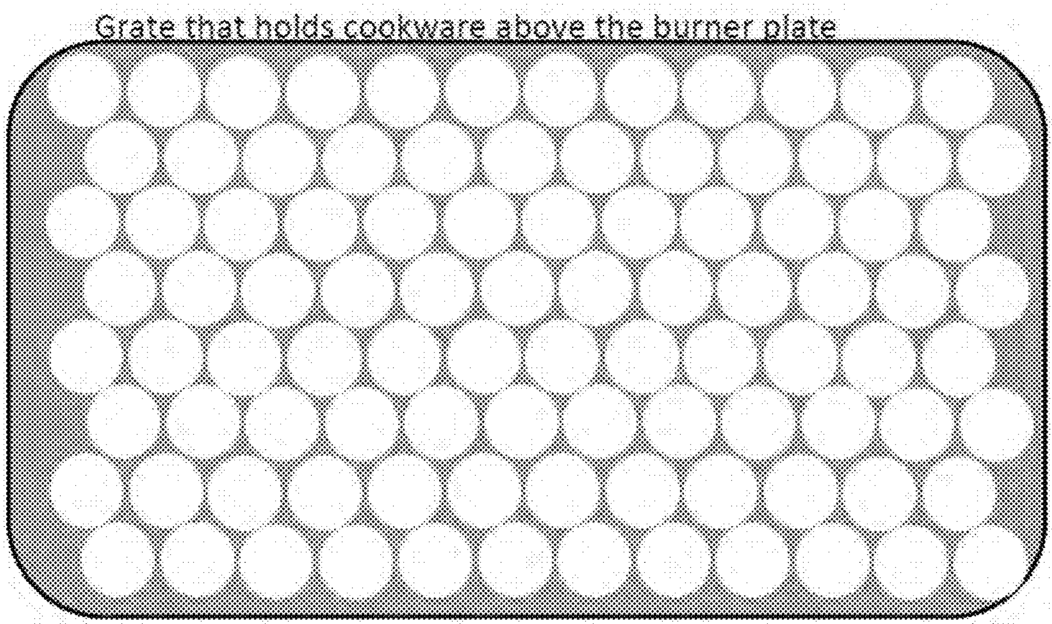


Figure 19B

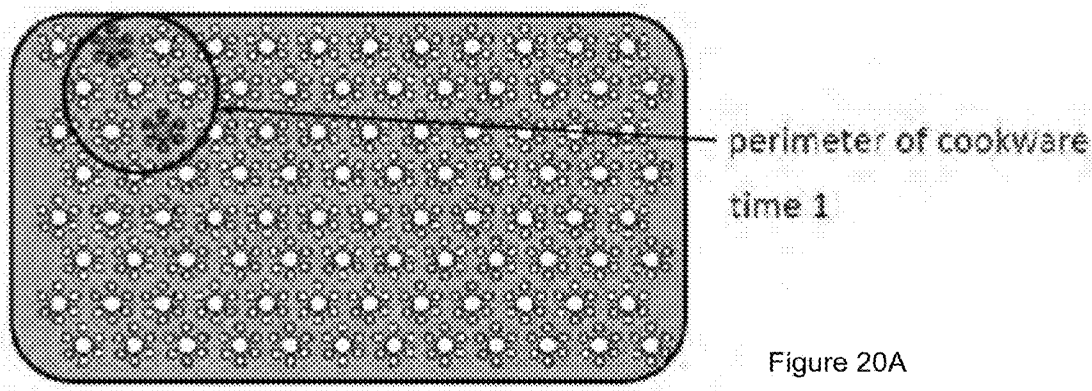


Figure 20A

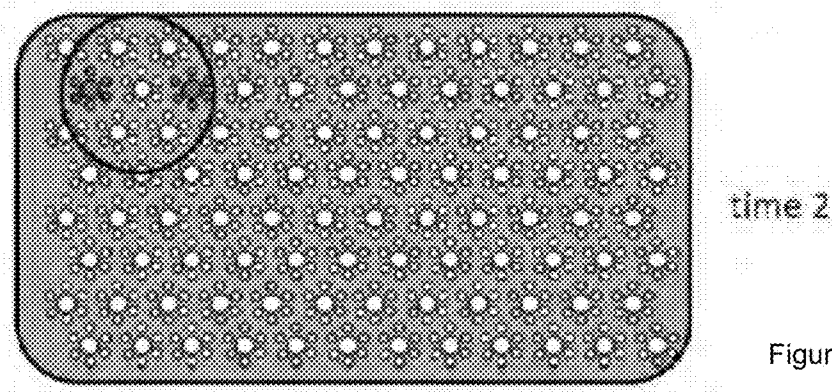


Figure 20B

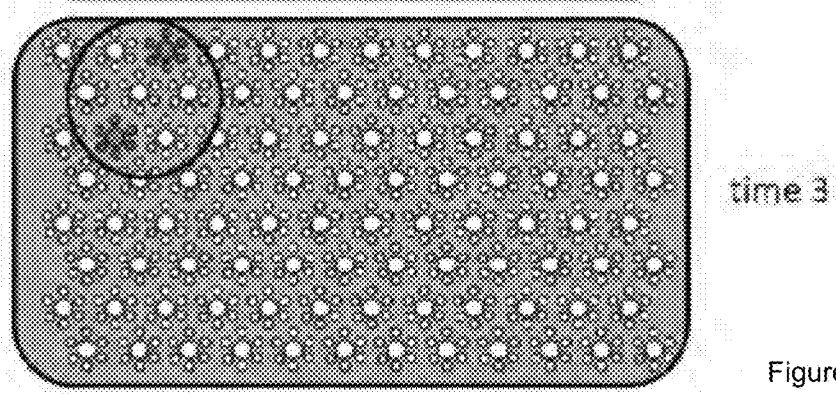


Figure 20C

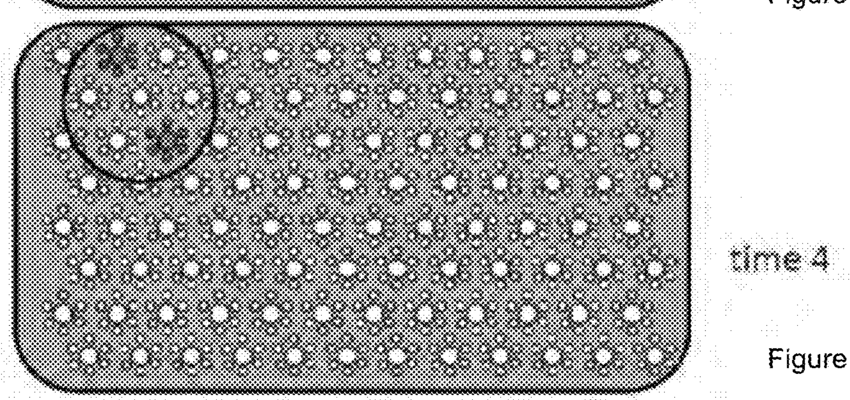


Figure 20D

Figure 21A

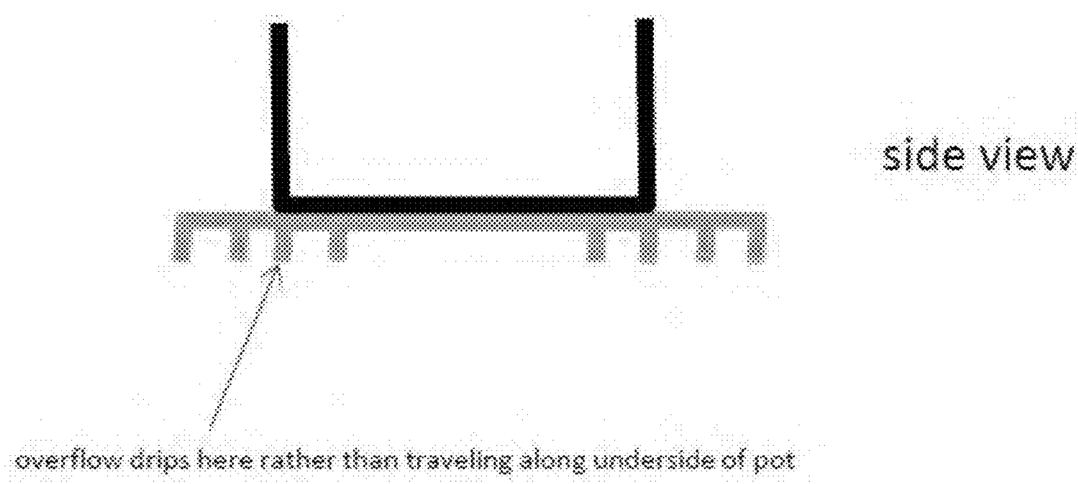
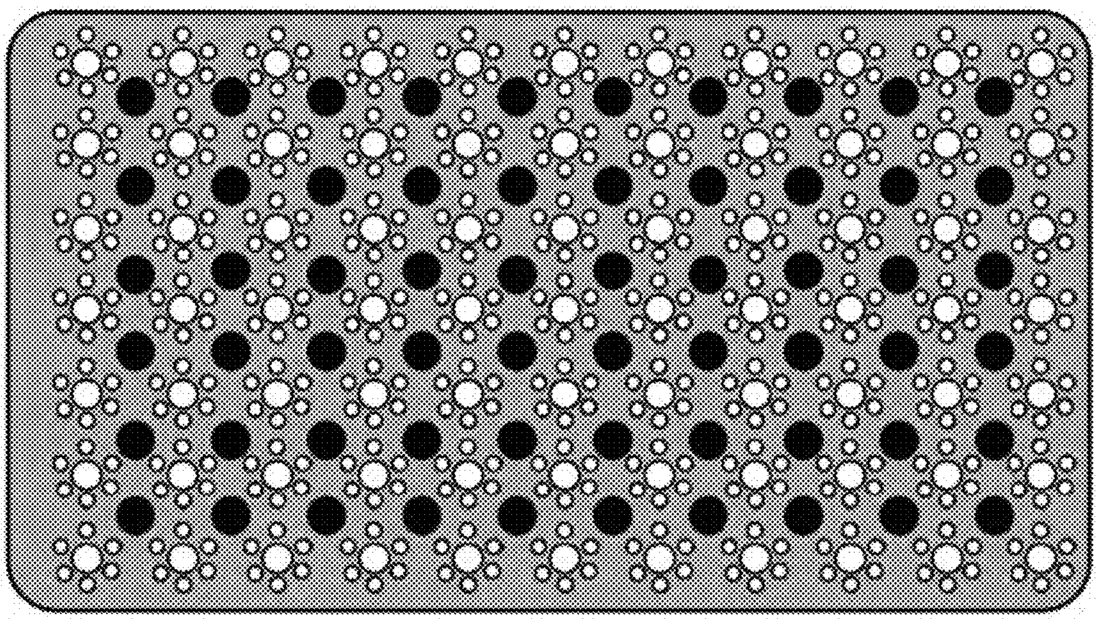


Figure 21B

Figure 22A



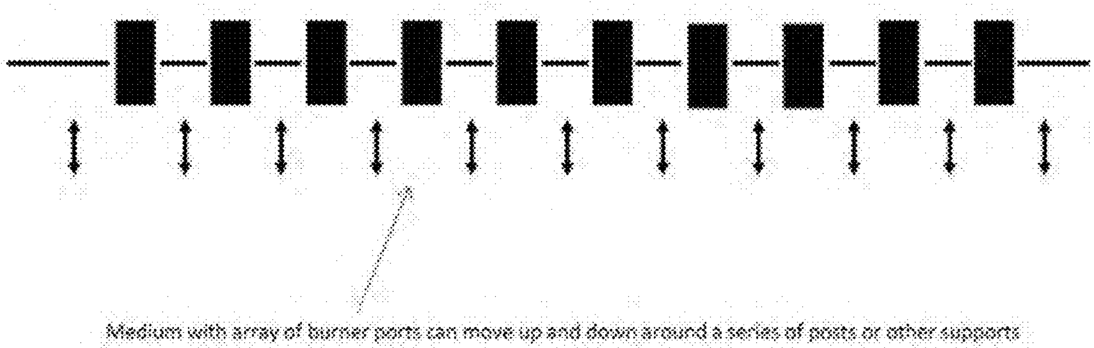


Figure 22B

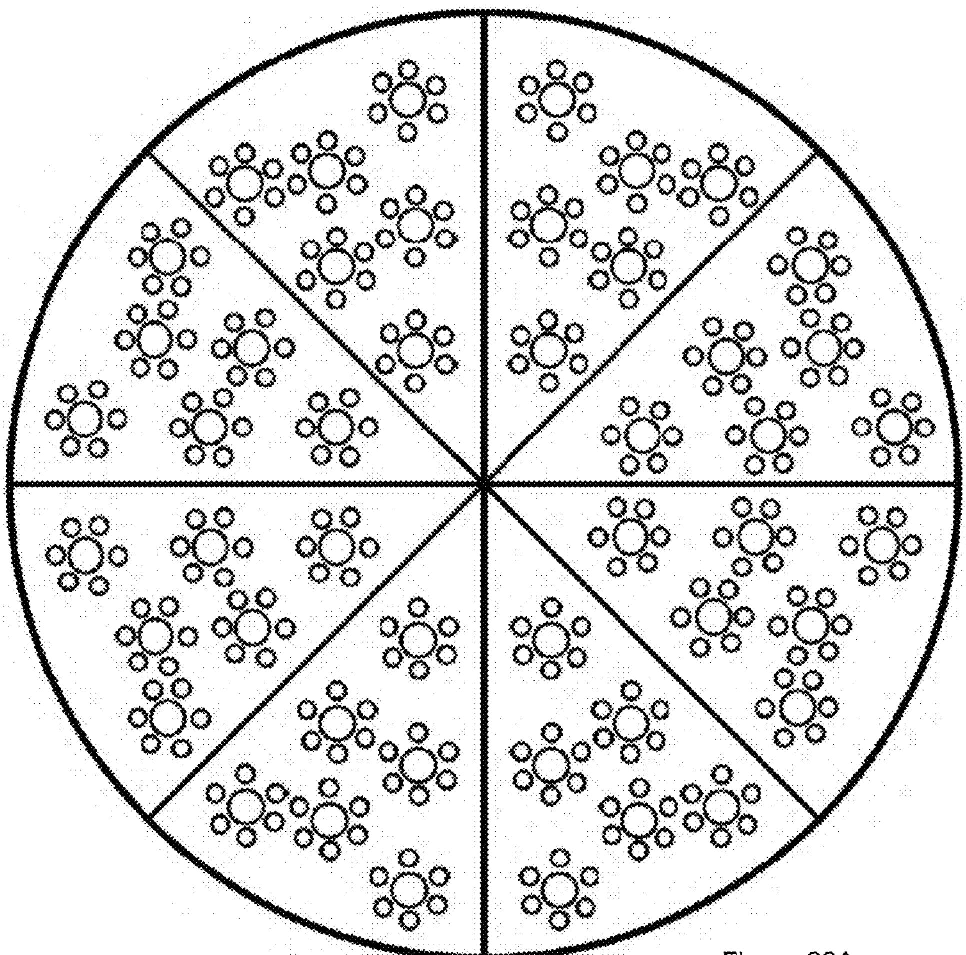


Figure 23A

Figure 23B

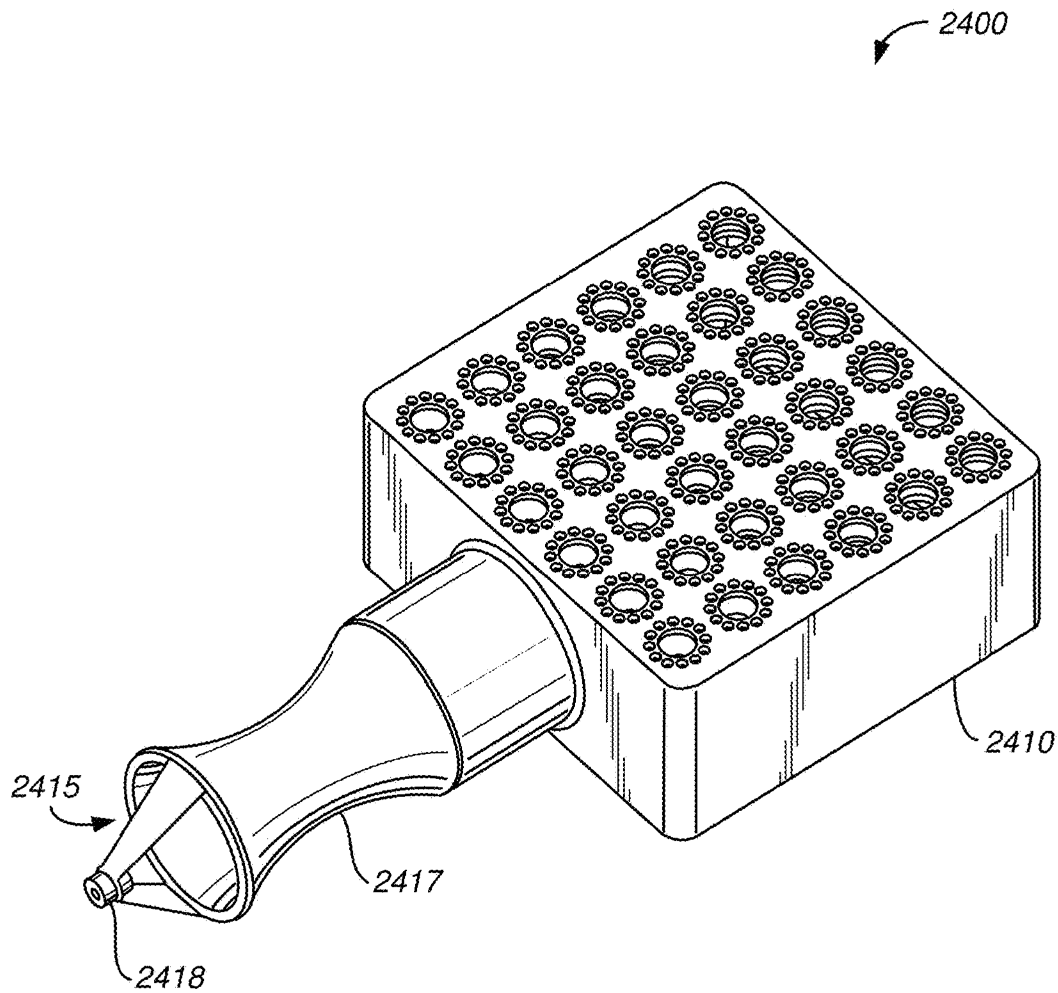


FIG. 24A

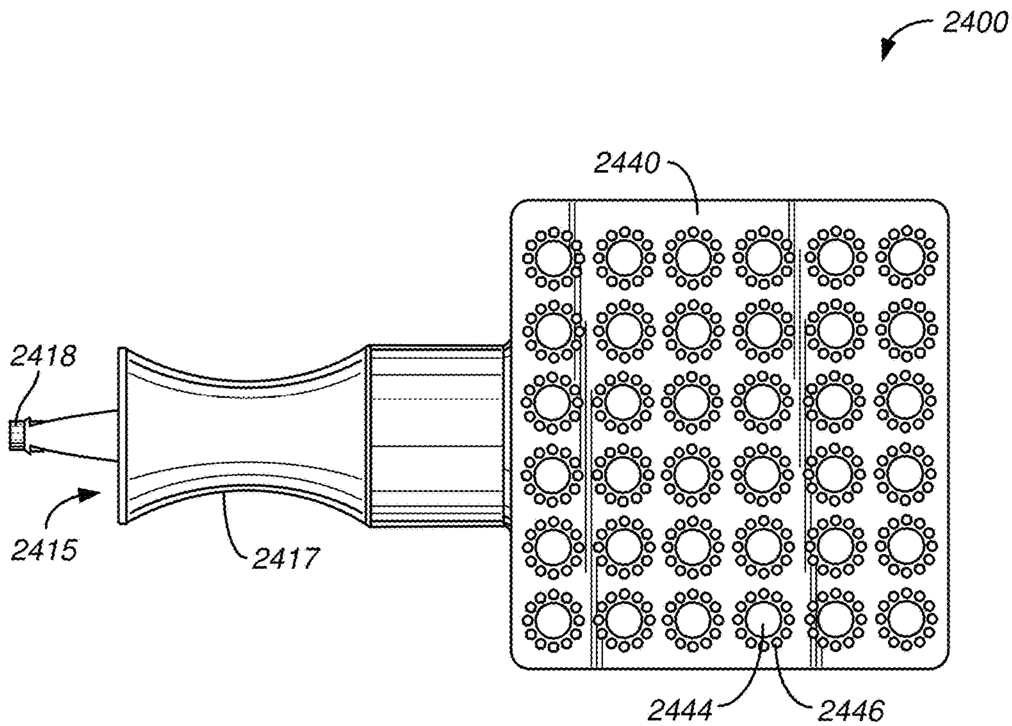


FIG. 24B

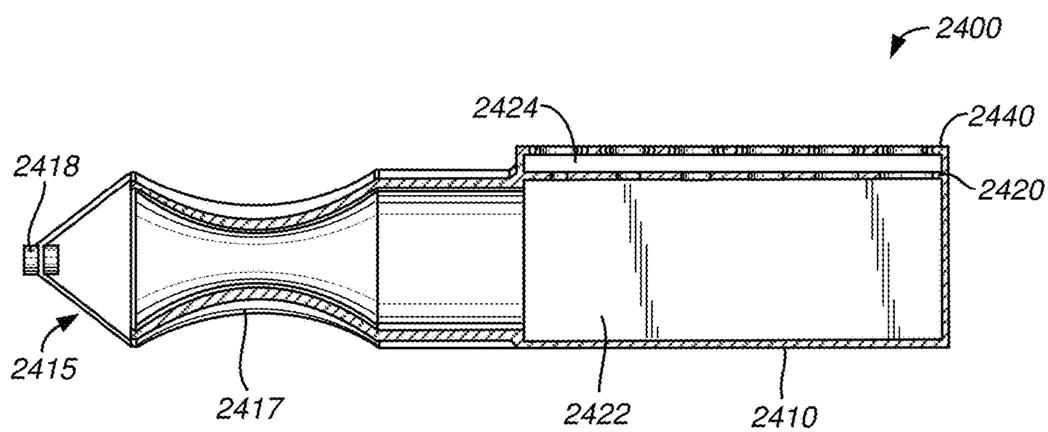


FIG. 24C

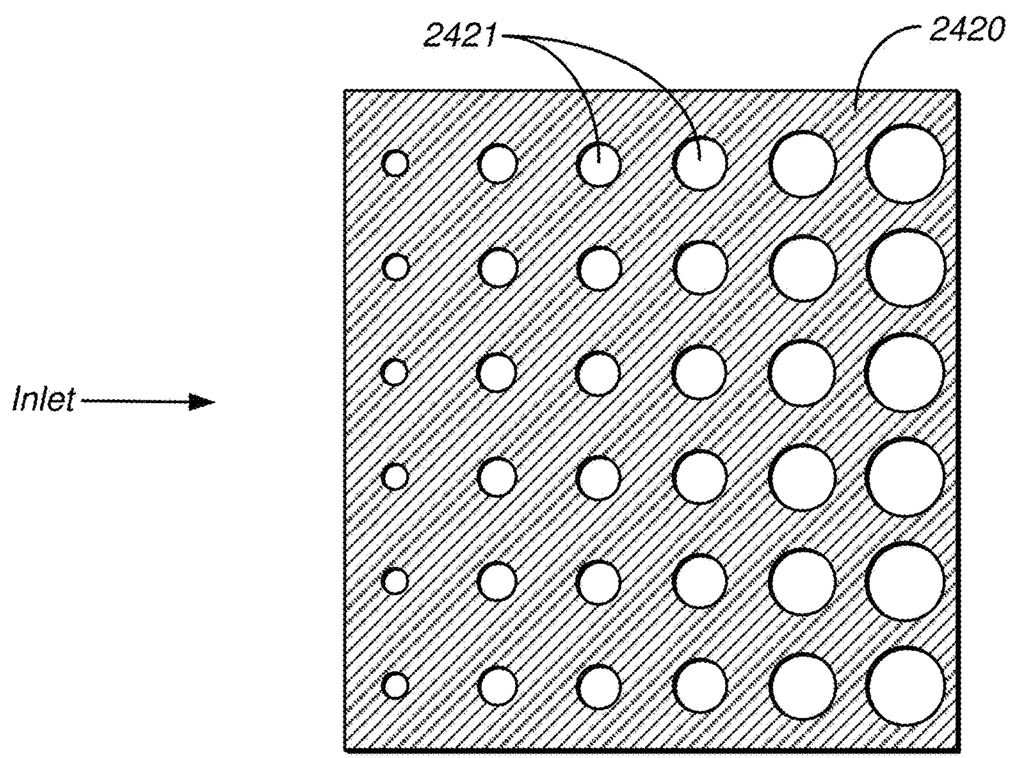


FIG. 24D

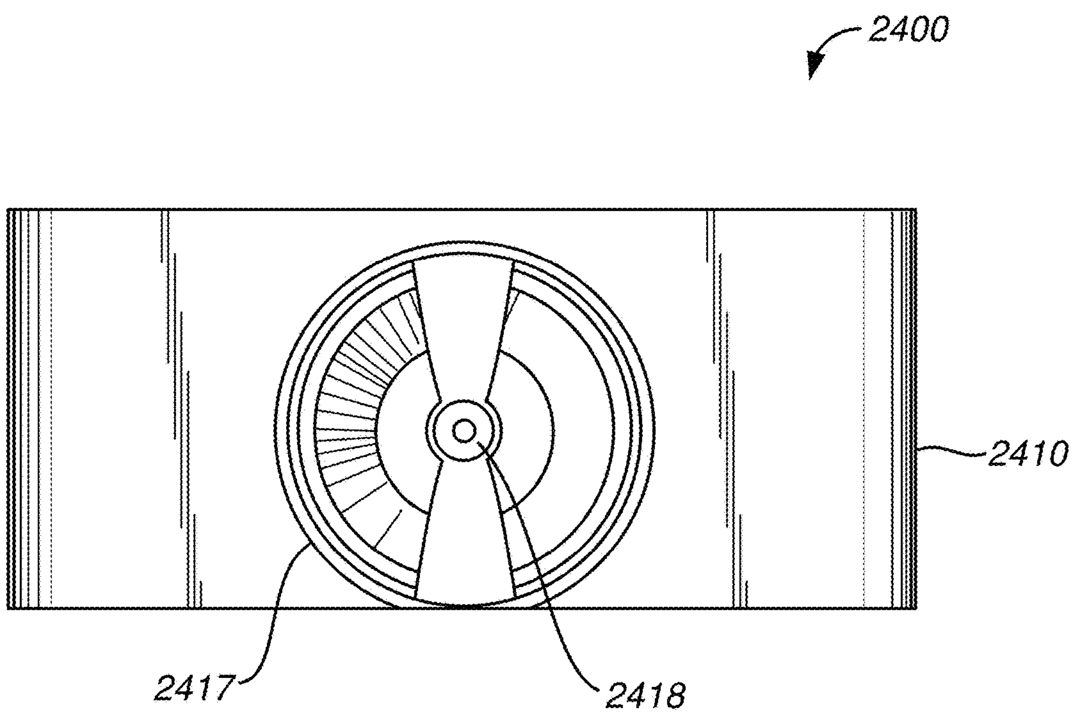


FIG. 24E

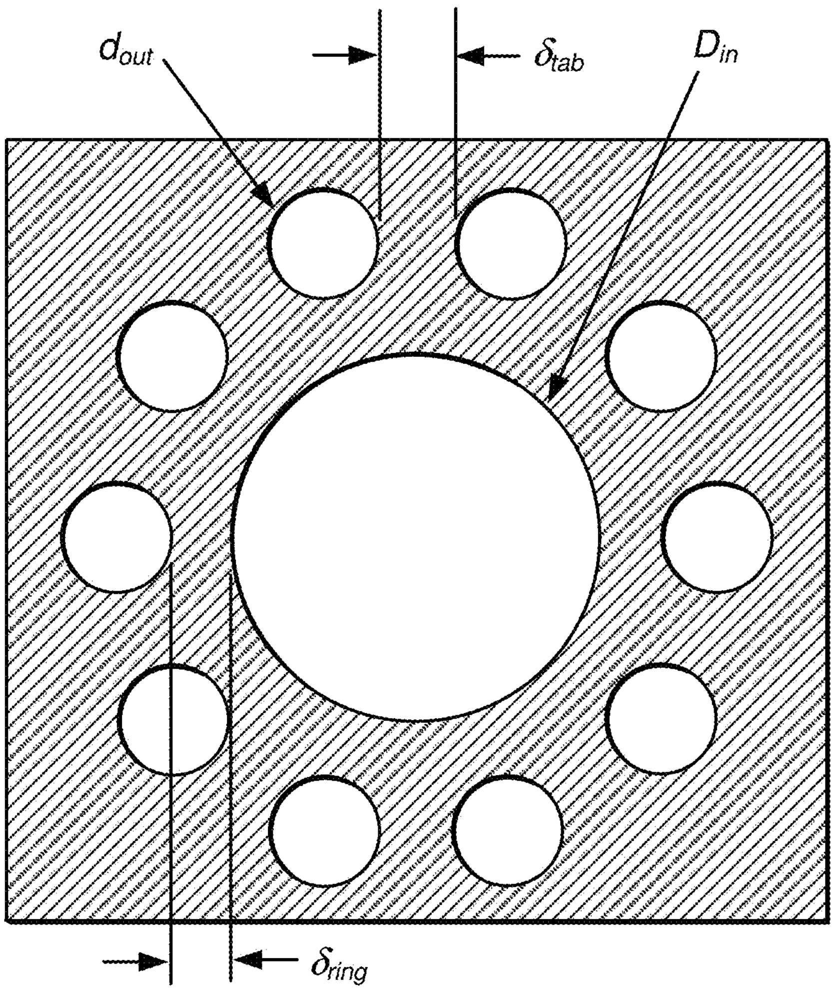


FIG. 24F

BURNER PLATES AND BURNER APPARATUS

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/239,804, filed Oct. 9, 2015, U.S. Provisional Patent Application No. 62/249,890, filed Nov. 2, 2015, U.S. Provisional Patent Application No. 62/329,938, filed Apr. 29, 2016, and PCT Application No. PCT/US2016/056301, filed Oct. 10, 2016, all of which are incorporated herein by reference. This application is a continuation-in-part of PCT Application No. PCT/US2016/056301.

STATEMENT OF GOVERNMENTAL SUPPORT

[0002] This invention was made with government support under Contract No. DE-AC02-05CH11231 awarded by the U.S. Department of Energy. The government has certain rights in this invention.

TECHNICAL FIELD

[0003] This disclosure relates generally to apparatus and methods for stably burning lean, premixed fuel/air mixtures.

BACKGROUND

[0004] There is a need to reduce indoor pollutant emissions and improve heat transfer from low velocity burners to equipment and processes needing heat. There is a need for an apparatus comprising a natural draft combustion system capable of stabilizing premixed flames at low velocities in order to significantly reduce criteria pollutant emissions.

[0005] Currently there is no natural draft, ultra-low emission burner that operates at low velocities. As an example, cooktop ranges utilize a partially premixed natural draft flame stabilizer; but because the fuel and air are only partially premixed, the emissions emitted by the flame are at levels unacceptable to the air quality goals of California, as well as being dangerous to human health in a home. Flames of current available technology are shown in FIGS. **1A-1C**. FIG. **2** shows an example of the ring burner technology.

[0006] Embodiments described herein are improvements over the invention of U.S. Pat. No. No. 5,516,280, issued May 14, 1996, which is herein incorporated by reference.

SUMMARY

[0007] Embodiments of the present invention provide an apparatus comprising a burner plate, a barrier, or both, and a method for burning a lean, premixed fuel/air mixture using the apparatus thereof.

[0008] Embodiments of the present invention provide a burner plate comprising one or a plurality of port groups, wherein each port group comprises a primary port surrounded by a plurality of secondary ports, and each port has a maximum linear distance from another port of about 0.125 inches. In some embodiments, each secondary port has a maximum linear distance from the primary port of about 0.125 inches. In some embodiments, all of the secondary ports are spaced from the primary port and/or each secondary port is equally spaced from a nearest adjacent secondary port.

[0009] In some embodiments, the lean, premixed fuel/air mixture has a low NO_x emission.

[0010] In some embodiments, each port group further comprises one or more sets of tertiary ports, wherein each set of tertiary ports surrounds an outside border of the plurality of secondary ports or an outside border of another set of tertiary ports, such that the plurality of secondary ports and the one or more sets of tertiary ports form a series of concentric rings around the primary port. In some embodiments, each port has a maximum linear distance from another port of about 0.125 inches. In some embodiments, each tertiary port has a maximum linear distance from a secondary port, or a tertiary port of another set of tertiary ports, of about 0.125 inches. In some embodiments, all of the tertiary ports of a set of tertiary ports are equally spaced from a secondary port or a tertiary port of another set of tertiary ports, and/or each tertiary port is equally spaced from a nearest adjacent tertiary port of the same set of tertiary ports. FIG. **17** shows an embodiment of a primary port surrounded by plurality of secondary ports, which in turn is surrounded by a set of tertiary ports.

[0011] Embodiments of the present invention provide a burner plate comprising one or a plurality of port groups, wherein each port group comprises a primary port surrounded by a plurality of secondary ports, and each port group has a maximum linear distance from another port group of about 0.125 inches. In some embodiments, the lean, premixed fuel/air mixture has a low NO_x emission. FIGS. **8A-8N** depict embodiments of the burner plate.

[0012] Embodiments of the present invention also provide an apparatus comprising a burner operating in free air to stably burn a premixed lean fuel/air mixture having a fuel/air equivalency ratio of less than unity to generate hot combustion products, and the burner plate of the present invention, the barrier of the present invention, or both, and optionally the apparatus does not contain a means to blow air and operates as a natural draft system.

[0013] Embodiments of the present invention also provide a barrier (or "hot box") designed or configured to create an enclosure between a lean, pre-mixed flame and a heating target, such that heat loss from the space is reduced or minimized, wherein the barrier is constructed from a non-combustible material.

[0014] Another innovative aspect of the subject matter described in this disclosure can be implemented in a method of burning a lean fuel/air mixture at substantially atmospheric pressure to generate hot combustion products comprising: (a) providing a lean fuel/air mixture having a fuel/air equivalency ratio of less than unity; (b) directing the lean fuel/air mixture in a stream, the stream having a direction of flow, and an extent in a plane perpendicular to the direction of flow; (c) mounting a burner plate of embodiments of the present invention in the stream of the fuel/air mixture to divide the stream into an inner portion and an outer portion having substantially similar flow velocities, through the primary ports and secondary ports respectively; and (d) igniting the stream of the lean fuel/air mixture at the eddies, whereafter the eddies recirculate a portion of the hot combustion products into the stream to continuously re-ignite the fuel/air mixture.

[0015] In some embodiments, the burner plate comprises a plurality of port group. In some embodiments, each port group comprises a primary port surrounded by a plurality of secondary ports. In some embodiments, each port group has a maximum linear distance from another port group of about 0.125 inches.

[0016] Another innovative aspect of the subject matter described in this disclosure can be implemented in a method of burning a lean fuel/air mixture at substantially atmospheric pressure to generate hot combustion products, comprising: (a) providing an apparatus comprising a burner operating in free air to stably burn a premixed lean fuel/air mixture having a fuel/air equivalency ratio of less than unity to generate hot combustion products, and (i) a burner plate comprising a plurality of port group, wherein each port group comprises a primary ports surrounded by a plurality of secondary ports, and each port group has a maximum linear distance from another port group of about 0.125 inches, or (ii) a barrier designed or configured to create an enclosure between a lean, pre-mixed flame and a heating target, such that heat loss from the space is reduced or minimized, wherein the barrier is constructed from a non-combustible material; (b) providing a lean fuel/air mixture to the apparatus; and (c) igniting the premixed lean fuel/air mixture to produce a lean, pre-mixed flame.

[0017] In some embodiments, the lean, premixed fuel/air mixture has a low NO_x emission. In some embodiments, the apparatus does not include a means to blow air and operates as a natural draft system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The foregoing aspects and others will be readily appreciated by the skilled artisan from the following description of illustrative embodiments when read in conjunction with the accompanying drawings.

[0019] FIGS. **1**A-**1**C show flames produced using currently available technology.

[0020] FIG. **2** shows an example of the ring burner technology.

[0021] FIGS. **3**A-**3**C show burner plates tested in Example 1 to determine port size.

[0022] FIG. **4** shows an experimental setup assembled to test various burner plates.

[0023] FIG. **5** shows the Forced Draft Test Results—Lean blowoff.

[0024] FIG. **6** shows the Forced Draft Test Results—Emissions (NO_x).

[0025] FIG. **7** shows the Forced Draft Test Results—Emissions (CO).

[0026] FIG. **8**A shows the plan view of one embodiment of a burner plate.

[0027] FIG. **8**B shows an isometric view of the embodiment of the burner plate depicted in FIG. **8**A.

[0028] FIG. **8**C shows the plan view of another embodiment of a burner plate.

[0029] FIG. **8**D shows an isometric view of the embodiment of the burner plate depicted in FIG. **8**C.

[0030] FIG. **8**E shows the plan view of another embodiment of a burner plate.

[0031] FIG. **8**F shows an isometric view of the embodiment of the burner plate depicted in FIG. **8**E.

[0032] FIG. **8**G shows the plan view of another embodiment of a burner plate.

[0033] FIG. **8**H shows an isometric view of the embodiment of the burner plate depicted in FIG. **8**G.

[0034] FIG. **8**I shows the plan view of another embodiment of a burner plate.

[0035] FIG. **8**J shows an isometric view of the embodiment of the burner plate depicted in FIG. **8**I.

[0036] FIG. **8**K shows the plan view of another embodiment of a burner plate.

[0037] FIG. **8**L shows an isometric view of the embodiment of the burner plate depicted in FIG. **8**K.

[0038] FIG. **8**M shows the plan view of another embodiment of a burner plate.

[0039] FIG. **8**N shows an isometric view of the embodiment of the burner plate depicted in FIG. **8**M.

[0040] FIG. **9**A shows an embodiment of a conventional cooktop, where a large portion of the heat is lost to the ambient air

[0041] FIG. **9**B shows an embodiment of the invention, where most of the heat is contained near the heat target, such as a cooking vessel, such as a pot or pan.

[0042] FIGS. **10**A and **10**B show one embodiment of an adjustable aperture on the top.

[0043] FIG. **11** shows an enclosure comprising a spiral wall.

[0044] FIG. **12**A shows one embodiment of one or a plurality of flames distributed across the heating area.

[0045] FIG. **12**B shows one embodiment of one or a plurality of flames distributed across the heating area.

[0046] FIG. **13** shows an enclosure connected to a vent that directly removes combustion gases from the enclosure or heating area.

[0047] FIG. **14** shows an enclosure comprising a heat exchanger to extract heat from the vented gases.

[0048] FIG. **15** shows an enclosure designed or configured to provide heat to the sides of the heat target.

[0049] FIG. **16**A shows an accessory for cleaning a specific pattern of a port group. FIG. **16**B shows a burner plate with a plurality of port groups with the specific pattern.

[0050] FIG. **17** shows an embodiment of a pattern of concentric rings of burner ports that can be turned on/off independently to fit the pot size or for more/less power.

[0051] FIGS. **18**A and **18**B show an array of burner ports that covers the majority of a burner plate, such as a cooktop, and can be turned on/off individually or as clusters so that the user or automated system can configure the fired area's shape, size, and pattern anywhere across the burner plate, and adjust it to the pot shape/size.

[0052] FIGS. **19**A and **19**B show an embodiment of a burner plate, and a corresponding grate for the burner plate. The grate has a flat top surface. In some embodiments, the grate has holes above each port group. Cookware, such as pots, can move seamlessly across the entire grate top surface, and the flames from each port group can reach the cookware without being blocked by the grate. In some embodiments, the grate is made of any material including those that allow it to be translucent or transparent, such as glass or ceramic, for visual access to the flames.

[0053] FIGS. **20**A-**20**D show an embodiment of a burner plate wherein different combinations of port groups can be turned on to produce flame, such that more than one port group heats a cookware. A combination of port groups can be alternated so that a temporal pattern of flames is produced, such that one or more port groups are on while the rest of the port groups are off.

[0054] FIGS. **21**A and **21**B show an embodiment of a grate comprising a plurality of concentric rings that extend down below a cookware/grate interface. These rings provide a dripline so any liquid which overflows from a cookware does not migrate to under the center of the cookware. The rings help keep burner ports under the cookware lit even if liquid drips down the sides of the cookware.

[0055] FIGS. **22**A and **22**B show a series of posts or other stands that support cookware. Material with an array or singular burner ports that can be moved up and down such that the distance between the cookware supported by the posts or other stands and the burner ports is varied.

[0056] FIGS. **23**A and **23**B show a burner plate with a singular or array of burner ports that is angled such that liquid or other materials will roll or run off and drain away.

[0057] FIGS. **24**A-**24**F show examples of illustrations of a burner apparatus.

DETAILED DESCRIPTION

[0058] Before the invention is described in detail, it is to be understood that, unless otherwise indicated, this invention is not limited to particular processes, as such may vary. It is also to be understood that the terminology used herein is for purposes of describing particular embodiments only, and is not intended to be limiting.

[0059] As used in the specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to a "port" includes a single port as well as a plurality of ports, either the same size or different sizes.

[0060] The term "about" refers to a value including 10% more than the stated value and 10% less than the stated value.

[0061] In this specification and in the claims that follow, reference will be made to a number of terms that shall be defined to have the following meanings:

[0062] The terms "optional" or "optionally" as used herein mean that the subsequently described feature or structure may or may not be present, or that the subsequently described event or circumstance may or may not occur, and that the description includes instances where a particular feature or structure is present and instances where the feature or structure is absent, or instances where the event or circumstance occurs and instances where it does not.

[0063] The term "cooktop" as used herein means cooktop, range top, or other open-flame or covered-flame cooking device with one, multiple, or continuous burner areas.

Burner Plate Embodiments

[0064] In some embodiments, the primary and secondary ports defined in a burner plate have a circular shape or an oval shape, or a shape having no sharp corners or acute angles (i.e., a shape having curved boundaries). In some embodiments, the number of port groups defined in a burner plate is 2 or more, 3 or more, 4 or more, 5 or more, 6 or more, 7 or more, 8 or more, or 9 or more. In some embodiments, the primary port has a diameter ranging from equal to or more than about 0.375 inches to equal to or less than about 0.4375 inches. In some embodiments, a secondary port has a diameter ranging from equal to or more than about 15% to equal to or less than about 25% of the diameter of the primary port to which the secondary port is grouped. In some embodiments, within a port group, the length between the primary port to each secondary port is about 12.5% of the diameter of the primary port, a value ranging from equal to or more than about 0.03 inches to equal to or less than about 0.06 inches, a value ranging from equal to or more than about 0.035 inches to equal to or less than about 0.055 inches, or a value ranging from equal to or more than about 0.04 inches to equal to or less than about 0.05 inches, or a value about 0.045 inches.

[0065] In some embodiments, the port groups defined in the burner plate are arranged in a pattern that has an at least 1-, 2-, 3-, 4-, 5-, or 6-fold reflectional symmetry. In some embodiments, the port groups on the burner plate are arranged in a pattern that has an at least 1-, 2-, 3-, 4-, 5-, or 6-fold rotational symmetry. In some embodiments, the burner plate has a uniform thickness in the portions wherein the port groups are located. In some embodiments, the uniform thickness is from about 0.3 millimeters (mm) to about 10 mm

[0066] The apparatus can be configured to operate as a forced draft combustion system, or as a "natural draft" system. In some embodiments, the natural draft combustion system comprises a flow of one fluid, such as a compressed fuel (such a natural gas or propane gas) to entrain another fluid (such as ambient air) before both fluids enter the combustion burner and reaction zone. Forced air is used to increase the velocity of the reactants (fuel and air) prior to combustion. High velocity flows create flames that are easier to stabilize than low velocity flows. In some embodiments, the system utilizes a pressurized flow of gaseous fuel to entrain and mix with ambient air with the same combustion stability mechanism and operate at low velocities. For example, the size of a ring burner can be scaled (i.e., the size can be increased or decreased) and a forced draft configuration can be used to enhance stability. In some embodiments, natural draft rather than forced draft can be used for low velocity flows. Low emission premixed (fuel and air mixed before the burner) burners like the ring burner are by and large operated in forced draft mode. One application of this technology is residential and commercial cooktops (ranges). Other application include water heaters and furnaces. While burners on these appliances are natural draft and operate at low velocities, they are not fully premixed and as a result emit large amounts of harmful pollutants. The perfectly premixed fuel and air stabilized by the ring burner will significantly (>50%) reduce these pollutants. Additionally, the method of flame stabilization used by the incumbent burner technology creates a series of small flamelets that do not evenly heat food. The ring burner allows for natural draft operation at low velocities while maximizing flame surface area that promotes even cooking.

[0067] Embodiments of the present invention allow for the stable operation of a fully premixed flame at low velocities while producing ultra-low emissions. In some embodiments, the apparatus does not have or need an air blower, or is not configured to require an air blower. The apparatus is useful for the operation of low velocity burners without the need for energy consuming air blowers, thereby increasing system efficiency with maintaining low emissions.

[0068] The natural draft ring burner is made possible by using advanced fluid dynamics techniques to entrain ambient air with pressurized fuel. The coupling of the air entrainment with the ring burner technology requires advanced engineering work and innovation to ensure the premixed flow enters the ring burner in a way that the burner can stabilize the flame.

[0069] Embodiments of the present invention include improvements over the ring stabilizer idea that uses geometry changes (ring stabilizers to hole stabilizers) and integration with a fuel venturi to enable natural draft operation while improving combustion efficiency, minimizing pollutant formation, increasing multi-burner design potential, and improving system stability at low Reynolds number operation. This development occurred as a result of the adaptation of the forced draft ring stabilizer to natural draft operation (see Examples). The ring stabilizer geometry was determined not to provide the optimal geometry. The new burner reduces the amount of unburned fuel emitted by the burner at high load and is cheaper to manufacture than either the ring stabilizer or other lean premixed low Reynolds number burners. One aspect of the new burner is the small satellite holes (i.e. the secondary ports) that surround a primary fuel/air hole (i.e. the primary port). These satellite holes anchor the flame of the main hole in a more efficient way than the previous ring burner did. The satellite holes also allow for more distributed arrays of the burner to be made. The primary target application for this technology is for residential and commercial heating (e.g., cook tops, air heaters, water heaters, and ovens) and the application of industrial process heating.

[0070] Embodiments of the present invention also provide an apparatus comprising protrusions that fit the ports of a port group. The apparatus can be an accessory of a burner plate. The apparatus is used to clean the hole pattern of a port group when food, or any matter, gets stuck in it. The protrusion can be solid, or comprise a wire brush, push rod, or the like, optionally with multiple parts that fit into each hole in the burner pattern. FIG. **16**A shows an accessory for cleaning a specific pattern of a port group. FIG. **16**B shows a burner plate with a plurality of port groups with the specific pattern.

[0071] In some embodiments, the port groups comprise one or more concentric rings of burner ports that can be turned on/off as needed to fit the pot size or for more/less power. Each ring may or may not have its own fuel supply system. FIG. **17** shows such an example.

[0072] In some embodiments, the burner plate is disposable. For example, when the burner plate is dirty, the user can throw it away.

[0073] In some embodiments, the burner plate is sized/shaped as desired and optionally coated so that it can be washed by a dishwasher and is dishwasher wash.

[0074] In some embodiments, the burner plate comprises wall-to-wall burner ports that cover entire burner plate, or cooktop, wherein optionally each port group can be turned on/off individually or as clusters so that the user can configure a desired flame pattern anywhere across the cooktop, and adjust it to the cookware shape/size. A screen or touchpad can be used that identifies where the cookware is and allows high/low heat, cook-time, or other user commands, such that where the cookware is to be placed is not limited by a pre-determined factory-placement of a burner. The user can configure the burner pattern, heat, and other operation (including selected on/off pulse operation) as needed for each cooking session. FIGS. **18**A and **18**B show such an example.

[0075] In some embodiments, the burner plate is coated with enamel, glass, ceramic, or other coating to enable easy cleaning. In some embodiments, the burner plate is made of material capable of sustaining a high temperature without melting, such as cast iron, steel, ceramic, glass, or the like.

[0076] In some embodiments, the burner plate has a corresponding grate for cookware that is a single flat surface, and has holes above each burner port. Each cookware, such as a pot, can move seamlessly across the entire cooktop surface, and the flame can reach the cookware without being blocked by the grate. The grate is made of any material including those that allow it to be translucent or transparent, such as glass or ceramic for visual access to the flames. FIGS. **19**A and **19**B show such an example.

[0077] In some embodiments, a cooktop comprising the burner plate can comprise one or more of the features described herein. Sensors (IR, camera, weight, or the like) can determine where a cookware, such as a pot, is and light the associated burner ports. Optionally, the sensors can also detect hands, handles and other non-cookware items for safety. A grate for cookware comprising a single flat surface, and has holes above each burner port, wherein a subset of the flames (or a single flame) can be on, and the rest are off, such that the ones that are on can circulate around to intermittently warm the bottom of the pan (like doing the "wave"). The subset that is on can vary with time or is intermittent, such that a pattern of flames can move across or around the cooktop. The subset can circulate around or randomly turn on and off around to intermittently warm various sections of the bottom of the cookware. FIGS. **20**A-**20**D show such an example.

[0078] In some embodiments, the grate has concentric rings that extend down below the cookware/grate interface. These rings can provide a dripline so that liquid which overflows from the cookware does not migrate to under the center of the cookware. This helps keep burner ports under the cookware lit even if liquid drips down the sides of the cookware. FIGS. **21**A and **21**B show such an example.

[0079] In some embodiments, the burner plate can have a plate disposed below the burner plate comprising an array of holes such that it can be rotated to expose fuel flow to different subsets of ports in the burner plate.

[0080] FIGS. **22**A and **22**B show a series of posts or other stands that support cookware. Material with an array or singular burner ports that can be moved up and down such that the distance between the cookware supported by the posts or other stands and the burner ports is varied.

[0081] FIGS. **23**A and **23**B show a burner plate with a singular or array of burner ports that is angled such that liquid or other materials will roll or run off and drain away.

Hot Box Embodiments

[0082] Embodiments of the present invention also provide a barrier (or "hot box") designed or configured to create an enclosure between a lean, pre-mixed flame and a heating target, such that heat loss from the space is reduced or minimized, wherein the barrier is constructed from a non-combustible material.

[0083] In some embodiments, the heating target of the barrier is a cooking vessel or cookware, such as a pot, pan, or wok. In some embodiments, the heating target has a round or flat bottom. In some embodiments, the heating barrier comprises a non-combustible material, and the non-combustible material is glass, ceramic, enamel, metal, or the like. In some embodiments, the top of the barrier is solid in order to facilitate cleaning. In some embodiments, the hot box can enclose multiple ring burners to expand the hot surface area, similar to induction or infrared cooktops. In some embodiments, the barrier top is translucent or transparent such that the burner flame is visible to the user. FIGS. **11** to **15** show variant enclosure designs.

[0084] Cooktops currently use rich flames (fuel-to-air stoichiometry of fuel/air mix coming into burner is fuel rich), and additional air diffuses/convects to the flame to complete combustion. This imposes a geometric requirement on the cooktop and cookware such that air diffusion is sufficient. Generally, unobstructed line-of-sight pathway between secondary ambient air and each flame is necessary. With the advent of lean flames (fuel-to-air stoichiometry of fuel/air mix coming into burner is air rich) for cooktops, this geometric requirement is relaxed, as the fuel/air mix has enough oxygen, and diffusion of secondary air to the flame is not necessary.

[0085] For embodiments of the present invention, ambient air is separated from the cooking zone, enabling improved cooking in terms of homogenous heat distribution, fuel efficiency, and thermal transfer to the food (e.g., reduced time to boil). FIGS. **9**A and **9**B compare an embodiment of the invention to a conventional cooktop. In the conventional cooktop, a large portion of the heat is lost to the ambient air (FIG. **9**A). In embodiments of the invention, most of the heat is contained near the heat target, such as a cooking vessel (e.g., a pot or pan) (FIG. **9**B). This containment results in a lower fuel consumption and improved heat transfer to the heat target, such as food contained within the cooking vessel.

[0086] In some embodiments, the barrier defines an enclosure that confines a flame or flames, and hot cooking gas, and prevents or limits exchange between the hot cooking gas and ambient air, and touches or is in proximity to the heat target, such as a cooking vessel.

[0087] In some embodiments, the barrier comprises one or more vent airs, which when open permits forced air or natural air draft cooling, which extends the range of turn-down, or enable rapid cooling of the heat target, such as a cooking vessel, to, for example, prevent burning or over-cooking of the food.

[0088] In some embodiments, the barrier is mounted on the cooktop, integrated into the heat target, or cooking vessel, or is a separate apparatus that is put in place before cooking.

[0089] In some embodiments, the heat target and the barrier are designed or configured for optimum performance such that the heat target and the barrier can "mate" together or have a tight fit.

[0090] In some embodiments, the barrier further comprises thermal insulation to reduce heat transfer with ambient air.

[0091] In some embodiments, the barrier comprises an adjustable aperture on the top to accommodate heat targets of various sizes, such as cooking vessels of different sizes. FIGS. **10**A and **10**B show one embodiment of an adjustable aperture on the top.

[0092] In some embodiments, the barrier comprises a solid top, such as a griddle or grill.

[0093] In some embodiments, the barrier comprises a spiral wall to permit venting while retaining heat. FIG. **11** shows a barrier comprising a spiral wall.

[0094] In some embodiments, the barrier is designed or configured to have one or a plurality of flames distributed across the heating area, such as a cooking area. FIGS. **12**A and **12**B show embodiments of one or a plurality of flames distributed across the heating area. This permits flexibility in burner design in terms of cost, turn-down ratio, and size (such as Btu output) of each flame.

[0095] In some embodiments, the barrier connects to a vent that directly removes combustion gases from the enclosure or heating area. This circumvents a need for a range hood to exhaust heat, carbon monoxide, NOx, and other undesirable combustion by-products. FIG. **13** shows a barrier connected to a vent that directly removes combustion gases from the enclosure or heating area.

[0096] In some embodiments, the barrier comprises a heat exchanger to extract heat from the vented gases. This can be used to preheat in coming fuel/air. FIG. **14** shows a barrier comprising a heat exchanger to extract heat from the vented gases.

[0097] In some embodiments, the barrier is designed or configured to provide heat to the sides of the heat target. FIG. **15** shows the barrier designed or configured to provide heat to the sides of the heat target.

[0098] In some embodiments, a heating system comprising the barrier uses an apparatus of embodiments of the present invention or an apparatus described in U.S. Pat. No. 5,516,280, issued May 14, 1996, which is incorporated by reference, or any other burner. In some embodiments, the system uses a lean premixed flame including natural draft or forced draft.

Burner Apparatus Embodiments

[0099] Described below are heating apparatus including a mechanism operable to distribute premixed fuel and air to burners. The heating apparatus can be used with burner plates and ring burners, and can operate with cooktops, water heaters, furnaces, and a number of other apparatus.

[0100] In some embodiments, a burner body includes a series of flow dividing channels that evenly distribute the fuel/air mixture to the multiple burner ports so that each burner port receives about the same amount of fuel/air mixture while the apparatus incurs low pressure drop so that it does not require a fan. The flow division mechanism may enable low pressure burner operation without fan assist across a large surface area.

[0101] In some embodiments, a burner apparatus includes a low-pressure drop fuel/air mixing system in which a gaseous fuel jet entrains air in excess of current practices, which can enable lean premix combustion. In some embodiments, the burner apparatus includes an internal mechanism to distribute the fuel/air mixture evenly to an array of burner ports spaced in a ring or other geometry patterns with a low-pressure drop. In some embodiments, the burner apparatus is operable to release a fuel/air mixture so that the exiting velocity is high enough to promote flame stability both in terms of preventing flashback and flame lift off and blow off.

[0102] In some embodiments, an internal mechanism of a burner body is operable to: (1) use gaseous fuel jets to entrain air for generating a stream of homogeneously mixed reactants (i.e., comprising or consisting of fuel and air) having an air to fuel ratio higher than is attainable with other devices; and (2) distribute the reactants evenly to multiple burner ports (e.g., a ring burner or a low-swirl burner) by internal passages in the internal mechanism. Burner ports may be arranged geometric patterns that are defined to increase or maximize heat transfer efficiency.

[0103] In some embodiments, a fuel/air mixture is supplied to multiple burner ports at specific velocities based on the combustion properties of the fuel/air mixture. In some embodiments, an internal mechanism in a burner apparatus is operable to suppress flow disturbances (e.g., turbulence and flow separation) without impeding air entrainment and fuel/air mixing. In some embodiments, an internal mechanism in a burner body is operable to supply each burner port with a fuel/air mixture at the same velocity such that the heat output from each burner port is the same or about the same as other burner ports.

[0104] FIGS. **24**A-**24**F show examples of illustrations of a burner apparatus. FIG. **24**A shows an example of a schematic illustration of a burner apparatus. FIG. **24**B shows an example of a top-down schematic illustration of a burner apparatus. FIG. **24**C shows an example of a cross-sectional schematic illustration of a burner apparatus. FIG. **24**D shows a top-down schematic illustration of a divider of a burner apparatus. FIG. **24**E shows an example of an end-view schematic illustration of a burner apparatus. FIG. **24**F shows a schematic illustration of a single primary port and the associated secondary ports defined in a burner plate.

[0105] As shown in FIGS. **24**A-**24**F, a burner apparatus **2400** comprises a burner body **2410**, an inlet **2415** to the burner body, a divider **2420** disposed in the burner body, and a burner plate **2440**. The burner body **2410** defines an open volume. The divider **2420** forms first section **2422** and a second section **2424** in the open volume defined by the burner body **2410**. That is, the divider **2420** divides the open volume into a first section **2422** of the open volume and a second section **2424** of the open volume. In some embodiments, components of the burner apparatus **2400** comprise a non-combustible material. In some embodiments, the divider **2420** comprises a first planar sheet of material. In some embodiments, the burner plate **2440** comprises a second planar sheet of material. In some embodiments, the burner apparatus **2400** is operable without a fan or an air blower for the delivery of the fuel/air mixture to the burner body **2410**.

[0106] The inlet **2415** is operable for delivery of a fuel/air mixture to the burner body **2410**. In some embodiments, the inlet **2415** is operable for delivery of the fuel/air mixture to the first section **2422** of the burner body **2410**. In some embodiments, the inlet **2415** comprises a venturi tube **2417**. The venturi tube **2417** is positioned such that the fuel/air mixture flows though the venturi tube and then into the burner body **2410**. A fuel port **2418** is suspended in front of the venturi tube **2417**. In some embodiments, the fuel port **2418** is suspended by two support members attached to the venturi tube **2417**. When the burner apparatus **2400** is in operation, as fuel flows through the fuel port **2418**, a jet of fuel is directed towards the venturi tube **2417**.

[0107] The burner plate **2440** defines a combustion surface for the fuel/air mixture that is delivered to the burner apparatus **2400**. The burner plate also forms a surface of the burner body **2410** and in part defines the second section **2424**. The burner plate **2440** defines a plurality of primary ports **2444**. The burner plate further defines a plurality of secondary ports **2446** surrounding each primary port of the plurality of primary ports **2444**. In some embodiments, the burner plate **2440** comprises a top surface of the burner apparatus **2400**. The secondary ports **2446** are arranged relative to a primary port **2444** to aid in ensuring constant burning of the fuel/air mixture that flows though the burner apparatus **2440**. The plurality of primary ports **2444** and the plurality of secondary ports **2446** are positioned such that adjacent ports are close enough to one another to ignite one another.

[0108] In some embodiments, the plurality of primary ports **2444** comprises about 2 to 500 primary ports, or about 10 to 70 primary ports. In some embodiments, the plurality of secondary ports **2446** surrounding each primary port of the plurality of primary ports **2444** comprises about 4 to 14 secondary ports. In some embodiments, the plurality of primary ports **2444** are defined in the burner plate **2440** such that centers of four adjacent primary ports form corners of a square. In some embodiments, secondary ports of the plurality of secondary ports **2446** surrounding each primary port of the plurality of primary ports **2444** are arranged symmetrically around said primary port. In some embodiments, secondary ports of the plurality of secondary ports **2446** surrounding each primary port of the plurality of primary ports **2444** are equidistant from said primary port.

[0109] In some embodiments, each primary port of the plurality of primary ports **2444** defined in the burner plate **2440** is circular. In some embodiments, each of the primary ports **2444** has a diameter of about 0.2 inches to 0.325 inches, or about 0.25 inches. In some embodiments, each secondary port of the plurality of secondary ports **2446** defined in the burner plate **2440** is circular. In some embodiments, each of the secondary ports **2446** has a diameter of about 0.045 inches to 0.075 inches, or about 0.06 inches.

[0110] In some embodiments, a distance between an edge of a primary port **2444** and an edge of a secondary port of the plurality of secondary ports **2446** surrounding the primary port is about 0.2625 inches to 0.4375 inches, or about 0.35 inches (bring in FIG. **24**F). In some embodiments, a distance between an edge of a first primary port and an edge of a second primary port of the plurality of primary ports **2444** is about 0.125 inches or less. In some embodiments, a distance between an edge of a first secondary port and an edge of a second secondary port of the plurality of secondary ports **2446** surrounding a primary port of the plurality of primary ports **2444** is at least about 0.057 inches (δ_{tab} in FIG. **24**F).

[0111] The divider **2420** defines a plurality of interior ports **2421** between the first section **2422** and the second section **2424**. In some embodiments, an interior port **2421** is associated with each of the plurality of primary ports **2444** defined in the burner plate **2440**; i.e., for each primary port **2444**, there is an interior port **2421**. In some embodiments, an interior port **2421** is directly underneath each of the plurality of primary ports **2444**.

[0112] In some embodiments, each interior port of the plurality of interior ports **2421** defined in the divider **2420** has a dimension in the divider of about 0.09 inches to 0.125 inches. In some embodiments, each interior port of the plurality of interior ports **2421** defined in the divider **2420** is circular. In some embodiments, a size of each interior port of the plurality of interior ports **2421** increases with increasing distance from the inlet **2415**. This increase in the size of the interior ports aids in generating an even pressure distribution of the fuel/air mixture across the surface of the burner plate **2440**. In some embodiments, the divider **2420** is disposed in the burner body **2410** such that a cross-sectional area defined by the first section **2422** increases with increasing distance from the inlet **2415**. In such an embodiment, the divider **2420** is disposed in the burner body **2410** such that it is angled upwards going from left to right across the open volume of the burner body as shown in FIG. **24**C. This can also aid in generating an even pressure distribution of the fuel/air mixture across the surface of the burner plate **2440**.

An even pressure distribution of the fuel/air mixture across the surface of the burner plate **2440** aids in generating an even distribution of the fuel/air mixture to the plurality of primary ports **2444** and the plurality of secondary ports **2446**.

[0113] It is to be understood that, while the invention has been described in conjunction with the preferred specific embodiments thereof, the foregoing description is intended to illustrate and not limit the scope of the invention. Other aspects, advantages, and modifications within the scope of the invention will be apparent to those skilled in the art to which the invention pertains.

[0114] All patents, patent applications, and publications mentioned herein are hereby incorporated by reference in their entireties.

EXAMPLES

[0115] Embodiments of the invention having been described, the following examples are offered to illustrate the subject embodiments by way of illustration, not by way of limitation.

Example—Optimized Reduced-Scale Ring-Stabilizer Port—Forced Draft

[0116] A goal is to optimize the configuration of a reduced-scale ring stabilizer port for operating at low Reynolds number flows. A goal is the determination of an optimal size and ring stabilizer configuration that is amenable to natural draft operation as well as scaling (via multi-port clustering approach) to the various shapes and sizes of residential and commercial heating appliances. The experiment involved a parametric study of the ring stabilizer to select designs that meet the metrics on operation, performance, and ease of manufacturing.

[0117] The experiment tested the effect of reducing ring-stabilizer port size. The manufacturing limitation (gap) is 0.60 inches. The minimum port diameter is 0.375 inches. This dimension was selected to minimize flashback potential. FIGS. **3A-3C** show burner plates tested to determine port size.

Example—Forced-Draft Ring-Stabilizer Test Stand Development

[0118] The test stand comprises: methane and air mass flow controllers, fuel and air mixing length, burner stand (plenum filled with glass beads to mitigate flashback events and straighten flow, and interface to quickly replace burner plates), emissions analyzer (for NO_x, CO, O_2, and CO_2), and custom control program with data logging capabilities. An experimental setup was assembled to test various burner plates (FIG. **4**).

Example—Forced Draft Test Plan

[0119] The experiment tested for stability, lean blowoff (lowest amount of fuel possible before flame disappears), flashback (how slow can fuel/air exit burner before flame travels upstream of the burner port), emissions (enclosed so emissions are not diluted by ambient air), turndown (range of power outputs that burner can operate), and crossover ignition (spacing between burners that allows for ignition).

Example—Forced Draft Test Results—Lean blowoff

[0120] The results showed consistent blowoff, lower velocity (i.e., lower temperature flame), and a large potential to match lower temperature flame of a 1 inch burner, and the possibility of reduced NO_x emissions (FIG. **5**).

Example—Forced Draft Test Results—Flashback

[0121] The results showed flashback propensity increases with reduced velocity or increased flame temperature. This follows the expected relationships. The results also showed that low velocity and flame temperature operation are not limited by flashback. The lowest velocity for the 1 inch burner is 0.4 m/s. See Tables 1 and 2.

TABLE 1

0.375 inch diameter ports (9 total)	
Equivalence ratio	U (m/s)
0.80	0.4
0.85	0.5
0.90	0.5

TABLE 2

0.4375 inch diameter ports (9 total)	
Equivalence ratio	U (m/s)
0.80	0.3
0.85	0.4
0.90	0.5

Example—Forced Draft Test Results—Emissions (NO_x and CO)

[0122] The results showed lower NOx than current cooktop emissions, and reduction of more than 80% (FIG. **6**). The results showed CO emissions are only acceptable at lowest equivalence ratios, and the potential of lower equivalence ratio operation will further reduce CO emissions (FIG. **7**).

Example—Forced Draft Test Results—Turndown

[0123] The results showed ring-stabilizer burners to have between 5:1 and 3:1 turndown. Commercial systems have much higher turndown. Additional engineering is required to increase turndown. Low turndown applications may include ovens, water heaters, and furnaces. See Tables 3 and 4.

TABLE 3

0.375 inch diameter ports (9 total)	
Equivalence ratio	Turndown ratio
0.80	3.0:1
0.85	3.4:1
0.90	4.0:1

TABLE 4

0.4375 inch diameter ports (9 total)	
Equivalence ratio	Turndown ratio
0.80	4.7:1
0.85	4.8:1
0.90	4.6:1

Example—Forced Draft Test Results—Crossover Ignition

[0124] The results showed various distances between ports, ignition at one end of a burner plate, and self-igniting until port distance is too large. The results showed that ports need to be less than 0.125 inches apart. An easy geometry to implement with low cost manufacturing techniques may be beneficial. See Tables 5 and 6.

TABLE 5

0.375 inch diameter ports (9 total)	
Equivalence ratio	Max edge distance (inches)
0.80	0.125
0.85	0.125
0.90	0.125

TABLE 6

0.4375 inch diameter ports (9 total)	
Equivalence ratio	Max edge distance (inches)
0.80	0.125
0.85	0.125
0.90	0.125

Example—Conclusions from Tests

[0125] Scaled down ring-stabilizer burners operated at designed residential power thermal outputs (5,000 BTU/hr to 7,000 BTU/hr). Forced-draft burners are capable of meeting project goal of 80% NO_x reduction. Burner ports are able to ignite each other within geometric limits. Smaller port and gap size allow for more distributed heat release across a burner plate.

CONCLUSION

[0126] While the present invention has been described with reference to the specific embodiments thereof, it should be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the true spirit and scope of the invention. In addition, many modifications may be made to adapt a particular situation, material, composition of matter, process, process step or steps, to the objective, spirit, and scope of the present invention. All such modifications are intended to be within the scope of the claims appended hereto.

What is claimed is:

1. An apparatus comprising:

a burner body;

an inlet to the burner body, the inlet operable for delivery of a fuel/air mixture to the burner body;

a divider disposed in the burner body, the divider forming a first section and a second section in the burner body, the divider defining a plurality of interior ports between the first section and the second section, the inlet operable for the delivery of the fuel air mixture to the first section of the burner body; and

a burner plate, the burner plate defining a combustion surface for the fuel/air mixture, the burner plate forming a surface of the burner body and in part defining the second section, the burner plate defining a plurality of primary ports, and the burner plate further defining a plurality of secondary ports surrounding each primary port of the plurality of primary ports.

2. The apparatus of claim **1**, wherein each primary port of the plurality of primary ports defined in the burner plate is circular, and wherein each of the primary ports has a diameter of about 0.2 inches to 0.325 inches.

3. The apparatus of claim **1**, wherein each secondary port of the plurality of secondary ports defined in the burner plate is circular, and wherein each of the secondary ports has a diameter of about 0.045 inches to 0.075 inches.

4. The apparatus of claim **1**, wherein a distance between an edge of a primary port and an edge of a secondary port of the plurality of secondary ports surrounding the primary port is about 0.2625 inches to 0.4375 inches.

5. The apparatus of claim **1**, wherein a distance between an edge of a first secondary port and an edge of a second secondary port of the plurality of secondary ports surrounding a primary port of the plurality of primary ports is at least about 0.057 inches.

6. The apparatus of claim **1**, wherein a distance between an edge of a first primary port and an edge of a second primary port of the plurality of primary ports is about 0.125 inches or less.

7. The apparatus of claim **1**, wherein the plurality of secondary ports surrounding each primary port of the plurality of primary ports comprises about 4 to 14 secondary ports.

8. The apparatus of claim **1**, wherein a size of each interior port of the plurality of interior ports increases with increasing distance from the inlet.

9. The apparatus of claim **1**, wherein each interior port of the plurality of interior ports defined in the divider has a dimension in the divider of about 0.09 inches to 0.125 inches.

10. The apparatus of claim **1**, wherein secondary ports of the plurality of secondary ports surrounding each primary port of the plurality of primary ports are arranged symmetrically around said primary port.

11. The apparatus of claim **1**, wherein secondary ports of the plurality of secondary ports surrounding each primary port of the plurality of primary ports are equidistant from said primary port.

12. The apparatus of claim **1**, wherein each interior port of the plurality of interior ports defined in the divider is circular.

13. The apparatus of claim **1**, wherein the divider comprises a first planar sheet of material, and wherein the burner plate comprises a second planar sheet of material.

14. The apparatus of claim **1**, further comprising:
a venturi tube, wherein the venturi tube is positioned such that the fuel/air mixture flows through the venturi tube and then into the burner body.

15. The apparatus of claim **1**, wherein the apparatus is operable without a fan or an air blower for the delivery of the fuel/air mixture to the burner body.

16. The apparatus of claim **1**, wherein the plurality of primary ports comprises about 10 to 70 primary ports.

17. The apparatus of claim **1**, wherein the plurality of primary ports is defined in the burner plate such that centers of four adjacent primary ports form corners of a square.

18. The apparatus of claim **1**, wherein the divider is disposed in the burner body such that a cross-sectional area defined by the first section increases with increasing distance from the inlet.

19. An apparatus comprising:
a burner body;
an inlet to the burner body, the inlet operable for delivery of a fuel/air mixture to the burner body;
a divider disposed in the burner body, the divider forming a first section and a second section in the burner body, the divider defining a plurality of interior ports between the first section and the second section, the inlet operable for the delivery of the fuel air mixture to the first section of the burner body; and
a burner plate, the burner plate defining a combustion surface for the fuel/air mixture, the burner plate forming a surface of the burner body and in part defining the second section, the burner plate defining a plurality of primary ports, each primary port of the plurality of primary ports being circular, each of the primary ports having a diameter of about 0.2 inches to 0.325 inches, and the burner plate further defining a plurality of secondary ports surrounding each primary port of the plurality of primary ports.

20. An apparatus comprising:
a burner body;
an inlet to the burner body, the inlet operable for delivery of a fuel/air mixture to the burner body;
a divider disposed in the burner body, the divider forming a first section and a second section in the burner body, the divider defining a plurality of interior ports between the first section and the second section, the inlet operable for the delivery of the fuel air mixture to the first section of the burner body; and
a burner plate, the burner plate defining a combustion surface for the fuel/air mixture, the burner plate forming a surface of the burner body and in part defining the second section, the burner plate defining a plurality of primary ports, and the burner plate further defining a plurality of secondary ports surrounding each primary port of the plurality of primary ports, each secondary port of the plurality of secondary ports being circular, and each of the secondary ports having a diameter of about 0.045 inches to 0.075 inches.

* * * * *