NON-CATALYTIC BIOMASS FUEL BURNER AND METHOD

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ABSTRACT

The present invention relates to a non-catalytic biomass burner that may be used to burn a variety of fuel types at high efficiencies. The burner may include a cylindrical combustion chamber with an auxiliary igniter to heat the fuel in the combustion chamber until desirable combustion temperatures are reached. Fuel may be added to the chamber via a fuel feed assembly, and the rate of fuel addition to the chamber by the fuel feed assembly may be controlled by a computer. A fan located on the distal side of a flue pipe from the chamber may also be provided that pulls air into the chamber through one or more air inlets that are designed to encourage cyclonic air and exhaust flow in the chamber. Methods are further provided for controlling the manner of operation of the burner by a computer that may be instructed by a computer program code.
FIG. 1
Cold Burner → Turn On Igniter

Control Fuel Rate

Comb. Temp > Igniter Off Temp?

Yes → Turn Off Igniter

Control Fuel Rate

No → Control Igniter Smoke Guard

Control Fan

FIG. 9
FIG. 11

1043
Set Fuel Rate to output of PI(D)

1041
Calculate Fuel Rate using PI or PID loop (user selectable)

1045
Output of PI(D) > Max Fuel Rate?

Yes
Set Fuel Rate to Max Fuel Rate

No

1049
Output of PI(D) < Min Fuel Rate?

Yes
Set Fuel Rate to Min Fuel Rate

No

1053
Combustion Temp > User Combustion Temp + Temperature Offset?

Yes
Fuel set to lowest level that allows combustion (factory set)

No

1057
Combustion Temp > Combustion Warning Limit OFF?

Yes
Disable Fuel System

No

1063
Combustion Warning Flag Set?

Yes
Combustion Temp < Combustion Warning Limit ON?

Enable Fuel System

No

1065
Reset Combustion Warning Flag

1067
Set Combustion Warning Flag
NON-CATALYTIC BIOMASS FUEL BURNER
AND METHOD

CROSS-REFERENCE TO RELATED
APPLICATIONS

[0001] This application claims benefit of priority to U.S.
Provisional Patent Application No. 61/563,921 filed on Nov.
28, 2011, the entire contents and disclosure of which are
incorporated herein by reference.

BACKGROUND

[0002] 1. Field of the Invention
[0003] The present invention relates to biomass burners and
more particularly to an apparatus and method for non-cata-
ytic biomass burning.
[0004] 2. Related Art
[0005] In the United States, the Environmental Protection
Agency classifies bio-mass burners into two categories: cata-
ytic burners and non-catalytic burners. The two different
types of stoves (or burners) are regulated differently and have
different operating requirements. A catalytic wood stove uses
a catalytic combustion device to heat, ignite and burn off the
smoke generated by the fire. In general, this results in maxi-
mum “use” of the fuel (e.g., wood), even and steady produc-
tion of heat, and very minimal output of smoke and pollutants.
The principles of catalytic wood stoves apply to other cat-
ytic stoves that burn fuels other than wood. The catalyst itself
is usually a ceramic honeycomb or waffle shaped plate coated
with a metal (e.g., platinum, palladium). The catalyst is
heated to very high temperatures so that when the smoke and
ash pass over it, they are heated and ignited, causing more
of this byproduct to be burned off, which generates more heat
and less creosote and vents less smoke to the outside. The
belief is that high efficiency is achieved by minimizing waste
and maximizing heat (energy) output.

[0006] Another type of stove is a non-catalytic wood stove
or a non-catalytic stove that burns other types of biomass.
While the catalytic stoves have a special combustor to
increase their efficiency by burning off the smoke and ash and
“cooking” the wood to produce heat, non-catalytic do not
have this modification and are thus structurally and function-
ally different. Even though typically viewed as less efficient
than catalytic stoves, a non-catalytic stove avoids many of the
complaints typically expressed about catalytic stoves. Most
complaints about catalytic stoves relate to maintaining or
replacing the catalytic combustor plate. Catalytic stoves are
generally thought to be harder to maintain as the catalytic
plate requires some amount of care with cleaning and replac-
ing. In most household-type stoves, users get about five sea-
sons on average before needing to replace the catalytic plate.
Improper use or burning can reduce this expected lifetime to
two years. As for expense, such replacement plates can cost
hundreds of dollars to purchase today. There is also a learning
curve to operating a catalytic stove. The catalyst must be
preheated to a certain temperature before the damper is
closed, and learning just the right timing may take a season or
two. No such requirement exists for non-catalytic stoves.

[0007] In either a catalytic stove or non-catalytic stove or
burner, providing biomass fuel in a form and condition to be
burned efficiently is presently difficult to accomplish. In par-
cular, most stoves or burners require the fuel to have a
particular size, uniformity, and predetermined moisture con-
tent. If all of those conditions are met, then the fuel can be
used efficiently in the stove, such that the fuel is burned
almost entirely with little or no smoke or pollutants exhausted
into the atmosphere. One way to completely burn the fuel and
produce little exhaust is to use large commercial burn cham-
bers that can operate in a range of about 1 million BTU/hour
or greater. However, this type of burner is not practical for
residential use where stoves may operate in the 100,000 BTU/
hour to 500,000 BTU/hour range.

[0008] Thus, there remains a need in the art for an improved
non-catalytic biomass stove or burner and method of its
operation that can burn a wide range of fuel types and gener-
ate from about 100,000 to about 500,000 BTU/hr or higher
while maintaining a high efficiency that may be near or
equivalent to a catalytic stove.

SUMMARY

[0009] According to a broad aspect of the present inven-
tion, a non-catalytic biomass burner is provided comprising:
a combustion chamber for burning a fuel to produce an exhaust
gas, wherein the combustion chamber has a cylindrical interi-
or shape with the sides of the combustion chamber enclosed
by a side wall; one or more air inlets spanning the side wall of
the combustion chamber to allow air to enter the combustion
chamber from the side wall of the combustion chamber through
the one or more air inlets; a flue pipe connected at its proximal
end to the top of the combustion chamber, the flue pipe being
configured to receive the exhaust gas from the combustion
chamber through a flue opening, a heat exchanger for trans-
ferring heat from the exhaust gas to a circulating fluid of the
heat exchanger, wherein the heat exchanger is positioned in
the path of the exhaust gas between the flue pipe and an exit
opening of the burner, wherein the flue pipe delivers the
exhaust gas to the heat exchanger; a fuel inlet tube having an
upper portion and a lower portion, wherein a fuel opening in
the side wall of the combustion chamber allows fuel to enter
the combustion chamber from the lower portion of the fuel
inlet tube; and an auxiliary igniter pointed toward the com-
bustion chamber through an igniter opening in the side wall of
the combustion chamber, the auxiliary igniter configured to
direct heat into a lower portion the combustion chamber.

[0010] According to a second broad aspect of the present
invention, a non-catalytic biomass burner is provided com-
prising: a combustion chamber for burning a fuel to produce
a hot exhaust gas, wherein the combustion chamber has a
cylindrical interior shape with the sides of the combustion
chamber enclosed by a side wall, one or more air inlets
spanning the side wall of the combustion chamber to allow air
to enter the combustion chamber from the outside of the
combustion chamber through the one or more air inlets; a
plurality of vertical side panels positioned above a floor of
the burner, the plurality of vertical side panels surrounding
the side wall of the combustion chamber to define a plenum
space between the side wall and the plurality of vertical side
panels; one or more air intake holes near the bottom of the plenum
space to allow air to enter the plenum space; a flue pipe
connected at its proximal end to the top of the combustion
chamber, the flue pipe being configured to receive the exhaust
gas from the combustion chamber through a flue opening and
deliver the exhaust gas to a heat exchanger, a fuel inlet tube
having an upper portion and a lower portion, wherein a fuel
opening in the side wall of the combustion chamber allows
fuel to enter the combustion chamber from the lower portion
of the fuel inlet tube; and an auxiliary igniter pointed toward
the combustion chamber through an igniter opening in the
side wall of the combustion chamber, the auxiliary igniter configured to direct heat into a lower portion the combustion chamber.

[0011] According to a third broad aspect of the present invention, a non-catalytic biomass burner is provided comprising: a combustion chamber for burning a fuel to produce an exhaust gas, wherein the sides of the combustion chamber are enclosed by a side wall; one or more air inlets spanning the side wall of the combustion chamber to allow air to enter the combustion chamber from the outside of the combustion chamber through the one or more air inlets; a flue pipe connected at its proximal end to the top of the combustion chamber, the flue pipe being configured to receive the exhaust gas from the combustion chamber through a flue opening, a fuel inlet tube having an upper portion and a lower portion, wherein a fuel opening in the side wall of the combustion chamber allows fuel to enter the combustion chamber from the lower portion of the fuel inlet tube; and an auxiliary igniter pointed toward the combustion chamber through an igniter opening in the side wall of the combustion chamber, the auxiliary igniter configured to direct heat into a lower portion the combustion chamber; a first temperature sensor positioned near the top of the combustion chamber to measure a combustion temperature of the exhaust gas exiting the combustion chamber; and a computer in communication with the first temperature sensor, the computer receiving the combustion temperature from the first temperature sensor.

[0012] According to a fourth broad aspect of the present invention, a method of operating a non-catalytic biomass burner is provided comprising: (a) turning on an auxiliary igniter, the igniter pointed toward a combustion chamber of the burner through an igniter opening in a side wall of the combustion chamber, the auxiliary igniter configured to direct heat into a lower portion the combustion chamber; (b) monitoring by a computer a combustion temperature of an exhaust gas exiting the combustion chamber, the combustion temperature of the exhaust gas measured by a first temperature sensor positioned near the top of the combustion chamber, the exhaust gas being produced by the burning of a fuel in the combustion chamber, and the computer receiving the combustion temperature from the first temperature sensor; (c) adding fuel to the combustion chamber at a first predetermined fuel rate when the combustion temperature reaches a first fuel temperature, wherein the rate of fuel addition to the combustion chamber is controlled by the computer controlling the fuel feed assembly that delivers fuel to a fuel inlet tube of the burner; (d) adding fuel to the combustion chamber at a second predetermined fuel rate by controlling the fuel feed assembly when the combustion temperature reaches a second fuel temperature, the second fuel temperature being higher than the first fuel temperature; and (e) turning off the auxiliary igniter when the combustion chamber temperature reaches an igniter off temperature.

[0013] According to a fifth broad aspect of the present invention, a method of operating a non-catalytic biomass burner is provided comprising: (a) measuring by a first temperature sensor a combustion temperature of an exhaust gas exiting a combustion chamber of the burner, the exhaust gas being produced by the burning of a fuel in the combustion chamber; (b) monitoring by a computer the combustion temperature of the exhaust gas exiting the combustion chamber, the computer receiving the combustion temperature from the first temperature sensor; (c) determining a fuel rate for adding fuel to the combustion chamber, wherein the fuel rate is determined by the computer based on the combustion temperature; and (d) adding fuel to the combustion chamber at the fuel rate determined in step (c), wherein the rate at which the fuel is added to the combustion chamber is controlled by the computer controlling a fuel feed assembly that delivers fuel to a fuel inlet tube of the burner.

[0014] According to a sixth broad aspect of the present invention, a computer program product for controlling the operation of a non-catalytic biomass burner is provided comprising: a computer readable storage medium having computer readable program code embodied therewith, the computer readable program code comprising: computer readable program code configured to receive from a first temperature sensor a combustion temperature of an exhaust gas exiting a combustion chamber of the burner, the exhaust gas being produced by the burning of a fuel in the combustion chamber; computer readable program code configured to monitor by a computer the combustion temperature of the exhaust gas exiting the combustion chamber; computer readable program code configured to determine by the computer based on the combustion temperature a fuel rate for adding fuel to the combustion chamber; and computer readable program code configured to control by the computer the addition of fuel to the combustion chamber a fuel feed assembly at the determined fuel rate, wherein the fuel rate is controlled by the computer controlling a fuel feed assembly that delivers fuel to a fuel inlet tube of the burner.

It is understood that other embodiments of the present invention will become readily apparent to those skilled in the art from the following detailed description, wherein it is shown and described only various embodiments of the invention by way of illustration. As will be realized, the invention is capable of other and different embodiments and its several details are capable of modification in various other respects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 depicts a block-level diagram of a biomass burner in accordance with the principles of the present invention;

[0017] FIG. 2A depicts a cut-away perspective view of a biomass burner in accordance with the principles of the invention;

[0018] FIG. 2B depicts a cut-away side view of the biomass burner in FIG. 2A;

[0019] FIG. 3 depicts an isolated view of a combustion chamber according to the principles of the present invention with side panels removed to show air inlet sources;

[0020] FIG. 4A shows a side view of an isolated combustion chamber according to principles of the present invention;

[0021] FIG. 4B shows a cross-sectional view of the combustion chamber in FIG. 4A through plane 4B that shows the air inlet tube into the chamber;

[0022] FIG. 5A shows another side view of an isolated combustion chamber according to principles of the present invention;

[0023] FIG. 5B shows a cross-sectional view of the combustion chamber in FIG. 5A through plane 5B showing the fuel inlet tube into the chamber.
FIG. 6 depicts a fuel feed hopper assembly that may be used with a burner of the present invention according to some embodiments;

FIG. 7 shows a close up or zoom view of a portion of the hopper in FIG. 6;

FIGS. 8A and 8B show different perspective views of an optional fuel restriction plate according to some embodiments of the present invention;

FIGS. 8C and 8D show the restrictor plate in FIGS. 8A and 8B that may be placed in the side chamber of the fuel feed hopper assembly in two different orientations;

FIG. 9 provides a high level flow chart or algorithm for operation of the burner according to embodiments of the present invention;

FIGS. 10 and 11 jointly show a flow chart according to embodiments of the present invention depicting the steps or algorithm for controlling the fuel flow rate into the combustion chamber of a burner; and

FIG. 12 is a spreadsheet diagram according to an example embodiment of the present invention for the operation of the burner based on different smoke guard settings.

DETAILED DESCRIPTION

The detailed description set forth below in connection with the appended drawings is intended as a description of various embodiments of the invention and is not intended to represent the only embodiments of the invention or the only manner in which the invention may be practiced. The detailed description includes some specific details for the purpose of providing an understanding of the invention. However, it will be apparent to those skilled in the art that these details may be provided as merely illustrative examples and/or optional features of the present invention. Some well-known structures and components may also be depicted in block diagram form to avoid obscuring concepts of the present invention.

The present invention relates generally to a non-catalytic multi-fuel burner (or stove) having improved efficiencies and methods of operation. Heat energy is created by burning either traditional or non-traditional biofuels inside a combustion chamber of the burner. Traditional fuels may include corn, wood chips, pellets, and the like. However, the present invention may also efficiently burn non-traditional fuels, such as crop stover, fine dust particles, animal feed, and other types of bio-waste mass. As described more fully below, a computer may monitor and control operation of a bio-mass burner of the present invention to provide efficient burning of a wide range of fuels. In general, the computer may control and coordinate multiple functions of the burner unit. For example, the computer may control the fuel to air ratio within the combustion chamber, such as to minimize the time that unburned fuel remains in the chamber, by controlling a fan, a gas igniter and/or the feed rate of fuel into the combustion chamber. The computer may control the gas igniter (or some other secondary igniter) to start up the burning and to eliminate or minimize smoke during certain periods of operation when the temperature gets too low. To ensure that there is an efficient burn with minimal output of smoke, temperatures within the combustion chamber and/or the exhaust stack may be monitored for adjusting operational parameters of the burner.

As a result of its design and control, a non-catalytic burner of the present invention can operate at about 100,000 to 500,000 BTU/hr output or more while still achieving high efficiency heat production. Such a non-catalytic burner of the present invention may be effective at burning fuel having a diameter as small as from about 20 mm (e.g., dust) up to about 2 inches or more and having a moisture content of about 40% or below, with greater than about 80% efficiency. These results may be achieved, in part, by operating the combustion chamber at a target combustion temperature within a range from about 1100 to about 1800°F (e.g., 1600°F).

Several design features come together to achieve a non-catalytic burner of the present invention with high efficiencies. First, the combustion chamber may be generally cylindrical in shape with air inlet(s) near the bottom of the combustion chamber that span the side wall of the chamber to allow air from the outside to enter the chamber. These air inlet(s) may also be positioned and angled to encourage a cyclonic air flow within the chamber during burning. A fan, such as a controllable variable speed fan, may be positioned distally to pull air into the chamber, and an igniter may be positioned and oriented to point or project into the interior of the chamber as an auxiliary energy source. Fuel may be generally metered or fed into the chamber continuously or in small incremental amounts over time (instead of being supplied in bulk or larger batches). Importantly, the rate at which fuel is fed into the chamber may be controlled in response to monitoring feedback information regarding the temperature of the combustion chamber. As a result, all burning may occur in a single chamber instead of having two or more burns in separate compartments or chambers as with catalytic burners or gasifiers. In addition, both the igniter and the fan of the present invention may be controlled as well in response to chamber temperature feedback information. Thus, each of these features of the burner, including temperature-dependent control of the various inputs into the combustion chamber, may be combined to allow for regulation of fuel burning, such that the combustion temperature inside the chamber may be maintained within a desired range.

The construction and material used to enclose the combustion chamber of the burner of the present invention are unlike prior combustion chambers that are surrounded by water jackets. The water jackets of these combustion chambers transfer heat from the chamber and thus prevent hot temperatures from being attained quickly. In contrast to these prior chambers, the combustion chamber 102 of the present invention may be designed to avoid absorption of heat as much as possible so that the heat remains in the chamber.

FIG. 1 provides a block-level diagram of a bio-mass burner in accordance with the principles of the present invention. A combustion chamber 102 of the burner is where the bio-mass fuel 108 is burned. The combustion chamber may be generally cylindrical in shape to encourage cyclonic air flow and may be enclosed by a wall that may have an upper portion and a lower portion. However, it is important to note that the cross-sectional shape of the combustion chamber may vary. Although a circular cross-section (i.e., a cylindrical shape) for the inside of the combustion chamber is generally preferred as shown in FIG. 1, other shapes are also contemplated that may not severely impede cyclonic air flow within the chamber, such as oval, octagonal, etc. The combustion chamber 102 may be enclosed by a (hollow cylinder) side wall. However, even for a cylindrical interior shape of the side wall and combustion chamber, the shape of the outside of the wall may be non-cylindrical without affecting the interior shape. The fuel 108 and air 110 into the combustion chamber 102 is controlled so that burning of the fuel takes place in a desired manner. An igniter 107 may be present to ignite the initial
load of fuel to start the combustion process and to augment fuel burning if the temperature of the chamber 102 drops below a predetermined temperature. The igniter 107 may not only project into the chamber 102, but also be pointed downward at an angle toward the fuel in the bottom of the chamber 102. Once burning of the fuel 108 at a desired temperature is reached, the igniter 107 may be disabled. The igniter is a secondary heat source, such as a liquid propane (LP) or natural gas (NG) burner. An example size may be an igniter that can generate an input between about 100,000 BTU and 400,000 BTU.

[0037] A first temperature sensor 104 may be present near the top of the combustion chamber 102 (e.g., near the top of the combustion chamber 102 or in a proximal portion of a flue pipe or flue 116 near the combustion chamber 102) such that the temperature of the exhaust gas 114 exiting the combustion chamber 102 may be monitored and maintained within a desired range (e.g., at a temperature between about 1100°F. to about 1600°F.). Such a first temperature sensor 104 may be positioned in the flue anywhere between the combustion chamber 102 and the heat exchanger 118. There may also be a fuel stirrer 106 located within the chamber 102, typically at or near the bottom of the chamber 102. The stirrer 106 may be of a variety of different designs, shapes, etc., but is configured to agitate the burning fuel within the chamber 102 so that different surface area portions of the burning fuel are exposed to the combustion temperatures and the air within the chamber 102. For example, the stirrer 106 may be a rod with a length about equal to, or less than, an inside diameter or radius of the combustion chamber 102 that spins about a central point near the floor of the combustion chamber 102.

[0038] The exhaust 114 from the combustion chamber 102 exits into the flue 116, which directs the exhaust 114 to a heat exchanger 118. A second temperature sensor 112 may be provided that monitors the temperature of the exhaust gases near a fan 122. Such a second temperature sensor 112 may be located on the distal side of the heat exchanger 118 or on the distal side of the partition 212 of the heat exchanger 118. The second temperature sensor 112 may also be located on the proximal side of the fan 122. The term “proximal” in reference to the flue 116 and the path of exhaust flow 114 refers to a position closer to the combustion chamber 102 (and further away from a distal exit opening where the exhaust gases exit the burner into the surroundings) in the path of the exhaust, whereas term “distal” refers to a position further away from the combustion chamber 102 (and closer to such a distal exit opening) in the path of the exhaust. Much like the first temperature sensor measurements, the temperatures measured by the second temperature sensor 112 may also be used to control the operation of the burner including possibly controlling the delivery rate of fuel 108 and/or the flow of air 110 into the chamber 102.

[0039] The temperatures of the exhaust within the combustion chamber and at a more distal location near an exit opening of the burner unit may generally vary hand-in-hand, but the distal temperature reading may depend on the size of the flue and the exact location of the second temperature sensor. High exhaust temperature readings in the flue and/or heat exchanger detected by the second temperature sensor (e.g., distal exhaust temperatures higher than a desired 250°F. to 450°F. range) may indicate a dirty flue, clogged fan, or dirty heat exchanger surfaces that need to be cleaned. For example, as a safety precaution, if the second temperature sensor 112 detects a flue temperature of about 450°F. or greater (or at or above some other predetermined temperature), then feeding of the fuel 108 to the combustion chamber 102 could be stopped. The fuel 108 may be later restarted when the second temperature sensor 112 detects a lower temperature (e.g., about 425°F. or less).

[0040] The exhaust gases produced by a bio-mass burner of the present invention may generally be provided to, and used by, a heat exchanger, to heat or increase the temperature of a circulating fluid (or gas) 120 in a separate compartment, which may then be utilized as an energy input for another process (e.g., a water heater, etc.). Embodiments of the present invention contemplate using any of a variety of different heat exchangers and peripheral equipment in the art that are suitable for use in conjunction with the burner of the present invention. A fan 122, such as an induced draft (ID) fan, may be located at a distal location within the exhaust flow, such as toward an end of the flue 116 or in a distal cavity on the distal side of the heat exchanger 118, near where the exhaust 114 exits into the surroundings through an exit opening. The fan may pull the exhaust gases 114 at a desired flow rate and thus control the amount of air 110 being drawn into the combustion chamber 102. The fan 122 creates a negative pressure within the combustion chamber 102 that causes air 110 to be drawn into the combustion chamber 102, which then flows into the flue 116 as an exhaust 114 and exits the apparatus through a distal exit opening after flowing through the fan 122.

[0041] A computer 124 may be provided as shown in FIG. 1 that controls the operation of the burner. The computer 124 may be a single computer, server, processor, etc., or multiple computer(s), server(s), processor(s), etc., that jointly perform the functions of the computer 124. A computer of the present invention may have a processor and a memory or computer readable medium that is part of, associated with, or accessible by the computer. The computer 124 may control the operation of the burner by implementing instructions of a computer readable code that is stored on a computer readable medium. The computer may further have a user input for the user to enter settings, values, preferences, etc. The computer 124 may be in communication with a number of different components of the burner either to receive feedback information from them, such as temperature readings, etc., or to send commands or instructions to control their operation. For example, the computer 124 may communicate with the first temperature sensor 104 and the second temperature sensor 112 to receive feedback information about combustion and fan temperatures, respectively. The computer may also communicate with a fuel feed assembly (not shown) to control the feed rate of fuel 108 into the chamber 102, the fan 122 to adjust the rate of air flow into the chamber, and/or the igniter 107 to timely supply a supplemental heat source to the fuel and exhaust gases. The computer 124 may also monitor the temperature of the circulating fluid 120 to ensure it is within an acceptable range (e.g., between about 135°F and 185°F.)

[0042] FIG. 2A depicts a cut-away diagram of a bio-mass burner according to an embodiment of the present invention, and FIG. 2B shows a side view of the burner in FIG. 2A. The combustion chamber 102 in FIG. 2A is shown partially cut-away to view its interior. The inside of at least an upper portion 204 of the combustion chamber 102 may be constructed of a ceramic or other material that allows the inside of the combustion chamber to reach operating temperatures quickly. A lower portion 202 of the combustion chamber 102 may be constructed of a wear resistant refractory brick or
castable ceramic with possibly additional insulation, whereas the upper portion 204 of the chamber 102 (i.e., away from the actual combustion site) may have a lighter insulating material, such as a ceramic fiber composite or the like, which may include C-Cast®, etc. The material surrounding the lower portion 202 may be chosen to withstand the intense heat and agitation of the combusting fuel, and the material surrounding the upper portion 204 may be selected to minimize absorption of heat so that it is kept inside the chamber 102. In addition to the materials described above forming the inner wall face, the wall surrounding the upper and lower portions 202, 204 of the chamber 102 (and enclosing the chamber itself) may have additional materials or insulation and a metal enclosure on the outside that defines the outside surface of the chamber. The boundary between such upper and lower portions 202, 204 of the combustion chamber 102 may be a horizontal boundary line that may be about ¼ to about ½ of the way up from the bottom of the chamber 102, although the boundary need not be perfectly linear. Such a boundary between the upper and lower portions 202, 204 may also intersect or bisect a fuel delivery inlet 206 where it opens into the chamber 102 and/or where the igniter 107 projects into the combustion chamber 102. The height of the lower portion 202 of the chamber 102 may be about 8-10 inches or more from the bottom of the chamber, and the height of the upper portion 204 of the chamber may be about 12-25 inches or more above the top of the lower portion 202, although these heights may vary and will depend on the overall size of the burner and combustion chamber. The lower portion 202 may be generally high enough to be above the chamber air inlet(s) and the fuel level.

FIG. 2A also shows the placement of the igniter 107, which can be used to pre-heat the combustion chamber 102, help ignite an initial load of fuel, and/or augment fuel burning if operating temperatures are too low or conditions are producing smoke or unwanted pollutants. Fuel at the bottom of the chamber 102 may also be turned and agitated by a stirrer 106 to generate a more efficient burn with the stirrer 106 being actuated by a motor 224, such as an electric motor, which may be connected to a lower portion 226 of the stirrer 106 via a drive chain. The lower portion of the stirrer 106 and the drive chain may be located beneath an inner floor 205 of the unit. There may also be a side access door 208 that allows physical access to the chamber 102. Ash and large objects may be removed when this door is opened or removed. Ash, debris, etc., may also be collected from a space or container under the bottom of the chamber 102 for easy removal. The flue 116 is also illustrated as a partially cut-away view to show a first temperature sensor 104 located inside the flue 116 near the top of the combustion chamber 102. The exhaust gases exiting the chamber 102 may travel through the flue 116 to a heat exchanger 118. After passing through the heat exchanger 118, the exhaust gases may then encounter the second temperature sensor 112 in a distal cavity before flowing through the fan 122 and out of the burner through a distal exit opening 210.

As shown in FIG. 2B, the exhaust 114 may flow through the fan 122 and into a cyclone 218 to separate any particulate matter from the rest of the exhaust 114 before exiting the machine through the distal exit opening 210. The particulate matter separated by the cyclone 218 may be collected in a container 222. An air inlet or vent 220 may also be provided on the top of the machine on the distal side of the heat exchanger 118 to pull in air for the fan 122. This additional air accommodates the higher capacity of the fan 122 and above the flow rate of the exhaust 114. The additional air combining with the exhaust 114 also helps to cool the exhaust 114 before entering the fan 122 and cyclone 218, which helps to protect the fan 122 from high temperatures. The air inlet 220 may also function as a vent to allow heat to escape from the exhaust flow before being pulled through the fan. The entire burner unit may be enclosed by an outer housing 201 that may comprise a plurality of assembled panels, pieces, etc.

An example of a heat exchanger 118 is shown in FIG. 2 having a plurality of vertical tubes or pipes with a spiraling turbulator or scraper disposed lengthwise in each of the tubes or pipes to discourage laminar flow of the exhaust gases 114 within them to cause more efficient heating of the surrounding fluid 120. Each turbulator or scraper may also be twisted to mechanically scrape away any ash, creosote, or any other buildup on the inner surfaces of these tubes from the exhaust gases 114 running through them. Any ash, etc., that is scraped off may fall into a collection tray 211 at the bottom that may be pulled out or removed for cleaning. According to this example for a heat exchanger 118, exhaust 114 flowing through flue 116 that enters exchanger 118 may encounter a divider or partition wall 212 dividing a top portion of the heat exchanger 118. Thus, the exhaust 114 is forced to flow down through the vertical tubes 215 on the proximal side of the partition 212 toward the bottom of the exchanger 118 where the exhaust may cross over through a common area or connectors near the bottom of the exchanger 118. The exhaust gases 114 may then flow up through the vertical tubes 216 on the distal side of the exchanger 118 before flowing out of the unit through the fan 122 and distal exit opening 210.

Exchange of heat with the circulating fluid 120 inside the heat exchanger 118 may occur with the tubes heated by the exhaust gases near the bottom portion of the exchanger 118. The fluid 120 may enter a distal compartment of the heat exchanger 118 surrounding the distal vertical tubes 216 and enter a proximal compartment of the exchanger 118 surrounding the proximal vertical tubes 215 through a lower opening (not shown) before exiting the heat exchanger 118. Thus, the fluid 120 may be described as being in counter flow relative to the flow of exhaust gases 114 traveling through the exchanger 118. However, as stated above, FIG. 2A only provides an example of a heat exchanger that may be used, and any of a variety of suitable heat exchangers may be used in conjunction with the burner of the present invention.

FIG. 3 depicts a view of the combustion chamber 102 isolated from the rest of the burner that further shows a partially cut-away view of an air inflow system in accordance with embodiments of the present invention. Additional features, such as an air inlet or intake source(s) or hole(s) 301a, 301b, a plenum and a preheated channel(s) 303a, 303b, may be provided outside the combustion chamber 102. A benefit of this design illustrated in FIG. 3 is that cool air that is drawn into the burner may be pre-heated by the outside of the combustion chamber 102. As shown in FIG. 3, a plurality of cold air intake holes 301a, 301b may be provided near the bottom of the plenum, such as in the floor 205 of the unit adjacent to, and around the perimeter of, the combustion chamber 102, to allow air to enter the plenum from the surroundings, such as from under the unit. Three such holes may provide beneficial results but more or less holes may be used without departing from the present invention. A plenum space may be formed by four side panels 305a, 305b, 305c, 305d and a top panel 326 that surround and enclose the plenum space between these panels and the outside of the chamber wall 302. If not
enclosed by the top panel 328, the top of the combustion chamber itself may be enclosed by a top wall 329 that has the flue opening 328 formed therein. The side panels may be generally vertically oriented and positioned above, resting on, and/or attached to, the floor of the unit. The plurality of cold air intake holes 301a, 301b may be positioned in the floor of the unit between the side panels and the combustion chamber (i.e., connected with the plenum space). A plenum is shown in FIG. 3 with two side panels 305c, 305d that surround the plenum removed for viewing. The side panels enclosing the plenum space are sized and positioned such that air drawn through the intake holes 301a, 301b is drawn into the plenum. The bottom of the combustion chamber may be enclosed by a bottom wall 331 (not shown) that is above the floor 205 of the unit that may be made of the same or similar material as used to enclose the sides of the lower portion 202 of the chamber 102. There may be a hole or bore through the bottom wall 331 and floor 205 of the unit to allow a shaft that rotates the stirrer 106 to reach the interior of the chamber 102.

To encourage greater circulation of air within the plenum and contact of the air with the outside of the chamber 102, and thus greater preheating of the air entering the chamber 102, one or more channel(s) 303a, 303b may be further provided inside the plenum space. The channels 303a, 303b may be juxtaposed with the outer side of the chamber and may reach or span from near or at the floor 205 of the unit to near the top of the plenum space. However, the channels 303a, 303b may generally not reach the top of the plenum space, the top panel 328 and/or the top of the chamber 102 such that there is a gap 310 near the top of the plenum where air inside the plenum may flow into the top of these channels 303a, 303b. Air entering the plenum through the air intake hole(s) 301a, 301b during operation near the bottom of the unit would then flow upward within the plenum where it would enter the channel(s) 303a, 303b through the gap 310. The air would then flow downward through these channel(s) 303a, 303b before entering the chamber 102 through an air inlet(s), which may be an air inlet tube, bore, etc., near or toward the bottom of the plenum (see below). Thus, the air entering the plenum 208 due to the negative pressure generated by the fan 122 is forced to flow over the outside combustion chamber 102 before descending through the channel(s) 303a, 303b and entering the chamber 102 through the outside of the chamber. In this way, the outside of the combustion chamber 102 is cooled while air entering the combustion chamber 102 is warmed or preheated. Although the channels 303a, 303b are shown as being vertically oriented, they need not be perfectly vertical or linear. Once the air is heated inside the chamber in and above the combustion zone to form an exhaust 114, the heated exhaust 114 then travels through a flue opening 330 in the top of the chamber.

A fuel inlet tube 502 is also shown in FIG. 3 for adding fuel to the chamber 102 (See FIG. 5 below). Also shown in FIG. 3 are an igniter receiving slot 322, a side door receiving slot 324, and an access point 326 for removing ash, etc., from under the chamber 102, such as by using a hand-operated auger screw (not shown).

FIG. 4 shows another set of views of the embodiment of the combustion chamber 102 described above in reference to FIGS. 2 and 3. FIG. 4A shows a side view of the isolated combustion chamber from FIG. 3, and FIG. 4B shows a cross-sectional view inside the chamber 102 as indicated by plane and arrows 43 in FIG. 4A. In particular, FIG. 4B shows an air inlet tube or bore 402 for allowing air to enter the combustion chamber 102 from a lower part of the one of the channel(s) 303a, 303b. Indeed, an air inlet may be provided for each of the channel(s) 303a, 303b to bring air from each channel into the chamber 102. The air entering the combustion chamber 102 through the inlet tube 402 is already preheated as a result of flowing up through the plenum and down through the channels 303a, 303b on the outside surface of the combustion chamber 102. This preheated air may enter the combustion chamber 102 through one or more air inlet tube(s) 402 associated with one or more channel(s) 303a, 303b.

As explained further below, the location, size and orientation of each air inlet tube 402 (along with the cylindrical shape of the chamber 102) is that air flow near the fuel in the bottom or lower portion of the chamber 102 is cyclonic in nature, which helps to burn the fuel more evenly and quickly and maintain a relatively uniform temperature within the lower fuel burning portion of the chamber 102. This design also helps to prevent or minimize sparks and unburned particles from escaping with the exhaust gases. In addition to being angled downward toward the combustion chamber 102, the air inlet tube 402 will also be angled off to one side such that it is tangential to the inner wall face of the combustion chamber. This combination of being angled downward and angled off to one side encourages the air flow to enter the bottom of the chamber 102 in an orderly fashion such that the air flows in a circular or spiral direction around the interior of the chamber to create a cyclonic flow of the heated air as it flows upward to the top of the chamber, which is further encouraged by the cylindrical shape of the chamber. This cyclonic flow of air and exhaust from the burn leads to a more complete and efficient burn of the fuel.

FIG. 5 shows yet another set of views of the combustion chamber 102. FIG. 5A shows a side view of the chamber and associated components isolated from the rest of the burner as in FIGS. 3 and 4, and FIG. 5B shows a cross-sectional view inside the combustion chamber 102 as indicated by plane and arrows 53 in FIG. 5A. As may be seen in FIG. 5B, a fuel inlet tube 502 may be generally cylindrical in nature and have a top portion 504 where the fuel enters, such as from a fuel feed assembly, and a bottom portion 506 near the combustion chamber 102 where the fuel exits the fuel inlet tube 502 and enters the chamber 102 through an opening in the lower portion 506. Thus, fuel travels down the inlet tube 502 by gravity and drops through the bottom portion 506 and into the chamber 102 for burning.

The figures described above illustrate an embodiment of a bio-mass burner in accordance with the principles of the present invention. The specific sizes, shapes and angles of the various components and features of the burner may vary without departing from the scope of the present invention. However, by way of example, specific sizes, shapes, angles, etc., of the components are provided below to illustrate configurations or embodiments of a non-catalytic biomass burner of the present invention that may be operable in the 100,000 to 500,000 BTU/hr range or higher. The non-catalytic bio-mass burner of the present invention may also operate at efficiencies of about 70-80% or higher, which may be at or near operating efficiencies of catalytic burners, although other efficiency ranges are also possible. According to some embodiments, there may be four cold air inlets with two of those inlets having a diameter of about two inches and the other two having a diameter of about 1 inch. The inside diameter of the combustion chamber may be about 10 or more
and the height of the combustion chamber may be between about 32 to 34 inches for a 100,000 BTU unit. But the height and diameter of the combustion chambers may be greater for units having higher BTU output. For example, the diameter of the chamber for a 500,000 BTU unit may be up to about 30 inches or higher, and the height of such a chamber may be up to 50 inches or higher. To maintain a cylindrical shape, the height of the chamber may generally increase as the diameter increases, and vice versa. The diameter of the flue from the combustion chamber to the heat exchanger may range from about 4 inches to about 8 inches. The fuel stirrer, if present, may have a length of about 9 inches or greater depending on the diameter of the chamber to allow for coverage and easy rotation within the chamber.

[0054] According to these embodiments, the fuel inlet tube may have a diameter of about 4 inches to 6 inches and have an opening in its lower portion nearest the combustion chamber that is between about 9 inches and 15 inches above the bottom of the combustion chamber. The fuel inlet tube may have a central or longitudinal axis that may be inclined more than 45° but less than or equal to 90° from horizontal (i.e., relative to the ground or the floor of the unit), such as approximately 55° from horizontal, so that the fuel may freely fall down the shaft of the fuel inlet tube. Each air inlet tube may have a diameter of about 1 or 2 inches and a central or longitudinal axis that is inclined or angled downward toward the combustion chamber at an angle in a range between about 15° and 40° from horizontal, such as about 25°, in addition to being angled off tangentially to one side as described above. The air inlet tube may enter the combustion chamber at a position that is in a range from about 2 inches to about 4 inches above the bottom of the combustion chamber.

[0055] There has been difficulty in providing a fuel feed assembly or mechanism that can deliver a wide range of fuels to the combustion chamber of a burner. In many fuel hopper designs, a phenomenon called “bridging” occurs that clogs the feed mechanism and requires frequent stoppage and cleaning of the feed mechanism. Thus, there is a need for a fuel hopper delivery system that can effectively provide a wide range of fuels to a burner or stove and avoid the consequence of bridging. Thus, according to another aspect of the present invention, a universal feed system is provided that can deliver a variety of fuel types to a burner. Although the burner itself of the present invention is described as being non-catalytic, such universal feed system could potentially be used to provide fuel to different types of stoves, burners, or boilers. The fuel hopper may be sized to hold a multi-day supply of fuel that may be automatically fed to the burner at various controlled rates to maintain desired operating characteristics of the burner.

[0056] FIG. 6 depicts a cutaway view of a fuel feed hopper in accordance with embodiments of the present invention. In general, the fuel feed hopper assembly in FIG. 6 may operate under control of a computer (e.g., computer 124 in FIG. 1) to feed fuel at a desired rate into a fuel inlet tube, such as the fuel inlet tube 502 shown in FIG. 5, which feeds into the combustion chamber of a burner. The assembly 600 may include a hopper 602 that may be cylindrical in shape as defined by a sidewall 604 and have a generally cylindrical opening. Although hopper 602 may generally be cylindrical in shape, other shapes or polygons formed by one or more sidewall(s) 604 may also be used. The hopper 602 may be shaped such that its sidewall(s) 604 taper inward from the bottom to the top such that an angle formed between the sidewall 604 and the bottom floor 606 of the hopper 602 would be 90 degrees or less. However, the smaller that angle is, the less the hopper 602 will hold. A taper angle of between about 3° and 10° (i.e., an angle between the sidewall and floor of about 80° to about 87°) may provide beneficial results. The size of the hopper 602 may depend on the desired amount of fuel to be stored in the hopper 602. Thus, the height and diameter of the hopper 602 may vary over wide ranges without departing from the scope of the present invention.

[0057] The hopper 602 may also include a floor 606 having an outside edge that is adjacent to the bottom of the sidewall (s) 604. The floor 606 may be “live” in that it can rotate relative to the sidewall(s) 604. Thus, the floor 606 may not be rigidly connected to the sidewall(s) 604 to allow for rotation. One of ordinary skill will recognize that there are functionally equivalent ways to create a live rotating floor 606. A motor 607 may be included and located beneath the floor 606 to provide the drive power to rotate the hopper floor 606. A variety of designs may be used to maintain a seal or barrier where the sidewall(s) and floor meet while allowing for free relative movement. For example, the outside edge of the floor 606 may travel in a groove within the sidewall 604 or the floor 606 may include a lip or groove that engages the bottom of the sidewall 604. The result in either case is that the sidewall 604 and floor 606 join in such a way that the floor 606 can rotate relative to the sidewall 604 but the fuel within the hopper 602 is prevented from inadvertently leaking from the hopper 602.

[0058] A generally horizontal rod 608 may be affixed to a center support 609 that is connected to the floor 606 such that rotation of the floor 606 causes the rod 608 to push the fuel that is within the hopper 602 against a feed auger 610 that pulls the fuel out of the hopper 602. Particularly with light fuels, rotation of the floor 606 can push the fuel up over the feed auger 610 if the rod 608 is not present. When the rod 608 is positioned in close proximity to the feed auger 610, the rod 608 acts to press, or hold, fuel near the feed auger 610 so that feed auger 610 may engage the fuel more effectively to pull it out of the hopper 602 instead of allowing a majority of the fuel to simply pass over the feed auger 610. The rod 608 may extend out lengthwise in one or both direction(s) from the center support 609 to a position near the sidewall(s) 604. If the rod extends out in one direction, it may generally be on the side where the fuel meets the feed auger 610. To be effective, however, it is not necessary that the rod 608 get very close or touch the sidewall 604. In general, the rod 608 will be positioned high enough off the floor to be above the flighting of the feed auger so that the rod 608 does not interfere with the fuel reaching the feed auger 610. The rod 608 may be positioned in a generally horizontal line or plane that is about 2 inches or less, or about 1 inch or less, above the floor of the hopper.

[0059] To pull and remove the fuel from the hopper 602, there is the feed auger 610 just above the floor 606 that rotates to move the fuel from inside the hopper 602 to an elevator screw 614 on the outside of the hopper 602. The elevator screw 614 then transports the fuel upwards to an exit opening 618 where it drops into a fuel inlet tube of a burner. The feed auger 610 and the elevator screw 614 may be driven separately by a first motor 612 and a second motor 616, respectively. As explained further below, the feed auger 610 along the bottom of the hopper 602 is positioned to span almost half the diameter of the inside of the hopper 602 from the sidewall 604 toward the center 609 of the hopper 602. Accordingly, the fuel inside the hopper 602 is moved by rotation of the floor
606 of the hopper 602 (see rotational arrow 620) to cause the fuel to engage the feed auger 610. The fuel is encouraged to meet the feed auger 610 in a uniform manner due to the action of the rod 608. The feed auger 610 rotates to pull the fuel out of the hopper through a side opening of the hopper 602 and into an elevator screw 614.

Fig. 7 shows a zoom view of a portion of the hopper in Fig. 6 near the side opening 708 near the bottom of the sidewall 604 where the fuel exits the hopper 602. The feed auger 610 has fighting that removes the fuel that is in the hopper 602 and delivers it to the opening 708 where it passes through an outside chamber 704 and into the elevator screw 614. The fuel delivered to the opening 708 falls through the chute 710 to the bottom of the elevator screw 614 (see first arrow 622). The elevator screw 614 has threads or fluting 706 that lift and carry the fuel upwards as the elevator screw 614 rotates (see second arrow 624). Rotation of the elevator screw 614 may be driven by a second motor 616. The feed auger 610 may generally be coupled to the first motor 612 located on an outer side of the outside chamber 704. The feed auger 610 may extend from the first motor 612 through outside chamber 704 and into the hopper 602 interior through the side opening 708.

The rate at which the fuel moves out of the hopper 602, into the elevator screw 614 and ultimately into the fuel inlet tube of the burner may be controlled at least in part by coordinating the operation of the first and second motors 612, 616. The rate of fuel flow into the burner will also depend on the pitch and diameter of the flighting (both the feed auger 610 and elevator screw 614) in addition to their rate of rotation. By coordinating the operation and speed of the motors 612, 616 (including turning them on or off), the rate of fuel addition to the combustion chamber of a burner may be controlled such that a desired operating temperature and BTU output may be attained. All augers and screw conveyors, such as the elevator screw and the feed auger, that may be used as part of a fuel feed assembly of the present invention may be referred to jointly and collectively as screw augers.

In conjunction with the control of the motors 612, 616, a drive motor 607 that causes rotation of the floor 606 of the hopper 602 may also be variably controlled as an additional way to further control the rate at which fuel is fed out of the hopper 602. Indeed, each of these motors (particularly the drive motor 607 and the first motor 612) may be controlled by a computer, such as computer 124 in Fig. 1, to increase or decrease their speed concurrently to speed-up or slow-down, respectively, the rate fuel is removed from the hopper 602. The relative speeds of rotation of the elevator screw 614 and the feed auger 610 will be determined, at least in part, on the flying dimensions of the feed auger 610. The speed of the feed auger 610 is selected to remove fuel from the hopper 602 at a desired rate and may thus be variably controlled between a minimum and maximum speed. The speed of the floor 606 may be selected or controlled accordingly to not overload the feed auger 610. Rotating the floor 606 at too great of a speed, based on the relative feed auger speed, would not result in more fuel being removed from the hopper 602 and might bend or otherwise damage the feed auger 610. On the other hand, rotating the floor 606 at too low of a speed may starve the feed auger 610 so that more revolutions-per-minute are required by the feed auger 610 to remove fuel from the hopper 602 at a desired rate. Thus, the speed of the floor 606 may be controlled to provide a maximum amount of fuel to the feed auger 610 without overfeeding.

The size or diameter of the fighting of the feed auger 610 and its length may be chosen to assist in keeping the fuel within the hopper from “bridging,” which refers to the fuel clumping together in such a way that it stops the flow of fuel from within the hopper 602 to outside the hopper 602. The feed auger 610 may generally extend toward the center 609 of the floor 606 of the hopper 602. A feed auger 610 that extends into the hopper 602 by about 90% of the hopper’s radius or greater may be sufficient to avoid bridging. The feed auger 610 may extend into the hopper 602 by about 98% of the hopper’s radius according to some embodiments. The size or diameter of the flighting of the feed auger may also depend on the size of the fuel. For example, a feed auger with feeds that is approximately 2-by-2 (i.e., a two inch outer diameter with a two inch pitch) may be effective and beneficial for use with fuel that has a particular size that ranges from about dust to about 2 inch or larger chips (e.g., GSO chip size).

The directions and speeds of rotation of the hopper floor 608, the feed auger 610 and the elevator screw 614, and thus motors 607, 612, 616, must be coordinated with each other for orderly flow of fuel out of the hopper and into the burner. According to the configuration shown in Figs. 6 and 7, the floor 606 may rotate in a counter-clockwise direction (viewed from the top); the feed auger 610 may be a right-handed auger that rotates in a clockwise direction (viewed from its drive motor 612); and the elevator screw 614 may be right-handed and rotate to push the fuel up as it rotates. One of ordinary skill would recognize that these rotation directions can be reversed relative to one another without departing from the scope of the invention. For example, if the floor 606 instead rotates in a clockwise direction (viewed from the top), the feed auger 610 may be a left-handed auger that rotates in a counter-clockwise direction (viewed from its drive motor 612). The second motor 616 may be located at the base of the elevator screw 614 instead of at the top.

According to another set of alternative embodiments, the floor of the hopper may not rotate, and instead a rod or some other functional equivalent, such as a plow, arm, etc., may be rotated around a center support to push the fuel to engage the feed auger. According to some embodiments, the feed auger may be recessed beneath the floor of the hopper in a cavity, and the fuel may be pushed into the cavity by the rotating rod, plow, arm, etc.

Generally speaking, the burner of the present invention may regulate the rate at which fuel is added to the combustion chamber by controlling the rate at which the fuel is delivered to a fuel inlet tube or opening of the burner that feeds, guides or drops the fuel into the combustion chamber of the burner. According to embodiments of the present invention, a fuel feed assembly that controls the rate at which the fuel is added to the burner (e.g., to the fuel inlet tube of the burner) may be any mechanized metering system known in the art, which may have one or more augers that have a rotational rate that is controlled by one or more motor(s). The auger system shown in Figs. 6, 7 and 8 are merely examples of an auger and hopper system that may be used as a fuel feed assembly according to the principles of the present invention. According to the fuel feed assembly shown in Figs. 6 and 7 (as mentioned above), the rate at which fuel is delivered to the burner by the fuel feed assembly may depend on the rate of rotation of the feed auger and/or the elevator screw, and/or the rate of rotation of either the hopper floor or the rotating rod, arm, etc.
In accordance with the principles of the present invention, many different types of fuel can be efficiently burned regardless of the particulate size of the fuel, its uniformity, or its moisture content. Thus, it would be beneficial for a fuel feeding hopper of the present invention to be able to effectively deliver such varying types of fuel to the combustion chamber of a burner to be burned. Accordingly, a restrictor plate is proposed for use in conjunction with a feed assembly and hopper to assist with controlled delivery of fuel to the elevator screw, and thus to the combustion chamber of the burner. Figure 8A shows a perspective view of an exemplary restrictor plate according to the present invention, and Figure 8B shows the restrictor plate as part of the outside chamber. This restrictor plate includes a generally vertical wall and a generally horizontal top. There is an opening in the face of the wall. The opening may be sized to correspond to the size or diameter of the flighting of the feed auger. In operation, the restrictor plate is not generally needed for bulk fuels, such as mulch or chip-type fuel. However, with pelleted and similar types of fuels, the restrictor plate may be utilized to limit the amount of fuel entering the outside chamber and being dropped down the chute. Thus, if the opening is sized slightly greater than the flighting of the feed auger, then the fuel being delivered to the outside chamber may be substantially limited to the fuel that is within the flighting of the feed auger.

Figure 8C shows the restrictor plate in use according to principles of the present invention. The top of the restrictor plate sits on top of an opening in the top of the outside chamber such that the wall is positioned near the end of the flighting of the feed auger, and the side opening of the hopper. Figure 8C further shows that the flighting of the feed auger may extend nearly the start of the chute below the chamber with about 1/4 to 1/2 of a turn of flighting of the feed auger present to the right of the wall to help ensure that the fuel is fed fully into the outside chamber. When use of the restrictor plate is not desired, it can be rotated 180 degrees around a vertical axis and positioned in operation at top of the chamber as shown in FIG. 8D. In this orientation, the fuel removed by the feed auger from the hopper may be delivered to the outside chamber in a less restricted manner (i.e., without the vertical wall of the restrictor plate constricting flow). The wall in FIG. 8D is instead positioned near the far edge of the chute so that fuel delivered to the outside chamber is directed down the chute.

As mentioned before, the computer may be used to control the rate at which fuel enters the combustion chamber, which may be by controlling the rate of operation of a fuel feed assembly that feeds the fuel accordingly to the fuel inlet tube. Controlling the rate of delivery of fuel is critical to controlling the combustion temperature and BTU output inside the chamber of the burner. As an example, the hopper described in FIGS. 6 and 7 may be used as the fuel feed assembly, and the rate of addition of fuel into the fuel inlet tube of the burner may be determined by the rate of rotation of the screw augers by controlling the motors that run the screw augers. However, any other suitable feed assembly device may be used instead to control the rate of fuel addition to the chamber.

As explained in the control algorithms below, the temperature inside the combustion chamber may be monitored and controlled to be at or near a desired temperature or within a desired range of temperatures by controlling the fuel flow rate, the air flow rate and operation of the auxiliary burner or igniter. Indeed, primary control of the combustion chamber temperature may be achieved by controlling the rate of fuel addition to the chamber with control of the fuel/air flow and the igniter providing additional control of uniformity by controlling the combustion chamber temperature. In general, use of the igniter and addition of more fuel may each lead to higher combustion temperatures, whereas faster operation of the fan may cool the temperature. Generally, the fuel delivery rate may be increased to increase operating temperatures and slowed down to decrease operating temperatures. However, addition of fuel above a certain rate may cool the chamber at least temporarily (especially if the fuel has a high moisture content) if the fuel rate oversaturates or exceeds the amount of fuel that can be quickly combusted or burned. Based on the size of the fuel, its moisture content, and fuel type, different fuel delivery rates may be used to achieve a desired operating temperature. Since operation of the burner may be based on feedback information regarding the chamber temperature, the burner may self-regulate the rate of fuel addition and other parameters to control the temperature to keep it within a desired range.

As in any control system, there is a hysteresis curve that describes how a maximum temperature may be overshot and a minimum temperature may be undershot before equilibrium is reached. Certain embodiments, different types of fuel may be associated with different respective hysteresis curves. By operating based on feedback information, the general control algorithms for the burner of the present invention may be customized and used to automatically control the temperature regardless of the fuel type. In this way, the same general control algorithm applies for any type of fuel with different customized values that may depend on the physical qualities of the fuel.

Fig. 9 is a flowchart showing a series of high level method steps for operation of an algorithm according to embodiments of the present invention that may be performed by a computer to control operation of a non-catalytic burner of the present invention. This algorithm provides a basis for methods of the present invention that may be implemented by a computer, such as a programmable logic controller (PLC) or microcontroller, that may also include, or be associated or in communication with, a computer readable medium, which may be used to store a computer readable program code configured to instruct the computer to implement or execute the methods and algorithms of the present invention.

Starting with a cold burner in step 901 with no fuel being present nor any auxiliary burner or igniter providing heat, an auxiliary heat source or igniter is turned ON in step 903 to begin warming and heating the combustion burner. If fuel were simply added to the combustion chamber and ignited at this time, the burner would produce smoke and pollutants until the combustion chamber temperature became high enough to cleanly burn the fuel.

While the igniter is still running, the combustion chamber temperature is monitored and the fuel rate is controlled in step 905 to determine when and how much fuel is added to the chamber. The combustion chamber temperature may be measured by a temperature sensor, such as the first temperature sensor 104 in FIG. 1. The process for step 905 is a method or algorithm in itself and is discussed more fully below in reference to FIGS. 10 and 11. The igniter continues
to run even after fuel begins being added to the chamber to ignite and cause combustion of the fuel until a threshold temperature is reached. In step 907, the computer determines based on feedback information whether the combustion chamber temperature has reached a first igniter off temperature (e.g., a temperature between about 1200°F and about 1800°F, or between about 1300°F and about 1600°F, or between about 1400°F and about 1600°F, such as 1500°F). The first igniter off temperature may also depend on a smoke guard setting (see below). If the combustion chamber temperature has not reached the first igniter off temperature, then the program or algorithm cycles back to the fuel control step 905 and subsequently returns to the Igniter OFF decision step 907. This cycle may repeat until the first igniter off temperature is reached. However, once the computer controller determines in step 907 that the combustion chamber temperature has reached the first igniter off temperature, the igniter will be turned OFF in step 909, and the algorithm will proceed to step 911 to control when and how much fuel is added to the chamber based on the combustion chamber temperature. Again, step 911 is a method or algorithm in itself that is performed identically to step 905 and is discussed further below in reference to FIGS. 10 and 11. Since many of the steps of the control algorithms of the present invention, including those in FIGS. 9, 10 and 11, are based on the chamber temperature, a step of monitoring the combustion chamber temperature from a temperature sensor may be performed over the course of these methods in a repeated, intermittent or continuous manner.

Once the algorithm in FIG. 9 reaches the fuel control rate step 911, it has escaped the igniter start-up routine for operation of the burner until the burner is later restarted after being cooled down or turned off between uses. However, the igniter may also be used during operation as an additional variable to help control the combustion chamber temperature. In step 913, the igniter may be turned on during operation of the burner if the chamber temperature falls below a threshold temperature to bring the combustion temperature back up to within a desired range. But if the combustion temperature is above the threshold temperature for the igniter, then the igniter would remain off at step 913. This step of controlling the igniter during operation of the burner may be referred to a smoke guard feature to avoid or minimize production of smoke during periods when the burner is operating at lower temperatures. Step 913 is a method in itself and is discussed further below. Much like how the igniter may function at step 913 to keep the combustion temperature from falling too far below a minimum threshold temperature, operation and control of the fan at step 915 may function to bring air into the combustion chamber and keep the combustion temperature from becoming too hot during periods of operation. Controlling the fan is also discussed further below. After the fan control step 915, the method or algorithm of the control computer may then cycle back to the fuel control step 911, and the cycle of steps 911, 913, and 915 may be repeated during operation of the burner.

In addition to the general control steps depicted in FIG. 9, additional control or safety step may also be implemented during operation of a burner of the present invention. These additional control or safety steps may be interposed or in sequence with, or carried out independently of, the other control steps, such as those in FIG. 9. These control steps may affect the rate of operation of the fan and/or a fuel feed mechanism based on feedback information regarding temperature(s). For example, the fuel may be shut off or the burner may be turned off for safety when a maximum fluid temperature (e.g., about 190°F) is reached for the circulating fluid of the heat exchanger discussed above. A thermal fuse may also be used in connection with the fuel inlet tube to stop fuel delivery to the chamber and/or to release a volume of water into the fuel inlet tube if the temperature of the fuel inlet tube gets too high (e.g., 165°F). Other safety controls may also be used. For example, the flow rate may be slowed or stopped and/or the fan rate may be increased if the second temperature sensor detects too high of a temperature.

According to embodiments of the present invention, FIGS. 10 and 11 present a method or algorithm for control of the fuel flow rate into the combustion chamber during operation of the burner to control the combustion chamber temperature. One pass through the entire fuel control algorithm presented in these figures may be performed in a very short period of time by a computer, such as in about 35 milliseconds. Thus, the fuel rate may be controlled by this algorithm over a period of time only by repeatedly passing or cycling through it over that period of time. Fuel delivery to the chamber at any given rate over time may occur continuously or in pulses. The method presented in FIGS. 10 and 11 may be performed independently or as part of another process, such as the high level algorithm in FIG. 9. In those cases where the fuel control algorithm, such as the one shown in FIGS. 10 and 11, is performed in the context of the high level method of FIG. 9, then the fuel control algorithm will correspond to steps 905 and 911 in that process.

At the beginning of the fuel control method shown in FIG. 10, a safety check is first performed to ensure that the igniter, if running, operates for a minimum period of time before the fuel is turned on at any rate. This check may be to conform to manufacturer and/or UL safety standards (e.g., as a purge timer). In a first step 1001, the algorithm determines or queries whether the igniter is turned on. Whether or not the igniter will be turned on or off at this point will be determined by separate a control method or steps, such as steps 903, 909 and 913 in the higher level method or algorithm of FIG. 9, that are independent of the fuel control algorithm. If the igniter is not ON (i.e., OFF), then the rest of the fuel control algorithm proceeds beginning at step 1009. However, if it is determined at step 1001 that the igniter is ON, then an igniter timer is started at step 1003 (if not already started and running), and a System Stable status is “reset” at step 1005. The meaning of the System Stable status will become more apparent below, but it refers to a status that may be achieved that affects which subsequent steps are taken by the fuel control algorithm. This status may be set to System Stable or not. The System Stable status may be achieved or set based on operating conditions at a later step in the algorithm. If System Stable status is not achieved (or if System Stable status is reset), then the status is not System Stable and may be described instead as System Unstable. Thus, resetting System Stable status results in the System Stable status not being achieved or set.

After resetting the System Stable status, a decision step 1007 is reached in which it is determined whether the igniter delay timer (started at a previous step 1003) has expired (e.g., after 35 seconds). Obviously, if the timer had just started, it may not yet have expired. But, the timer would eventually expire after several passes or cycles through the algorithm. If it is determined at step 1007 that the igniter delay timer has not yet expired, then the fuel is turned (or remains) OFF at step 1011, which means that no fuel is added.
to the combustion chamber. The algorithm then proceeds to the “end,” at which point the fuel control algorithm is exited until the next pass through it according to a higher level control algorithm, such as the one in FIG. 9. If, however, the delay timer is determined to have expired at step 1007, then the remainder of the fuel control algorithm proceeds beginning at step 1009.

[0080] After the igniter safety check step(s), the fuel control algorithm continues with the fuel rate being determined according to the following steps. At step 1009, a decision is made whether the combustion chamber temperature has reached a minimum fuel run temperature. The minimum fuel run temperature (e.g., a temperature in a range from 250°F to 990°F, or from 400°F to 700°F) may be preset or set by the user (within limits) depending on a tolerable amount of smoke that may be produced during an initial period of time while the chamber is warming up to a more desirable operating temperature. Thus, even though very little smoke, if any, may be generated at a lower setting (i.e., a lower minimum fuel run temperature), a higher minimum fuel run temperature may ensure less smoke production when the fuel is first added. According to some embodiments, the minimum fuel run temperature may depend on a smoke guard setting or may be held constant regardless of smoke guard setting (see below). If it is determined at step 1009 that the combustion chamber temperature is not greater than the minimum fuel run temperature (e.g., 600°F), then the fuel is turned (or remains) OFF at step 1011, and the algorithm proceeds to “End.” If, on the other hand, the combustion chamber temperature is greater than the minimum fuel run temperature, then the fuel control algorithm proceeds on to decision step 1013 to determine if a higher temperature threshold is reached, which affects the fuel rate. At step 1013, it is determined whether the combustion chamber temperature is greater than or equal to a full fuel run temperature, which may be any temperature in a range from about 600°F to 1600°F, or any temperature from about 900°F to 1100°F (e.g., 990°F). According to some embodiments, the full fuel run temperature may depend on a smoke guard setting (see below). If it is determined that the combustion chamber temperature is greater than or equal to a full fuel run temperature, then the method proceeds to step 1015 to run the fuel at a user selected fuel rate/speed. However, if it is determined instead that the combustion chamber temperature is less than the full fuel run temperature (or less than the full fuel run temperature minus 1°F), then the method proceeds to step 1017 to run the fuel at slower rate that is a predetermined fraction (e.g., about half or 50%) of the user selected fuel rate. The user selected fuel rate may be set by the user before and/or during operation of the burner, but the user selected fuel rate may be limited to being within a preset range.

[0081] According to some embodiments, the user selected fuel rate may range about 20% and about 100% of the motor capacity causing rotation of one or more augers of a fuel feed assembly. It may be selected numerically by the user or according to a preset recipe (that may depend on the fuel type). The selected rate may be higher for lighter and/or wetter fuels (e.g., dust) and lower for denser fuels (e.g., pellets). Any preset or selected levels or ranges of fuel rate or speed for a particular type of fuel may vary according to empirical evidence. Indeed, the fuel rate may vary substantially depending on fuel type and density. For example, a denser fuel may be fed at a user selected rate of about 40% of the capacity of the fuel feed assembly motor, whereas a lighter or wetter fuel may be fed at a user selected rate of about 60% of the capacity of the fuel feed assembly motor. The feeding of fuel into the combustion chamber at a given rate (when running) may also be pulsed on/off for alternating time periods, such as for alternating 5-10 second (or longer) ON and OFF periods.

[0082] Continuing from step 1015 after it is determined at step 1013 that the chamber temperature is less than the full fuel run temperature, the algorithm proceeds to step 1023 in which a fuel prime timer is “reset.” The fuel prime timer is described further below, but resetting the fuel prime timer means that the timer is reset to a full amount of time for use later if the temperature falls below the full fuel run temperature. After resetting the fuel prime timer at step 1023, the fuel control algorithm proceeds to step 1025 discussed below.

[0083] Continuing instead from step 1017 (after it is determined at step 1013 that the chamber temperature is less than the full fuel run temperature), the algorithm proceeds to step 1019 in which a fuel prime timer is enabled or started to run for a period of time if it is not already started and running. After step 1019, a decision step 1021 is reached in which it is determined whether the fuel prime timer (started at a previous step 1019) has expired (e.g., after a period of time between about 30 seconds and about 10 minutes, such as after 120 seconds). Obviously, if this timer had just started, it may not have expired yet. But, decision step 1021 may eventually be reached with the fuel prime timer having expired after several passes or cycles through the algorithm. If it is determined at step 1021 that the fuel prime timer has not expired, then the fuel control algorithm proceeds to step 1025 discussed below. However, if it is determined at step 1021 that the fuel prime timer has expired, then the fuel control algorithm proceeds to step 1011 and the fuel is shut off. Basically, the fuel prime timer allows for a period of time to pass during which the fuel is allowed to run at a fraction or half the user selected fuel rate, but if the chamber temperature cannot reach the full fuel run temperature during this time, the fuel is shut off and remains off until the chamber temperature reaches the full fuel run temperature, after which the fuel prime timer is reset. Importantly, the fuel prime timer is not reset when it expires unless step 1023 is reached.

[0084] At decision step 1025 with the fuel running at the user selected fuel rate or at a fraction or half of the user selected fuel rate depending on the combustion chamber temperature, the algorithm determines whether Auto Combustion is enabled. Auto Combustion is a state or manner of operation that may be selected by a user input (i.e., enabled or disabled by the user). If Auto Combustion is enabled, then a more elaborate set of controls are implemented to automatically control the fuel rate and thus the combustion chamber temperature. However, if Auto Combustion is not enabled, then a more simple control is employed to control the flame and temperature of the chamber.
combustion temperature (e.g., 1600°F), then the fuel is turned OFF at step 1029, and the method proceeds to step 1031. If the combustion chamber temperature is not determined to be greater than the user combustion temperature at step 1027, then the method proceeds to step 1031 without turning the fuel OFF (i.e., step 1029 is bypassed). Step 1031 determines instead if the combustion chamber temperature is less than the user combustion temperature or less than the user combustion temperature minus one or more degrees (e.g., 1590°F). If the combustion chamber temperature is less than the user combustion temperature (or less than the user combustion temperature minus one or more degrees), then the method proceeds to step 1033 and the fuel is turned ON (if not already running) at the user selected fuel rate or at the slower fraction (e.g., half) of the user selected fuel rate depending on the determination at decision step 1013. After step 1031, the fuel control algorithm (without Auto Combustion enabled) then proceeds to “End.” If the combustion temperature is oscillating around the user combustion temperature, the fuel will not quickly and repeatedly switch back and forth between ON and OFF because the combustion chamber temperature reading received from the thermocouple of the temperature sensor is actually an integration (like a running average) over a period of time (e.g., 20 seconds). Therefore, the decisions at steps 1027 and 1031 will not result in the fuel being turned on and off too quickly due to short term temperature fluctuations around the user combustion temperature.

Returning to step 1025, if it is determined that Auto Combustion is enabled, the fuel control algorithm then proceeds to decision step 1035, which asks whether the combustion chamber temperature is greater than a user stable temperature (e.g., a temperature in a range from about 1100°F to 1500°F, or from about 1200°F to 1400°F), which may be preset or selected by the user (within limits). The user stable temperature (e.g., 1350°F) will generally be lower than the user combustion temperature and may function like a minimum chamber temperature for running the Auto Combustion algorithm. The user stable temperature and the user combustion temperature may vary together and may be separated by about 250°F. If it is determined that the chamber temperature is not greater than the user stable temperature, then the System Stable status (discussed above; see also step 1005) is reset at step 1037 (i.e., the system is set as unstable or not stable), and the method proceeds to the “End.” The System Stable status will become relevant in the subsequent step 1039 of the Auto Combustion algorithm.

If it is determined instead that the chamber temperature is greater than the user stable temperature, then the fuel control algorithm proceeds to step 1039 to determine whether the system is set to Stable. Whether or not the system is set to System Stable depends on (1) steps 1005 and 1037 discussed above, which reset the System Stable to being unstable or not stable (if not already set as unstable) due to upstream decision steps that are based on operating conditions, and (2) step 1049 discussed below which sets the system to Stable as a result of upstream decision steps based on operating conditions. If it is determined at step 1039 that the system is Stable, then the Auto Combustion algorithm proceeds to step 1041 to calculate an auto fuel rate (discussed below in reference to FIG. 11). If it is determined instead at step 1039 that the system is not set to Stable, then the method proceeds to step 1043 to determine whether the combustion chamber temperature is greater than the user combustion temperature discussed above. If the combustion chamber temperature is determined in step 1043 to be greater than the user combustion temperature, then the system is set to System Stable, and the program proceeds to “End.” However, if the combustion chamber temperature is not determined in step 1043 to be greater than the user combustion temperature, then the method proceeds to step 1045 to start a stable countdown timer (if not already started and running). If it is determined at a subsequent step 1047 that the stable countdown timer has expired (e.g., after about 2 to 6 minutes, such as after 5 minutes or 300 seconds), then the system will be set as System Stable at step 1049, the stable countdown timer is reset, and the fuel control algorithm proceeds to “End” (similar to when the chamber temperature is found to be greater than the user combustion temperature in step 1043 as discussed above). However, if it is determined at step 1047 that the stable countdown timer has not expired, then the algorithm proceeds to “End” for the general fuel control algorithm to be repeated. Basically, the system will be set to Stable in step 1049 if it is found that either (1) the chamber temperature is greater than the user combustion temperature (i.e., hot enough) or (2) the chamber temperature is greater than the user stable temperature over a long enough period of time for the stable countdown timer to expire (i.e., hot enough for long enough).

With Auto Combustion enabled, if it is found that (1) the chamber temperature is greater than the user stable temperature at step 1035 and (2) the system is set to System Stable at step 1039, then the Auto Combustion control of the fuel rate is implemented first by calculating an auto fuel rate at step 1041 followed by additional steps depicted in FIG. 11 before proceeding to “End.” In FIG. 11, step 1041 is presented with some additional detail. If step 1041 is reached, the auto fuel rate is calculated based on a proportional-integral-derivative (PID) control function (or a proportional-integral (PI) control function) that is run by a computer, such as a programmable logic controller (PLC). The PID function is a combination of a proportional term, an integral term, and a derivative term that works to keep a measured process variable (e.g., the combustion chamber temperature) at or near a set point or target value (e.g., the user combustion temperature) by affecting a manipulated variable (e.g., the fuel flow rate into the chamber). Each of the terms of the PID function inputs a measure of error (i.e., based on the departure of the process variable from the set point or target value) to affect the level or rate of operation of the manipulated variable (e.g., fuel rate). Each of the terms of the PID function has a separate constant that gives them relative weight, and the values for these constants may be determined empirically. The proportional (P) term is computed based on current error or deviation (e.g., difference between the combustion chamber temperature and user combustion temperature), the integral (I) term is based on the past error over a period (e.g., “area under the curve” over a period of time for chamber temperatures relative to the user combustion temperature), and the derivative (D) term is a measure of anticipated future error (e.g., current rate of change of combustion chamber temperature). A PID function has all three terms, whereas a PI function has only the P and I terms. Based on the combustion chamber temperature, the fuel rate may be modified according to a summation of these terms, which depend on the process variable (i.e., combustion chamber temperature readings) and the target value (i.e., a user combustion temperature). Again, the thermocouple of the temperature sensor integrates the temperature readings that are sent to the
computer, and the PID function itself may integrate over a period of time interval or scan time (e.g., about 10-12 seconds). Thus, these integrations help to avoid rapid fluctuations in the fuel rate (discussed here and below) during Auto Combustion cycles. The variables of the PID including the integration time may also be chosen by the user directly or indirectly according to a preset recipe that is selected by the user (perhaps according to fuel type).

The output of the PID (or PI) function calculated in step 1041 provides an absolute value or a positive or negative value by which to change or alter the manipulated variable (i.e., the auto fuel rate). Continuing with FIG. 11, once an updated auto fuel rate is calculated in step 1041, the fuel rate may then be set to the calculated auto fuel rate in step 1043. However, to keep the auto fuel rate tethered to the user selected fuel rate (e.g., same value as in step 1015), a couple decision steps 1045, 1049 are provided to make sure that the auto fuel rate does not deviate from the user selected fuel rate by more than a maximum fuel offset (above) and a minimum fuel offset (below). In decision step 1045, if it is determined that the calculated auto fuel rate is greater than a maximum fuel rate (i.e., the user selected fuel rate plus a maximum fuel offset), then the fuel rate is set to the maximum fuel rate in step 1047, and the method proceeds past 1049 to step 1053. If the calculated auto fuel rate is not greater than the maximum fuel rate, then the method proceeds to step 1049 and bypasses step 1047. Similarly, if it is determined in decision step 1049 that the calculated auto fuel rate is less than a minimum fuel rate (i.e., the user selected fuel rate minus a minimum fuel offset), then the fuel rate is set to the minimum fuel rate in step 1051, and the method then proceeds to step 1053. If the calculated auto fuel rate is not less than the minimum fuel rate, then the method proceeds to step 1053 and bypasses step 1051.

As described above, the user selected fuel rate may vary, such as from about 20% to about 100% of capacity of fuel feed assembly motor capacity). According to these embodiments, the maximum fuel offset and the minimum fuel offset may each be about 10-40% above or below the user selected fuel rate. A larger fuel offset(s) may be permitted for lighter and/or wetter fuels, whereas a smaller fuel offset(s) may be tolerated for denser fuels. For example, a denser fuel type (e.g., pellets) may be fed into the chamber at a user selected rate of about 40% of motor capacity with a maximum fuel offset of about 10% and a minimum fuel offset of about 20%, whereas a lighter fuel (e.g., wood dust) may be fed into the chamber at a user selected rate of about 60% of motor capacity with a maximum fuel offset and a minimum fuel offset of each about 40%. Feeding of any fuel type may be pulsed on/off, especially denser fuel types.

After the fuel rate is set to the auto fuel rate within the maximum and minimum fuel offset limits relative to the user selected fuel rate, then that Auto Combustion algorithm continues with a set of temperature and safety control steps based on the combustion chamber temperature. At decision step 1053, if it determined that the combustion chamber temperature is greater than the user combustion temperature (discussed above) plus a temperature offset, which may be from about 20 to about 100°F or more, then the fuel rate is set to a low factory preset level at step 1055, which may be a minimum fuel rate needed to maintain combustion, and the method may then proceed to step 1057. If the combustion chamber temperature is greater than the temperature offset, then the fuel rate will remain at the low factory preset level until this condition is no longer met, which may be achieved by ignoring the output of the PID (even though it may continue to calculate auto fuel rates) and maintaining the rate at the factory preset level. If the combustion chamber temperature is not greater than the user combustion temperature plus the temperature offset, then the method proceeds to step 1057 and bypasses step 1055. At decision step 1057, if it is determined that the combustion chamber temperature is greater than a combustion warning off temperature (e.g., any temperature between about 1800°F and 2100°F, such as about 1900°F F), then the fuel system is disabled (i.e., turned OFF) in step 1059 for safety and temperature control, and a combustion warning flag is set in step 1061 before the method proceeds to step 1063. If it determined instead that the combustion chamber temperature is not greater than the combustion warning off temperature, then steps 1059, 1061 are bypassed, and the method proceeds directly to step 1063.

Continuing with the method in FIG. 11, decision step 1063 determines whether the combustion warning flag is set (from a previous step 1061). If the combustion warning flag is not set, then the method exits the algorithm and method of FIG. 11 and proceeds to the “End” in FIG. 10. If it is instead determined in step 1063 that the combustion warning flag is set, then the method proceeds to step 1065. At decision step 1065, if it is determined that the combustion chamber temperature is less than a combustion temperature warning limit, which is generally less than the combustion temperature warning off limit (e.g., 1875°F), then the fuel system is re-enabled (i.e., turned ON) at step 1067, and the combustion warning flag is reset in step 1069. However, if it is determined at step 1065 that the combustion chamber temperature is not less than the combustion temperature warning on limit, then steps 1067, 1069 are bypassed. After these steps are taken, the general method exits the algorithm of FIG. 11 and proceeds to the “End” of the fuel control algorithm in FIG. 10.
temperatures may generally be used for wet fuels, and lower temperatures may be used for dry fuels. As an example, the igniter on temperature may be about 900°F and the second igniter off temperature may be about 1100°F for a dry fuel, whereas the igniter on temperature may be about 1200°F and the second igniter off temperature may be about 1400°F for a dry fuel. The igniter on temperature may also depend on a smoke guard setting (see below).

With the igniter ON in step 913, the combustion chamber temperature should begin to recover and rise until a second igniter off temperature is reached (e.g., potentially any temperature within a wide range from 900°F and about 1700°F, such as between about 1100°F and about 1700°F, or between about 900°F and about 1400°F, or between about 1200°F and about 1400°F), at which point the igniter may be turned back OFF. The second igniter off temperature may depend on a smoke guard setting and/or whether an R1 or R2 state is determined or set (see below). Thus, the igniter step 913 may function to maintain minimum chamber temperatures by turning ON when the igniter on temperature is reached until the combustion chamber temperature rises to the second igniter off temperature. The second igniter off temperature is distinguished from the first igniter off temperature discussed above in 907, 909 for turning ON the igniter during initial startup, although the second igniter off temperature may be the same temperature as the first igniter off temperature. The igniter on temperature and/or the second igniter off temperature may be varied or adjusted within a range of temperatures depending on user selection(s), such as the smoke guard setting. Generally speaking, the igniter on temperature will always be lower than the second igniter off temperature, and the temperature gap between the lower igniter on temperature and the higher second igniter off temperature may vary but may typically be about 200-250°F or more. Indeed, the igniter on temperature and the second igniter off temperature may vary in tandem for different smoke guard settings with the temperature gap between them remaining constant or varying only slightly.

A user selected “smoke guard” setting may also be provided and selected for determining in step 913 when the igniter runs. The smoke guard setting may be selected by a user depending on the user’s tolerance for lower temperatures and/or smoke during operation of the burner. The smoke guard setting may also depend on the type and moisture content of the fuel. Basically, a higher smoke guard setting would translate into a higher igniter on temperature and/or second igniter off temperature, whereas a lower smoke guard setting would mean a lower igniter on temperature and/or second igniter off temperature. A higher smoke guard setting may ensure higher operating temperatures and less smoke being produced (but may also consume more gas/energy over time to run the auxiliary igniter), whereas a lower smoke guard setting may conserve energy consumed by the igniter but may permit lower operating temperatures and increased exhaust smoke to occur. A higher or lower smoke guard setting will generally correspond respectively to a higher or lower igniter on temperature and/or second igniter off temperature. According to some embodiments, both the igniter on temperature and the second igniter off temperature may be raised or lowered depending on the smoke guard setting (i.e., raised for a higher setting; lowered for a lower setting). According to some alternative embodiments, only one of the igniter on temperature and the second igniter off temperature may be raised or lowered depending on the smoke guard setting with the other remaining fixed.

The smoke guard setting may be on a scale of 0 to 10 (or some other value) with this scale corresponding to temperature increments for the igniter on temperature and/or second igniter off temperature ranging from a lowest igniter on temperature and/or second igniter off temperature (i.e., lowest smoke guard setting) to a highest igniter on temperature and/or second igniter off temperature (i.e., highest smoke guard setting). Therefore, a lower smoke guard setting (e.g., “1”) would set the igniter on temperature and/or second igniter off temperature to lower temperature(s) within their respective temperature range(s), whereas a higher smoke guard setting (e.g., “10”) would set the igniter on temperature and/or second igniter off temperature to a higher temperature within their respective temperature range(s). According to some embodiments, the available smoke guard temperature ranges of the igniter on temperature and/or second igniter off temperature for a set of smoke guard settings may also be set by the user (perhaps within limits). According to some embodiments, there may also be additional ‘smart’ variables that are used by the computer to control or adjust these smoke guard temperature thresholds relative to those determined directly by the user-selected smoke guard setting (see, e.g., discussion below). For example, if the combustion temperature is determined to be falling rapidly (instead of slowly) toward the igniter on temperature, then the relevant temperature thresholds of the smoke guard feature (e.g., the igniter on temperature) may be set a little higher (relative to such temperature based only on the smoke guard setting) to anticipate and curtail the falling temperatures sooner.

As an example of the foregoing (without additional variable controls), if the smoke guard temperature range for the igniter on temperature was from 600°F to 1200°F, the smoke guard temperature range for the second igniter off temperature was from 800°F to 1400°F, and the smoke guard setting is at “8,” then the igniter would turn ON when the combustion chamber temperature fell below the igniter on temperature of 1080°F but would later turn OFF when the chamber temperature reached 1280°F. As another example, if the igniter on temperature is fixed at 900°F, and the smoke guard temperature range for the second igniter off temperature was from 1000°F to 1600°F, and the smoke guard setting is at “4,” then the igniter would turn ON when the combustion chamber temperature fell below the igniter on temperature of 900°F but would later turn OFF when the chamber temperature reached the second igniter off temperature of 1240°F. In this latter example, if the smoke guard setting is instead set at “7,” then the igniter would turn ON when the combustion chamber temperature fell below 900°F but would later turn OFF when the chamber temperature reached the second igniter off temperature of 1420°F.

In addition to controlling the combustion chamber temperature by controlling the fuel rate in step 911 and the igniter in step 913, operation of the fan may also be controlled in step 915 to help control the combustion chamber temperature before the high level algorithm in FIG. 9 cycles back to the fuel control step 911. Basically, much like the igniter functioning mostly below the targeted user combustion temperature (i.e., like a floor) to help raise the chamber temperature when it is too low, the fan may function to help cool the combustion chamber temperature when the temperature gets too high above the user combustion temperature (i.e., like a ceiling) by pulling in more cool air into the chamber. How-
ever, both the igniter and the fan may operate over temperature ranges that overlap the user combustion temperature. Each of these control steps 911, 913, 915 may operate independently of each other, but according to some embodiments, steps 913, 915 may be considered additional optional controls, such that the fuel control step 911 may operate without the igniter and fan control steps 913, 915, or in conjunction with only one of these additional control steps 913, 915. However, preferably all three control steps 911, 913, 915 will be used together, such as in FIG. 9. Indeed, by joint operation of these control steps by a computer, the air/fuel ratio may be tightly controlled to maintain efficient burning above 80% efficiency and, often, near 87% efficiency.

[0101] Generally, the fan may operate at a range of speeds, which may be expressed as a percentage of fan’s full speed capacity. The fan may be set at a highest predetermined fan speed (e.g., between about 60% and about 100%, such as about 100%) when the combustion chamber temperature rises to or above a maximum fan temperature (e.g., any temperature between 1500°F and 2100°F, such as 1800°F), and the fan may be set at a lowest predetermined fan speed (e.g., greater than 0% but less than about 50%, such as about 15%) when the combustion chamber temperature falls to or below a minimum fan temperature (e.g., any temperature between 800°F and 1200°F, such as 1000°F). According to some embodiments, the maximum fan temperature may be set to the user combustion temperature. When the chamber temperature rises above the maximum fan temperature and the fan is operating at its highest predetermined speed, then the fuel may also be optionally shut off or set to preset factory maximum rate (see, e.g., steps 1053 to 1061 in FIG. 11). The lowest (or minimum) predetermined fan speed as well as the highest (or maximum) predetermined fan speed may be set by the user, and these speeds may depend on the type and moisture content of the fuel.

[0102] Generally, the fan will usually be operating at least at a lowest or minimum predetermined fan speed even when the chamber temperature is low so that orderly air flow is maintained through the burner at all times. However, the fan may be turned OFF below a predetermined fan off temperature (e.g., a temperature between about 400°F and 1200°F, such as 600°F). Turning off the fan may also be tied to a shut off cycle for the burner unit or if a thermostat is no longer calling for heat. Likewise, the fan may be turned off if an excessively hot combustion temperature, such as 2100°F, is reached or surpassed.

[0103] When the fan speed increases in response to temperature, the chamber temperature may continue to rise slightly until enough cool air is infused into the chamber by operation of the fan for the chamber temperature to begin to fall. To respond to temperature changes and fluctuations over the range of temperatures between the minimum fan temperature and the maximum fan temperature, the fan speed may be adjusted over this temperature range between the lowest predetermined fan speed and the highest predetermined fan speed. More particularly, the fan speed or rate within this range of temperatures (i.e., the intermediate fan speed) may simply be a linear interpolation between the minimum and maximum predetermined fan speeds with the number of fan speeds between them corresponding to the number of equal temperature intervals (e.g., 100°F) between the minimum and maximum fan temperatures. For example, if the maximum or highest predetermined fan speed is set to 80% of the fan capacity at a maximum fan temperature of 1800°F and the minimum or lowest predetermined fan speed is set to 40% of the capacity of the fan at a minimum fan temperature of 1000°F, with eight 100°F intervals between them, then the (intermediate) fan speed or rate at 1300°F would be set at 55% of the capacity of the fan. The number of temperature intervals between the minimum and maximum fan temperatures will determine the size of each fan speed increment, which may be about 1% to about 5% increments.

[0104] FIG. 12 provides an example or embodiment of the present invention showing temperature thresholds for a set of smoke guard settings described above. These smoke guard settings may affect not only the operation of the igniter but also the fuel feed assembly and fan under some circumstances. Each smoke guard setting is shown bracketed in FIG. 12 and labeled with numbers 1-10. R0 refers to the initial start up of the igniter for a given smoke guard setting, whereas R1 and R2 refer to different modes of igniter operation depending on operating conditions. During initial start up of the burner from a cold state, the igniter will stay ON until the combustion chamber temperature reaches a first igniter off temperature where the igniter will turn off (depicted as IGN R0 OFF in FIG. 12 for each smoke guard setting). Once this temperature is reached, the operation of the igniter according to FIG. 12 will thereafter depend on the R1 and R2 states until the next start up of the burner.

[0105] Continuing with FIG. 12, if the combustion chamber later falls below an igniter on temperature (shown as IGN ON in FIG. 12 for each smoke guard setting), the igniter will turn back on until the combustion chamber temperature reaches a second igniter off temperature. The second igniter off temperature for each smoke guard setting in FIG. 12 will depend on whether the R1 or R2 state or mode is set. The decision between R1 and R2 will depend on the combustion temperature reading a period of time after the igniter is first turned on, such as after the end of the purge cycle for the igniter (see above). If the combustion temperature is within the R2 range (e.g., as depicted in FIG. 12) after that period of time, then the R2 state would be set for that cycle and the second igniter off temperature will be lower (e.g., the IGN R2 OFF temperature threshold in FIG. 12) than if the combustion temperature is below the R2 range. If the combustion temperature is below the R2 range (e.g., below the R2 low limit depicted in FIG. 12, then the R1 state would be set for that cycle and the second igniter off temperature will be higher (e.g., the IGN R1 OFF temperature threshold in FIG. 12). Basically, the R1 and R2 states have the effect of keeping the igniter on longer (i.e., until a higher temperature is reached) if the temperature is determined to be falling more rapidly over the time period than if the temperature is falling more slowly.

[0106] As further depicted in FIG. 12, the smoke guard setting may also affect the rate at which fuel is fed into the burner and/or the operation of the fan when there is no longer a call for heat. While a minimum fuel run temperature (e.g., Fuel ON temperature in FIG. 12) may be constant between different smoke guard settings, a full fuel run temperature (e.g., Fuel Reduced Speed temperature in FIG. 12) may depend on the smoke guard setting. When there is no longer a call for heat from the thermostat, the fan may continue to run for a period of time to complete the burn of the fuel. However, the period of time that the main fan or blower of the burner continues to run and pull air into the chamber after there is no more call for heat may vary depending on the smoke guard setting. Although the y-axis in FIG. 12 represents temperature for all of the other variables, the line for the “Blower Off”
Actually refers to seconds. Thus, the amount of time that the fan or blower may continue to run after there is no more call for heat may vary incrementally from more than zero (0) seconds to about 300 seconds depending on the smoke guard setting.

There may be instances in which the combustion chamber temperature falls below a predetermined low threshold temperature such that additional measures are needed to raise the chamber temperature. For example, if the combustion chamber temperature falls below a predetermined low threshold temperature while the igniter is ON and the fuel is ON, then the following procedure may be used: First, the fuel and the auxiliary igniter may be turned off; the fan may be kept running so that the any combustible gasses may be purged from the combustion chamber; the igniter may then be turned back ON; the fuel may be turned back ON after that at a user selected fuel rate; and finally, the igniter may be turned OFF once a higher predetermined chamber temperature is reached.

In addition to the foregoing, there may also be additional control mechanisms including an over-arching system on/off control. Such on/off control may be tied to a thermostat that relates to the function of the unit involved in the heat exchanger (e.g., use of the circulating fluid to heat air in a house, water in a water heater, etc.). An internal thermostat may also be tied to the temperature of a circulating fluid in the heat exchanger to make sure it does not get too hot or boil. If the unit does not receive a call for heat from a control thermostat, then the unit may be shut down, which may cause the fuel and/or fan to be turned off, the timing of which may depend on various settings. Operation of the unit may be tied to other variables as well, such as the level of circulating fluid in the heat exchanger, etc.

The method described above in reference to FIGS. 10 and 11 describes the fuel, fan or igniter being turned on/off or being set to a particular rate. It is important to note that these steps may or may not be action steps in themselves, but may instead be merely setting those values to being on/off or to a particular rate. When only a value is set during the running of the algorithm or method, the action of actually adjusting fuel rate based on the algorithm(s) may not occur until after the full algorithm(s) has been processed or performed. Only after completing a full cycle through the corresponding control algorithm (e.g., the fuel control algorithm) may the action (e.g., adjusting the fuel rate) actually carried out and brought into effect (e.g., after “End” is reached). This helps to control against alterations in the determined state, rate or other variable over the course of the algorithm(s) if multiple conditions are met.

In such cases where action does not occur until the end of the algorithm, the last value assigned for a given operational parameter will determine the relevant action taken upon completion of the algorithm. For example, in reference to FIGS. 10 and 11, if the fuel rate was first determined to be the user selected fuel rate at step 1013, 1015 but later determined to be the auto fuel rate at steps 1041, 1043, the minimum fuel rate in steps 1049, 1051, and then the lowest factory present level in steps 1053, 1055 before reaching “End,” then the fuel rate would be set to the factory present level after completion of the algorithm because it was the last determined value that may have been written over the previously determined values. In addition, a status of enable (or turn ON) or disable (or turn OFF), will function like a master control over a particular rate. If the fuel is enabled or turned ON, then the fuel will be delivered at the determined rate, but if the fuel is turned OFF or disabled, then the determined fuel rate is not realized and the fuel rate is zero. Similarly, if a status is determined for a given function, that status will generally remain until changed.

Methods of the present invention may be implemented via hardware, software or a combination of software and hardware (including firmware, resident software, microcode, etc.). Aspects of the present invention may be implemented by a computer according to a computer readable program code present on a computer readable medium. Indeed, some aspects of the present invention may take the form of a computer readable program product embodied in one or more computer readable media having the computer readable program code present thereon. The above-identified algorithms may be performed automatically by a programmable computer, such as a microcontroller or microprocessor, that executes software residing in an accessible non-transitory computer-readable media. The computer may include a programmable logic controller (PLC) or microcontroller for receiving inputs and sending outputs to control the burner on the basis of feedback information. The computer may further include a user interface that allows a user to enter values and operating parameters, such as various settings, fan speeds and temperatures, as discussed above.

As stated above, the computer of the present invention for controlling operation of the burner may comprise a processor and one or more computer readable media that may be part of, in communication with, and/or utilized by the computer. The computer may comprise a programmable logic controller (PLC), a microcontroller, or other programmable data processing apparatus. The computer may also comprise one or more computers, processors, servers, etc., jointly functioning to control the operation of the burner. The computer may be part of the burner unit and/or a separate computer remote in communication with the burner. Any combination of one or more computer readable media may be utilized. The computer readable media may be a computer readable signal medium or a computer readable storage medium.

A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an appropriate optical fiber with a repeater, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system,
apparatus, or device. Program code embodied on a computer readable signal medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

[0115] Computer program code for carrying out operations for aspects of the present disclosure may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Scala, Smalltalk, Eiffel, JADE, Emerald, C++, CIL, VB.NET, Python or the like, conventional procedural programming languages, such as the "C" programming language, Visual Basic, Fortran 2003, Perl, COBOL, 2002, PHP, ARAP, dynamic programming languages such as Python, Ruby and Groovy, or other programming languages. The program code may be executed on a computer that is part of the burner unit and/or a remote computer or server. If used, the remote computer may be connected to the burner unit through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider) or in a cloud computing environment or offered as a service.

[0116] Aspects of the present disclosure are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatuses (systems) and computer program products according to embodiments of the disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of the computer to implement the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer program instructions may be stored in a computer readable medium as stated above that when executed can direct the computer to function in a particular manner, such as to control the operation of the burner. The computer program instructions may also be loaded onto the computer to cause a series of operational steps to be performed on the computer to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. It will be further understood that the method of the present invention may comprise all or a portion of the method steps described herein, and such steps may be performed in different orders as long as the sequence of steps maintains necessary logic flow and groupings.

[0117] While the present invention may have been disclosed with reference to certain embodiments to enable one skilled in the art to practice the invention, it will be apparent that modifications and variations are possible without departing from the spirit and scope of the invention as defined herein. Furthermore, it should be appreciated that any and all examples in the present disclosure, while illustrating embodiments of the invention, are provided as non-limiting examples and are, therefore, not to be taken as limiting the various aspects so illustrated. The present invention is intended to have its full scope consistent with the language of the claims and equivalents thereof. Accordingly, the drawings and detailed description are to be regarded as illustrative and not as restrictive.

[0118] Various modifications to the embodiments presented herein will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments. Reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." Nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for" (or "step for") in the case of a method claim.

What is claimed is:

1. A method of operating a non-catalytic biomass burner comprising:
   (a) turning on an auxiliary igniter, the igniter pointed toward a combustion chamber of the burner through an igniter opening in a side wall of the combustion chamber, the auxiliary igniter configured to direct heat into a lower portion of the combustion chamber;
   (b) monitoring by a computer a combustion temperature of an exhaust gas exiting the combustion chamber, the combustion temperature of the exhaust gas measured by a first temperature sensor positioned near the top of the combustion chamber, the exhaust gas being produced by the burning of a fuel in the combustion chamber, and the computer receiving the combustion temperature from the first temperature sensor;
   (c) adding fuel to the combustion chamber at a first predetermined fuel rate when the combustion temperature reaches a first fuel temperature, wherein the rate of fuel addition to the combustion chamber is controlled by the computer controlling a fuel feed assembly that delivers fuel to a fuel inlet tube of the burner;
   (d) adding fuel to the combustion chamber at a second predetermined fuel rate by controlling the fuel feed assembly when the combustion temperature reaches a second fuel temperature, the second fuel temperature being higher than the first fuel temperature; and
   (e) turning off the auxiliary igniter when the combustion chamber temperature reaches an igniter off temperature.

2. The method of claim 1, wherein the first fuel temperature is a temperature between about 400°F and about 500°F.

3. The method of claim 1, wherein the second fuel temperature is a temperature between about 900°F and about 1100°F.

4. The method of claim 1, wherein the igniter off temperature is a temperature between about 1400°F and about 1600°F.

5. The method of claim 1, wherein the second predetermined fuel rate is a user selected fuel rate, and wherein the first predetermined fuel rate is less than the second predetermined fuel rate.

6. The method of claim 5, wherein the first predetermined fuel rate is about half of the second predetermined fuel rate.

7. The method of claim 1, further comprising:
   (f) heating a circulating fluid of a heat exchanger by transferring heat from the exhaust gas to the circulating fluid.
   (g) pulling air into the combustion chamber through one or more air inlets by operation of a fan positioned near an exit opening of the burner on the distal side of the heat exchanger, wherein each of the air inlet spans the side wall of the combustion chamber such that air flows into
the combustion chamber from the outside of the combustion chamber through the one or more air inlets.

9. The method of claim 8, further comprising:
   (h) controlling the speed of the fan by the computer based on the combustion temperature from the first temperature sensor.

10. The method of claim 8, further comprising:
    (i) controlling the rate of fuel addition to the combustion chamber by the computer controlling a fuel feed assembly based on a distal exhaust gas temperature from a second temperature sensor in the path of exhaust flow near an exit opening of the burner.

11. A method of operating a non-catalytic biomass burner comprising:
    (a) measuring by a first temperature sensor a combustion temperature of exhaust gas exiting a combustion chamber of the burner, the exhaust gas being produced by the burning of a fuel in the combustion chamber;
    (b) monitoring by a computer the combustion temperature of the exhaust gas exiting the combustion chamber, the computer receiving the combustion temperature from the first temperature sensor;
    (c) determining a fuel rate for adding fuel to the combustion chamber, wherein the fuel rate is determined by the computer based on the combustion temperature; and
    (d) adding fuel to the combustion chamber at the fuel rate determined in step (c), wherein the rate at which the fuel is added to the combustion chamber is controlled by the computer controlling a fuel feed assembly that delivers fuel to a fuel inlet tube of the burner.

12. The method of claim 11, wherein the fuel rate is determined in step (c) to be a first predetermined fuel rate if the combustion temperature is equal to or greater than a first fuel temperature, and wherein the fuel rate is determined in step (c) to be a second predetermined fuel rate if the combustion temperature is equal to or greater than both the first fuel temperature and a second fuel temperature, and wherein the second fuel temperature is greater than the first fuel temperature, and wherein the second predetermined fuel rate is greater than the first predetermined fuel rate.

13. The method of claim 12, wherein the first fuel temperature is a temperature between about 400°F and about 700°F.

14. The method of claim 12, wherein the second fuel temperature is a temperature between about 900°F and about 1100°F.

15. The method of claim 12, further comprising:
    (e) selecting by a user the second predetermined fuel rate.

16. The method of claim 12, wherein the first predetermined fuel rate is about half of the second predetermined fuel rate.

17. The method of claim 11, further comprising:
    (f) turning off the addition of fuel to the burner such that the fuel rate is zero if the combustion temperature is greater than a user combustion temperature.

18. The method of claim 17, wherein the user combustion temperature selected by a user is a temperature between about 1500°F and 1700°F.

19. The method of claim 17, further comprising:
    (g) turning on the addition of fuel to the burner at the fuel rate determined in step (c) if the combustion temperature is less than the user combustion temperature.

20. The method of claim 11, wherein step (c) of determining the fuel rate comprises:
    (h) calculating the fuel rate automatically using a proportional-integral-derivative (PID) function based on monitored combustion temperatures.

21. The method of claim 20, wherein step (c) further comprises:
    (i) determining by the computer if the fuel rate calculated in step (h) is greater than a maximum fuel rate equal to a user selected fuel rate plus a maximum fuel offset; and
    (j) setting the fuel rate to the maximum fuel rate if the fuel rate calculated in step (h) is greater than the maximum fuel rate.

22. The method of claim 20, wherein step (c) further comprises:
    (k) determining by the computer if the fuel rate calculated in step (h) is less than a minimum fuel rate equal to a user selected fuel rate minus a minimum fuel offset; and
    (l) setting the fuel rate to the minimum fuel rate if the fuel rate calculated in step (h) is less than the minimum fuel rate.

23. The method of claim 20, wherein step (c) further comprises:
    (m) determining by the computer if the combustion temperature is greater than a user combustion temperature plus a temperature offset; and
    (n) setting the fuel rate to a preset minimum fuel rate if the combustion temperature is greater than the user combustion temperature plus the temperature offset.

24. The method of claim 20, wherein the temperature offset is a temperature difference in a range from about 20°F to about 100°F.

25. The method of claim 20, wherein step (h) is performed if an auto combustion state has a status of being enabled.

26. The method of claim 20, wherein step (h) is performed if the combustion temperature is greater than a user stable temperature.

27. The method of claim 26, wherein user stable temperature is a temperature in a range from about 1200°F to about 1400°F.

28. The method of claim 20, wherein step (h) is performed if a system status is set to stable, wherein the system status is set to stable if the combustion temperature is greater than a user combustion temperature or if the combustion temperature is greater than a user stable temperature for a period of time greater than a stable countdown timer.

29. The method of claim 28, wherein the system status is reset and not set to stable if the combustion temperature is less than or equal to a user stable temperature or if an auxiliary igniter is turned on.

30. The method of claim 11, further comprising:
    (o) turning off the addition of fuel to the burner such that the fuel rate is zero if the combustion temperature is greater than a combustion warning off temperature.

31. The method of claim 11, further comprising:
    (p) determining by the computer if the combustion temperature is less than an igniter on temperature; and
    (q) turning on an auxiliary igniter if the combustion temperature is less than the igniter on temperature, wherein the igniter is pointed toward the combustion chamber of the burner through a igniter opening in a side wall of the combustion chamber, the auxiliary igniter configured to direct heat into a lower portion of the combustion chamber.

32. The method of claim 31, wherein the igniter on temperature is determined by a user selected smoke guard setting.
33. The method of claim 31, wherein the igniter on temperature is a temperature within a range from about 800°F to about 1300°F.

34. The method of claim 31, further comprising:
   (r) determining by the computer if the combustion temperature is greater than an igniter off temperature; and
   (s) turning off the auxiliary igniter if the combustion temperature is greater than the igniter off temperature,
   wherein the igniter off temperature is greater than the igniter on temperature.

35. The method of claim 34, wherein the igniter off temperature is determined by a user selected smoke guard setting.

36. The method of claim 34, wherein the igniter off temperature is a temperature within a range from about 1100°F to about 1700°F.

37. The method of claim 11, further comprising:
   (i) operating a fan at a fan speed, wherein the fan operates to pull air into the combustion chamber of the burner, and wherein the fan speed of the fan is controlled by the computer based on the combustion temperature.

38. The method of claim 37, further comprising:
   (u) determining by the computer if the combustion temperature is equal to or greater than a maximum fan temperature; and
   (v) setting the fan speed of the fan to a maximum fan speed if the combustion temperature is equal to or greater than the maximum fan temperature.

39. The method of claim 38, wherein the maximum fan temperature is a temperature between 1500°F and 2100°F.

40. The method of claim 38, wherein the maximum fan speed is between about 60% and about 100% of the capacity of the fan.

41. The method of claim 37, further comprising:
   (w) determining by the computer if the combustion temperature is equal to or less than a minimum fan temperature; and
   (x) setting the fan speed of the fan to a minimum fan speed if the combustion temperature is equal to or less than the minimum fan temperature.

42. The method of claim 41, wherein the minimum fan temperature is a temperature between 800°F and 1200°F.

43. The method of claim 41, wherein the minimum fan speed is greater than 0% but less than about 50% of the capacity of the fan.

44. The method of claim 31, further comprising:
   (y) determining by the computer if the combustion temperature is greater than a minimum fan temperature and less than a maximum fan temperature; and
   (z) setting the fan speed of the fan to an intermediate fan speed if the combustion temperature is greater than the minimum fan temperature and less than the maximum fan temperature,
   wherein the intermediate fan speed depends on a predetermined number of temperature intervals between the minimum fan temperature and the maximum fan temperature and on which temperature interval includes the combustion temperature.

45. A computer program product for controlling the operation of a non-catalytic biomass burner comprising:
   a computer readable storage medium having computer readable program code embodied therewith, the computer readable program code comprising:
   computer readable program code configured to receive from a first temperature sensor a combustion temperature of an exhaust gas exiting a combustion chamber of the burner, the exhaust gas being produced by the burning of a fuel in the combustion chamber;
   computer readable program code configured to monitor by a computer the combustion temperature of the exhaust gas exiting the combustion chamber;
   computer readable program code configured to determine by the computer based on the combustion temperature a fuel rate for adding fuel to the combustion chamber; and
   computer readable program code configured to control by the computer the addition of fuel to the combustion chamber a fuel feed assembly at the determined fuel rate, wherein the fuel rate is controlled by the computer controlling a fuel feed assembly that delivers fuel to a fuel inlet tube of the burner.

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