Title: DIRECT-FIRED, GAS-FUELED HEATER

Abstract: A direct-fired, gas-fueled heater for greenhouse use. The heater has a base with an airflow assembly disposed within the housing and configured so as to draw a flow of ambient air into the heater through the air inlet matrix, to circulate airflows within the housing, and to direct heated air out of the heater through an air housing exit. Also disposed within the housing is a heat chamber, the heat chamber including an outer wrapper, an upper insert and a lower insert. The lower insert has a lower insert slot having a lower insert slot area and is configured to allow passage of a quenching airflow therethrough to join and mix with a combustion discharge and dilution airflows circulated within the heater. Reduced emissions of certain combustion byproducts are realized.
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
DIRECT-FIRED, GAS-FUELED HEATER

Related Application

This application claims priority to provisional U.S. Application Serial Number 60/494,706, filed August 12, 2003, the entire disclosure of which is hereby incorporated by reference.

Field of the Invention

The invention relates to direct-fired, gas-fueled heaters, and more particularly to direct-fired, gas-fueled heaters for greenhouse heating use.

Background of the Invention

Historically, greenhouses typically consisted of transparent panes of glass forming a roof to enclose a growing area and draw air from the outside. More recent greenhouses are constructed of a metallic frame structure, utilizing thin wall poly for the roof and side and typically corrugated fiberglass for end panels. Regardless of construction, greenhouses present an enclosed or internal environment where control of the atmosphere and other conditions, e.g., temperature, in the environment is needed in order to protect plants grown or raised therein, providing an optimal environment for desirable plant yield, and to protect the humans who work within the environment.

Due to seasonal temperature fluctuations, particularly during the colder months of the year and more particularly in colder climes, greenhouses are usually provided with a heater to heat the internal environment. This heat may be provided by a variety of different types of heaters such as forced air heaters; vented, indirect-fired unit heaters (sometimes referred to herein as “vented unit heaters”); or direct-fired, gas-fueled heaters (sometimes referred to
herein as "direct-fired heaters"). Such heaters typically utilize a gas, such as natural gas or LPG gas (e.g., propane or butane), as a fuel source.

As a result of the combustion of natural gas or LPG gas, combustion byproducts, such as carbon monoxide (CO) nitrogen dioxide (NO₂) and ethylene, may enter the greenhouse either through a leak in the exhaust vent system of an indirect-fired (e.g., vented) heater, or directly with the heated air in a direct-fired (e.g., non-vented) heater. These byproducts have the potential for causing illness or other negative or deleterious effects in workers and damaging the plants grown in greenhouses. Carbon monoxide is a combustion byproduct of particular concern to humans in closed environments. Ethylene is a byproduct of particular concern for plants as it can disrupt plant growth cycles, either killing sensitive plants or stunting the growth of less sensitive plants. Nitrogen dioxide is also a combustion byproduct of concern for plants and humans and of general overall concern for ambient air quality of external environments. Carbon dioxide (CO₂) is a beneficial combustion byproduct for plants that promotes plant growth but is suspected of negative impacts to the overall global environment.

Greenhouses do not generally have large amounts of natural air exchange and concentrations of deleterious combustion byproducts can accumulate at unacceptable levels. Thus, it would be desirable and advantageous to provide a heater, particularly a direct-fired heater, that produces or emits lower concentrations of harmful gaseous pollutants or byproducts.

Gas-fueled heaters utilized in greenhouses are typically vented unit heaters. Manufacturers of vented unit heaters include Modine, Reznor, Lennox and Sterling. These products have a fuel efficiency of about 80%, and a seasonal operating efficiency of as low as 62% to as high as 78%. The lowest seasonal operating efficiencies are found on "gravity
vent" style heaters, where the exhaust vent is open continuously providing for a constant air leakage path. The higher efficiencies are found on relatively more expensive power vent style heaters. Vented unit heaters are generally fuel inefficient compared to direct-fired heaters, and have performance problems due to mechanical failures of such elements as the heat exchanger, burner manifold, gas valves, electronics and other components. The typical life of such a product in a greenhouse is between 5-7 years. Also, if these heaters develop leaks in their vent systems, combustion byproducts harmful to humans and/or plants can accumulate in a greenhouse.

Direct-fired heaters produced by European manufacturers are generally of the “tube style” type with combustion air blowing directly through the unit. The direct-fired heater manufactured by Holland Heater, USA is an example of this type of product, which is typically sold as a CO₂ generator, i.e., for limited use and not as a primary heat source. They are physically large and expensive products containing an open flame.

There are several manufacturers of “cabinet-style” direct-fired heaters which are typically utilized in animal containment buildings, but have been of limited use in greenhouses due to emission of high levels of gaseous pollutants. These manufacturers include Hired Hand, Grain Systems International, and LB White. These direct-fired heaters can have thermal efficiencies as high as about 99.96% and, therefore, are generally much more fuel efficient than the vented unit heaters. However, despite the greater fuel efficiency, these heaters can produce undesirably high levels of deleterious combustion byproducts, e.g., CO, NO₂, and ethylene. Due to the levels of these combustion byproducts, manufacturers have typically sold their agricultural confinement, direct-fired heaters for limited greenhouse use as an outdoor mounted heater. They can be used in this fashion with a greenhouse having a high amount of natural air exchange in order to minimize the potential effects of the
combustion byproducts, particularly in greenhouses where sensitive plants are not being grown. However, in the absence of high amount of natural air exchange, direct fired heaters of this type are of little utility for greenhouse use.

In view of the deficiencies of the above-mentioned vented unit heaters and “cabinet style” direct-fired heaters, it would be desirable to provide a direct-fired heater for use as a heater for enclosed structures such as greenhouses, without need for high amounts of natural air exchanges. Further, it would be desirable that such a heater provide any one or combination of the following: high fuel efficiency, lower product cost, increased operational reliability and durability, reduced emission of deleterious combustion products, and increased CO₂ production to stimulate plant growth. Applicants have found that with the direct-fired heater of the invention one or more of the aforementioned benefits can be achieved, particularly high fuel efficiency and reduced emission of deleterious combustion byproducts.

**Summary of the Invention**

In an embodiment of the invention, the direct-fired, gas-fueled heater comprises a base, a housing, an airflow assembly, a heat chamber, and a burner. The base has an air inlet matrix through which ambient air enters the heater. The housing is mounted to the base and is comprised of an outer casing, at least one door, and an air housing exit. The airflow assembly is disposed within the housing and configured so as to draw a flow of ambient air into the heater through the air inlet matrix, to circulate the flow of ambient air as dilution airflows, a primary combustion airflow, and a quenching airflow within the housing, and to direct a combustion discharge stream out of the heater through the air housing exit. The heat chamber is disposed within the housing and is comprised of an outer wrapper, an upper insert and a lower insert, the two inserts being mounted in spaced relationship to define a heat
chamber inlet. The burner is disposed within the heat chamber inlet and has at least one
discharge port configured with at least one discharge slot from which a combustion discharge emanates and a burner inlet. The burner is attached in spaced relationship to the base to allow a gaseous fuel and the primary combustion airflow to enter the burner through the burner inlet. The lower insert further comprises at least one lower insert slot sized and configured to allow passage of the quenching airflow therethrough to join and mix with the combustion discharge and the dilution airflows to form the combustion discharge stream. The heater is adapted to receive gaseous fuel into the inlet under lower pressure from an external gaseous fuel supply.

In embodiments of the invention, the airflow assembly is mounted to the lower insert in spaced relationship from the outer wrapper. The airflow assembly may be comprised of a fan motor having a shaft, a motor mount, a fan wheel attached to the shaft, an inner scroll disposed between two end panels, the end panels each having a entrance, one entrance facing the heat chamber and being configured to receive the combustion discharge stream and the other entrance facing away from the heat chamber and being configured to receive the fan wheel within the inner scroll, the inner scroll and the two end panels cooperating to define a combustion discharge stream opening that is aligned with the air housing exit when the airflow assembly is mounted within the housing.

The airflow assembly may be mounted in spaced relationship from the outlet of the heat chamber with the space between the airflow assembly and the heat chamber exit defining a mixing zone where dilution airflows, combustion discharge and quenching air flows are intermingled to begin forming the combustion discharge stream.

In other embodiments of the heater of the invention, the heater may further include a gas control assembly adapted for connection to the gaseous fuel supply. The gas control
assembly may be comprised of a pressure regulator through which gaseous fuel enters the gas control assembly; a manual shutoff valve; a sediment trap; a gas control valve; and a burner manifold having a burner orifice.

In embodiments of the heater of the invention, the burner orifice has a burner orifice area, the inlet has an inlet area, the lower insert slot has a slot area, and the inlet matrix has an inlet matrix area. For example in an embodiment of the invention utilizing propane as the fuel, the burner orifice has a burner orifice area of about 0.00013 in\(^2\) per 1000 BTUH to about 0.00014 in\(^2\) per 1000 BTUH; the inlet has an inlet area of about 0.9 in\(^2\) per 1000 BTUH to about 1.2 in\(^2\) per 1000 BTUH; the lower insert slot has a slot area of about 0.28 in\(^2\) per 1000 BTUH to about 0.31 in\(^2\) per 1000 BTUH, and the inlet matrix has an inlet matrix area of between about 0.008 CFM per BTUH to about 0.009 CFM per BTUH. In a further example of an embodiment of the invention utilizing natural gas as the fuel, the burner orifice has a burner orifice area of about 0.00025 in\(^2\) per 1000 BTUH to about 0.00027 in\(^2\) per 1000 BTUH; the inlet has an inlet area of about 0.9 in\(^2\) per 1000 BTUH to about 1.2 in\(^2\) per 1000 BTUH; the lower insert slot has a slot area of about 0.28 in\(^2\) per 1000 BTUH to about 0.31 in\(^2\) per 1000 BTUH, and the inlet matrix has an inlet matrix area of between about 0.008 CFM per BTUH to about 0.009 CFM per BTUH.

The heater of the invention in its various embodiments may incorporate a controller to regulate operational parameters. Thus the heater may include a control box comprised of a panel, an ignition controller, a transformer, a power cord, and a harness. The controller may further comprise additional elements and switches, such as fan motor switch.

Brief Description of the Drawings
Figure 1 is an exploded, perspective view of an embodiment of a heater according to the invention.

Figure 2 is a front, perspective view of an embodiment of a heater according to the invention.

Figure 3 is a perspective view of a heat chamber utilized in an embodiment of a heater according to the invention.

Figure 4 is an internal, side view of a prior art heater, illustrating air flow and flame paths.

Figure 5 is an internal, side perspective view of an embodiment of a heater according to the invention, illustrating air flow and flame paths.

Figure 6 is a partial side view of the lower portion of a burner.

Figure 7 is a perspective view of a burner.

Figure 8 is a perspective view of a heater inside a greenhouse in accordance with an embodiment of the present invention.

Figure 9 is a perspective view of a heater external to a greenhouse in accordance with an embodiment of the present invention.

**Detailed Description of the Preferred Embodiments**

The following detailed description should be read with reference to the drawings, in which like elements in different drawings are numbered identically. The drawings, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of the invention.

Figure 1 illustrates a “cabinet style” direct-fired gas-fueled heater suitable for use in an enclosed structure, such as a greenhouse or an agricultural animal confinement. The
heater 10 includes a housing 20, air flow generating assembly 30, heat chamber 40, base 50, and burner 60. The heater 10 may further include a gas control assembly 70 and an ignition controller 80.

These major components, as well as some of their subcomponents, are generally manufactured out of heat durable materials, generally known to those skilled in the art, that can tolerate heater operating temperatures. Such materials may include metals and polymeric materials having high softening or melting temperatures. Particularly suitable materials generally will be those additionally exhibiting good to high physical and mechanical durability that is maintained over the life of the product when exposed to the elements and/or the temperature cycles experienced as a result of fuel combustion in heat chamber 40 and circulation of heated air and combustion byproducts throughout the internal environment of the housing. Preferably, the materials forming the heater components and subcomponents additionally exhibit good chemical durability, i.e., rust resistance in a humid environment, corrosion resistance, or ammonia resistance. Examples of suitable materials include, but are not limited to, stainless steel, galvanized steel and pre-painted steel. Some elements or components of heater 10 may be formed of plastic or polymeric materials exhibiting good temperature and/or thermal durability.

Referring to Figure 1, housing 20 includes outer casing 22 and door 24. Door 24 is provided to allow access to the components internal to the housing 20. A second door 26 may also be provided to similarly allow more ready access to heater components on the opposite side of the housing 20. Doors 24, 26 may be provided with a securing means such as latch assembly 28. Thus, the heat chamber 40 and the air flow assembly 30, both mounted within housing 20, may be accessed without need for removal or disassembly of housing 20 which is mounted to the base 50 of heater 10. Of course housing 20 may be removed or
disassembled from base 50 in order to allow unobstructed access to heat chamber 40, air flow assembly 30, and burner 60. Housing 20 further includes an air housing exit 29 from which heated air and combustion byproducts are discharged or exhausted from heater 10 in order to heat the internal environment of a greenhouse or animal confinement. Housing 20 is depicted in front view in Figure 2 showing air housing exit 29.

Referring again to Figure 1, airflow assembly 30 includes inner scroll 32, two end panels 33, fan wheel 35, motor mount 36 and motor 37. End panels 33 are each provided with an entrance. One entrance is configured to receive fan wheel 35 within inner scroll 32, and the other entrance is configured to receive heated air flow and combustion byproducts into inner scroll 32 to be discharged or exhausted from heater 10 via air housing exit 29 by operation of fan wheel 35. Airflow assembly 30 may further include an air proving system formed of flapper 38 and air proving switch 39, a microswitch. Flapper 38 lifts up when there is sufficient airflow through heater 10 and closes air proving switch 39, thus allowing electrical power to flow to a gas valve 74 and the heater to operate. Other air proving systems known to those skilled in the art may be used as an alternative. As an example, the air proving system may be of a “paddle switch” configuration with a small piece of stainless steel, the paddle, spot welded to an actuating arm of a microswitch.

When assembled, inner scroll 32 is positioned between end panels 33; and fan wheel 35 is disposed within inner scroll 32, through the entrance, and is mounted to the shaft of motor 38, which provides rotational motion to fan wheel 35. Inner scroll 32, in cooperation with end panels 33, defines an airflow opening 34 through which the combustion discharge stream or heated airflow that is drawn into airflow assembly 30 is directed out of heater 10 through air housing exit 29. Airflow assembly 30 may be mounted to the interior of housing 20 and/or to a lower insert 46 of heat chamber 40. When mounted within housing 20, airflow
opening 34 is positioned and aligned with air housing exit 29 so that the heated airflow being
blown out of airflow assembly 30 by fan 35 may be discharged or exhausted from heater 10
via air housing exit 29.

With reference to Figures 1 and 3, heat chamber 40 includes outer wrapper 42, upper
insert 44 (not shown in Figure 1), and lower insert 46. Inserts 44, 46 are mounted or secured
to the interior surface of outer wrapper 42 and positioned in space relationship so as to define
a heat chamber inlet 48 into which burner 60 is disposed. Upper insert 44 is configured to
direct the flame or combustion discharge from burner 60 in a “bent flame” path. Turning to
Figure 3, lower insert 46 is provided with a lower insert slot 49 sized to allow a quenching
airflow to pass through lower insert 46. Lower insert 46 may be provided with one or more
lower insert slots 49. Though slots of various sizes may be provided to allow a quenching
airflow to pass through lower insert 46, Applicants have found that one or more lower insert
slots 49 presenting a total area of about 1.806 to about 2.006 cm²/1000 BTUH (about 0.28 to
about 0.31 in²/1000 BTUH) are preferable.

Lower insert slot 49 typically will only partially span the width of lower insert 46.
However, in some embodiments, a single lower insert slot 49 may span the entire width of
lower insert 46, with lower insert 46 being formed of first and second portions. The first
portion being mounted to and within heat chamber 40, and the second portion being mounted
and secured to the interior surface of housing 20. A single slot 49 of a desired area is formed
with consideration of the overall width of lower insert 46 and the size of the spacing between
the first and second portions of lower insert 46.

Referring briefly to Figure 5, airflow assembly 30 can be seen mounted above lower
insert 46 via end panels 33. Airflow assembly 30 is mounted in spaced relationship from heat
chamber outlet 47. The space between airflow assembly 30 and the heat chamber outlet 47
defines a mixing zone where, with reference to Figure 5, dilution airflows 104, combustion discharge (essentially represented by "bent" flame path 108) and quenching airflow 110 are intermingled and mixed to begin forming and to form a combustion discharge stream.

As shown in Figure 7, burner 60 has a top section or discharge port 62 at one end and a lower section 66 with a burner inlet 64 at the other end. The burner inlet has an inlet area. The inlet area may be provided with a single opening or a plurality of openings into which gas a dilution air 104 enter burner 60. In Figure 7, manifold 71 is shown disposed beneath the inlet area (not shown) within burner inlet 64. Discharge port 62 and burner inlet 64 are joined in flow-through communication by an internal venturi channel (not shown). Discharge port 62 as shown in Figures 1 and 7 is "fan-shaped" but may be provided in other shapes.

Port 62 may be configured with one or more discharge slots 68 at which the air/gas mixture is ignited to provide the flame and heat source; however port 62 is preferably of a single slot discharge construction. Discharge slot 68, in a "fan-shaped" discharge port 62, may typically be about 0.190" wide and about 10.250" long. Depending upon the configuration or shape of discharge port 62, discharge slot 68 may have other and appropriate dimensions.

Additionally, Applicants have found that with the addition of a "waffle plate," such as a piece of corrugated steel, inserted in discharge slot 68, multiple combustion discharge passages are created, resulting in a noticeable reduction in NO₂ emissions during natural gas combustion. Thus, discharge port 62 may have a waffle plate inserted within discharge slot 68. It should be understood that burner 60 may be provided in various known configurations but the dimensions of the discharge slot 68 or alternative discharge openings may have to be optimized in order to provide the desired combustion efficiencies realized with the fan-shaped configuration.
When burner 60 is mounted within heat chamber inlet 48 of heater 10, it is attached via burner inlet 64 to base 50 by suitable attachment means known to those skilled in the art so that burner inlet 64 is sufficiently spaced away from the surface of base 50 so as to allow primary combustion air 106 (shown in Figures 4 and 5) to enter within and/or to be drawn into the inlet area of burner inlet 64. The discharge from discharge port 62 of burner 60 accelerates the air/gas mixture. Primary combustion air 106 is pulled or drawn into the burner inlet 64 by the gas jet velocity created by the volume of gas flowing through a burner orifice 72 of a burner manifold 71.

Gas is received in heater 10 by a gas control assembly 70 which is connected to an external source or container of gas, e.g., LPG or natural gas (not shown). Gas control assembly 70 regulates the delivery of gas to heater 10. Gas control assembly 70 contains burner manifold 71 which includes single hole manifold orifice 72, and a gas control valve 74, preferably equipped with a power control valve. Manifold 70 is positioned within heater 10 immediately below the inlet area of burner inlet 66 in order to deliver gas to burner 60. As shown in Figure 6 burner orifice 72 is positioned immediately beneath the inlet area of burner inlet 64 and preferably is centered and aligned along a common central axis with burner 60. Manifold orifice 72 is preferably formed of a suitable metal and more preferably of brass.

Gas control valve 74 may be a single-stage control valve that delivers gas at a single pressure or flow rate or it may be a valve that delivers gas at a plurality of pressures or flow rates, such as a dual-stage control valve, a multi-stage control valve, or a modulating control valve. With a single-stage control valve, gas flow is either completely switched on, 100% on, or completely switched off, 100% off. With a dual-stage control valve, gas flow may be, for example 100% off, 50% on (or other percentage less than 100% on), or 100% on. A multi-stage control valve will be understood to regulate gaseous fuel flow rate according to the
number of stages provided, providing gas flow a different rates and pressures. With a modulating control valve, gaseous fuel flow rate or pressure is provided as a function of the rate of change of room temperature. Gas delivery assembly 70 may be connected to an external supply of gaseous fuel with standard piping or tubing and connectors, which may include additional valves, regulators, hoses, brackets, various connectors, nipples, and the like such as is commonly known to be used in the art.

Heater 10 may also be equipped with a controller 80. Controller 80 may electrically communicate with an environmental control system. Such a system may receive inputs from temperature, humidity, and/or pollution sensors and determine heating and air exchange needs. In an alternative embodiment, control 80 may electrically communicate with a temperature controlling device, such as a thermostat. As shown in Figure 1, controller 80 is incorporated into and an integral part of heater 10 and may have a hinged cover 82; however controller 80 may be provided without a cover. Controller 80 may incorporate any desired combination of a number of different elements to control different operational functions of heater 10, such as igniting gaseous fuel introduced into burner 60 with an electric spark element of a sensor assembly 90, signaling gas control valve 74 to cycle gas flow, turning fan motor 37 on and off, and electronically communicating with air proving switch 39, igniter and sensor assembly 90 and/or a temperature limit switch 92. If provided with an igniter and sensor assembly 90, assembly 90 may include an electric spark element for igniting the gaseous fuel passing from discharge slot 68 of burner 60 and a flame sensing element for detecting a flame by passing a current through the discharge or flame from the discharge slot to ground. Assembly 90 may be mounted to the heat chamber with the electric spark element positioned, preferably centered, over discharge slot 68 and with the flame sensor positioned over discharge slot 68, preferably tilted up over discharge slot 68.
Controller 80 as shown in Figure 1 includes an ignition control 84, transformer 86, power cord 87 and harness 88. Controller 80 may be mounted with harness 88 or other appropriate connectors to heater 10 or to a structural component of an enclosure, such as a greenhouse or of an agricultural animal confinement. Controller 80 may be mounted to a side of heater 10, as shown in Figure 2, or in other positions on heater 10, such as the back, front or in an upper position.

Whether mounted to the heater 10 or structural component, ignition control 84 of controller 80 is in electronic communication with gas control valve 74 and, if provided, with ignition and sensor assembly 90 and temperature limit switch 92, which is preferably a high limit switch. Temperature limit switch 92 and air proving switch 39 may be wired in series to a power terminal of gas control valve 74. If the flame sensor fails to detect or sense a flame, either controller logic may signal the air proving switch to open or temperature limit switch to open in order to shut off the flow of gaseous fuel and thus heater 10. Ignition control 84 may operate as to regulate or control the ignition cycle and/or as a safety monitoring device.

Ignition control may be programmed with a basic logic or logic sequence, for example: check air proving switch 39 open, start fan motor 37 and check air proving switch 39 closed, power or energize gas control valve 74 to initiate flow of gaseous fuel to burner 60, start ignition spark sequence, and detect flame. Ignition control 84 may be in electronic communication with a thermostat, and based upon inputs received from the thermostat may signal the heater to shut off, increase gaseous fuel flow to a first flow rate or pressure, e.g., to 50%, increase gaseous fuel flow a second flow rate or pressure, e.g., to 100%, or to otherwise regulate gaseous fuel flow rate according to the number of stages provided in gas control valve 74. Heater 10 may be equipped to run in air circulation mode or in normal heater mode and controller 80 may incorporate an electric switch that can be manually operated to set heater
10 in air circulation mode or heater mode. For example, the switch may comprise a three position rocker switch with "circulate," "off," and "heat" positions. Controller 80 may also be configured to electrically communicate with the environmental control to switch the heater 10 between "circulate," "off," and "heat" positions. Further, control 80 can be configured to actuate a shutter assembly 134 and an exhaust fan 136, as discussed later herein below relative to Figures 8 and 9.

Figures 4 and 5, respectively, illustrates the airflow through a prior art heater 100 and an embodiment of heater 10 of the invention. Note identical reference numbers are used to refer to like elements in Figures 4 and 5. Further, note that lower insert 46 in Figure 4 does not include a lower insert slot, while lower insert 46 in Figure 5 does include lower insert slot 49.

Turning now to Figure 4 illustrating the airflow through a prior art heater 100. Ambient air 102 can be seen being drawn into heater 100 through inlet matrix 52 of base 50. As ambient air 102 enters into the housing of heater 100 it is channeled in different directions within the housing 20 and heat chamber 40 forming dilution air or airflows 104. Dilution air 104 can be seen circulating around and into the airflow assembly 30, between housing 20 and upper insert 44, and into heat chamber inlet 48 of heat chamber 40. The flame or combustion discharge (essentially represented by "bent" flame path 108) is shown being discharged vertically from burner 60 and being directed by the configuration of upper insert 44 into the "bent" flame path 108. The flame or combustion discharge of flame path 108 can be seen to exit heat chamber 40 joining and mixing with dilution airflows 104 in the mixing zone. In the mixing zone, dilution airflows 104 and the combustion discharge mix to begin forming and to form a combustion discharge stream and are drawn into the entrance of panel 33 of airflow assembly 30 by the rotational pulled fan 35 into airflow assembly 30. As previously
mentioned, the combustion discharge stream is passed from airflow assembly 30 via airflow
opening 34 and discharged or exhausted from heater 20 via air housing exit 29, thereby
heating the environment within a greenhouse or animal confinement. Primary combustion air
106 is shown flowing into burner inlet 64 where it is mixed with gaseous fuel fed into burner
inlet 64 from burner orifice 72 of manifold 71. Fan 35 imposes some pressure or draw on the
combustion discharge from burner 60, contributing to the rate of flow of primary air 106 into
burner inlet 64.

Prior art heater 100 is representative of a direct-fired, gas-fueled heat more typically
utilized to heat agricultural animal confinements or greenhouses having a high amount of
natural air exchanges. Such prior art heaters typically have a temperature rise of 220 °F, with
temperature rise being the temperature difference between ambient air 102 entering inlet
matrix 52 and the combustion discharge stream exiting air housing exit 29.

With reference to Figure 5 and common reference numbers for ambient air intake 102,
dilution air 104, primary combustion air 106, and flame path 108, the flow of air through
heater 10 of the invention is understood to be similar to that of the airflow through prior art
heater 100; however lower insert 46 is provided with lower insert slot 49. This allows for the
addition of quenching airflow 110. The flame or combustion discharge of flame path 108 can
be seen to exit heat chamber 40 joining with dilution airflows 104 and quenching airflow 110
in the mixing zone. In the mixing zone, dilution airflows 104, quenching airflow 110 and the
combustion discharge mix to begin forming and to form a combustion discharge stream and
are drawn into the entrance of panel 33 of airflow assembly 30 by the rotational pulled fan 35
into airflow assembly 30. The combustion discharge stream is passed from airflow assembly
30 via airflow opening 34 and discharged or exhausted from heater 20 via air housing exit 29,
thereby heating the environment within a greenhouse or animal confinement. Primary
combustion air 106 is shown flowing into burner inlet 64 where it is mixed with gaseous fuel
ted into burner inlet 64 from burner orifice 72 of manifold 71. Fan 35 imposes some pressure
or draw on the combustion discharge from burner 60, contributing to the rate of flow of
primary air 106 into burner inlet 64.

Providing quenching air 110 that joins with dilution air 104 and the combustion
discharge of flame path 108 serves to reduce overall combustion stream temperature to
provide acceptable outlet temperatures. This is because quenching air 110 is mixing an
additional airflow with the combustion discharge at an earlier point of the combustion cycle
thereby lowering the overall flame or combustion discharge temperature. Applicants believe
that the lowering of the temperature results in less NO₂ being produced as a combustion
byproduct. Applicants have found that a temperature rise substantially less than 220 °F is
generally sufficient to provide adequate combustion without the increase NO₂ production that
may be seen from prior art direct fired heaters. A temperature rise of between about 100 °F to
about 180 °F is preferable. More preferable is a temperature rise of between about 110 °F to
about 120 °F, with a temperature rise about 120 °F being even more preferred.

Applicants have found that particular combinations of lower temperature rise, gaseous
fuel type specific burner orifice area range, inlet area range, inlet matrix area range, a low gas
manifold pressure, a lower insert slot area range, high total airflow into heater 10, in
conjunction with the BTU/ft³ of the gaseous fuel type utilized determines the firing rate (BTU
per hour) of the heater.

Applicants' attention to and recognition of these interrelationships has resulted in an
improved direct-fired heater 10 capable of achieving high fuel efficiency and any one or
combination of reduced emission of deleterious combustion gas products, high or increased
fuel efficiency, improved CO₂ production to stimulate plant growth, lower product cost and
lower operating costs. Heater 10 of the invention being of the direct-fired type can achieve at
least the same high fuel efficiencies of prior art direct-fired heaters of up to about 99.96% and
may possibly achieve even higher fuel efficiencies.

Applicants have found that a lower insert slot area range of between about 0.28 in² per
1000 BTUH to about 0.31 in² per 1000 BTUH is suitable. The low gas manifold pressures of
not more than about 0.5 psig necessary for the gas supplied to burner inlet 66 of burner 60
can be achieved, in part, with attention to the specific type of gas being utilized and the size,
expressed as a “burner orifice area” or “orifice area,” of burner orifice 72 in manifold 71. For
example, an orifice area range of 0.00013 to 0.00014 in² per 1000 BTUH has been found
suitable for propane (and may also be suitable for butane) and an orifice area range of
0.00025 to 0.00027 in² per 1000 BTUH has been found suitable for natural gas. A high
amount of total air flow in the order of about 0.008 CFM per BTUH to about 0.009 CFM per
BTUH is suitable in order to provide the volume of air necessary to achieve high fuel
efficiency that can result in reduced emissions of deleterious combustion byproducts.

Applicants have further found that the size of burner inlet 64, expressed as “inlet area,”
assists in providing the desired high amount of total airflow to burner 60 to provide the
appropriate air/gas mix. An inlet area range of about 0.9 in² per 1000 BTUH to about 1.2 in²
per 1000 BTUH has been found to be suitable.

With the provision of high total airflow through the heater in combination with the
inlet matrix area of inlet matrix 52, gas BTU content, low gas manifold pressure, burner
orifice area, and a lower insert slot 49 combinations of various benefits of the invention can
be achieved. This can be accomplished in heaters of different firing rates or ratings, for
example heaters of 220,000 BTUH and 120,000 BTUH can be produced. Without being
bound by theory and although several of the different area ranges were developed as result of
experimentation and observation of empirical data gathered, Applicants believe that at least some of these ranges may be capable of being determined based upon or derived from a formulaic calculation or algorithm.

Applicants have confirmed the reduction in deleterious combustion byproducts achieved with heater 10 of the invention by sampling and testing of the heated air exiting from a standard direct-fired heater and from a direct-fired heater according to the invention.

Applicant performed comparative testing of a standard agricultural animal confinement heater and of a heater of the invention. Tests were conducted for carbon monoxide, nitrogen dioxide, ethylene, and carbon dioxide utilizing heater outlet sampling methodology prescribed in IAS Requirements for Gas-Fired Greenhouse Heaters. The heater is operated in an atmosphere having approximately normal oxygen supply, under the specified airflow conditions. Emission levels are based upon the difference between the background or ambient air concentrations in the incoming air to the heater and the levels in the combustion discharge stream or discharge air from the heater. A test duct of the same cross-sectional shape as the heater outlet is used to direct the combustion discharge stream from the heater to gas concentration analysis instruments or to suitable sample container for off-site analysis. Applicants sampled and tested, on-site at Applicants’ facility, for CO and CO₂ concentrations utilizing a Ultramat 23 analyzer manufactured by Siemens and for NO₂ utilizing a high chemiluminescent, NO-NO₂-NOₓ analyzer, Model 42C manufactured by Thermo Environmental Instruments, Inc. For ethylene, samples of discharge air were pulled utilizing a vacuum pump and collected in Tedlar™ bags which were packaged and shipped to the Horticultural Department of North Carolina State University. There the samples were measured utilizing a precision gas chromatograph with a minimum detection level threshold of 0.5 ppb.
The results of the testing is presented in the Table 1 immediately below:

TABLE 1

<table>
<thead>
<tr>
<th>Combustion Byproduct</th>
<th>Standard Ag Heater</th>
<th>Heater of the Invention</th>
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</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>10-12 ppm</td>
<td>1-1.5 ppm</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>1.0-2.0 ppm</td>
<td>0.3-0.4 ppm</td>
</tr>
<tr>
<td>Ethylene</td>
<td>90-200 ppb</td>
<td>0.5 ppb</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>5000 ppm</td>
<td>2800-3000 ppm</td>
</tr>
</tbody>
</table>

As is apparent from the data in the above table, dramatic reductions in the concentrations of CO₂, NO₂, and ethylene were realized with operation of a direct-fired heater of the invention. Lower CO₂ production is realized with levels of production still beneficial to plants and less harmful to humans than from standard agricultural confinement heaters.

As discussed above, heater 10 may be used to heat an enclosed structure, such as a greenhouse 120 as shown in Figures 8 and 9. Greenhouse 120 may comprise a first end panel 122, a second end panel 124, a first side wall 126, a second side wall 128, and a roof 129. Heater 10 may be located within or external to greenhouse 120, and fuel may be supplied by external gas supply 130. A regulator 131 may be provided for supplying fuel at a constant pressure which pressure may be varied or regulated by operation of gas control valve 74. A manual shutoff valve 132 may be included downstream of the regulator 131, if so desired.

Further, a sediment trap 133 may also be provided to remove sediment and other contaminants from the fuel line.

In the embodiment of Figure 8, heater 10 is located within greenhouse 120. A shutter assembly 134 may be provided to facilitate fresh air entry into the greenhouse 120. Preferably, shutter assembly 134 is located near the heater 10 in the greenhouse 120 to
provide combustion air for the heater 10. In some embodiments, shutter assembly 134 may be motor actuated and provided with a trigger to power open when the heater 10 is powered. In such embodiments, shutter assembly 134 automatically opens when heater 10 is actuated.

Also shown in Figure 8 is an exhaust fan 136. Exhaust fan 136 is useful for facilitating air exchange between the interior and exterior of greenhouse 120, and may be driven by an exhaust fan motor. Such air exchange reduces the amount of pollutants within greenhouse 120. Preferably, exhaust fan 136 is located substantially off the floor generally across the greenhouse 120 from heater 10. For example, heater 10 may be located on first end panel 122 and exhaust fan 136 may be located on second end panel 124. This location promotes uniform air circulation within the greenhouse 120. For example, such a location may establish an airflow path between the heater 10 to the exhaust fan 136, as shown by arrow A in Figure 8.

In the embodiment shown in Figure 9, heater 10 is located external to greenhouse 120. In this embodiment, combustion air is provided to the greenhouse from the ambient environment, and heated air is delivered to the greenhouse interior from the heater 10. Shutter assembly 134 may be provided to facilitate air movement from the greenhouse 120. Preferably, the shutter assembly 134 is located substantially off the floor generally across the greenhouse from heater 10. This location promotes uniform air circulation within the greenhouse 120. For example, such a location may establish an airflow path (e.g., as shown by arrow A in Figure 9). In some embodiments, shutter assembly 134 is opened by a positive pressure created by heater 10 forcing heated air into the greenhouse 120. In an alternative embodiment, shutter assembly 134 may be motor actuated and provided with a trigger to power open when the heater 10 is powered.
Heater 10 could also be operated in an air circulation mode, where the heater is not fired but the air flow generating assembly 30 is used to generate air movement. If the heater is located inside the building, as in Figure 8, air flow generating assembly 30 may be used to circulate the air and promote uniform temperature distributions. If the heater is located outside the building, as in Figure 9, air flow generating assembly 30 may be used to introduce fresh air into the building.

While exemplary embodiments of this invention have been illustrated and described, it should be understood that embodiments shown in drawings and described above are merely for illustrative purposes, and are not intended to limit scope of the invention as defined in the appended claims. Further, it will be understood that various changes, adaptations, and modifications might be made without departing from the spirit of the invention and the scope of the appended claims.
WHAT IS CLAIMED IS:

1. A direct-fired, gas-fueled heater, comprising:
   a base having an air inlet matrix through which ambient air enters the heater; a
   housing mounted to the base, the housing being comprised of an outer casing, at least one
doors, and an air housing exit; an airflow assembly disposed within the housing and
configured so as to draw a flow of ambient air into the heater through the air inlet matrix, to
circulate the flow of ambient air as dilution airflows, a primary combustion airflow, and a
quenching airflow within the housing, and to a direct a combustion discharge stream out of
the heater through the air housing exit; a heat chamber disposed within the housing, the heat
chamber being comprised of an outer wrapper, an upper insert and a lower insert, the two
inserts being mounted in spaced relationship to define a heat chamber inlet; and a burner
disposed within the heat chamber inlet, the burner having a discharge port configured with at
least one discharge slot from which a combustion discharge emanates and a burner inlet, the
burner being attached in spaced relationship to the base to allow a gaseous fuel and the
primary combustion airflow to enter the burner through the burner inlet;
   wherein the lower insert further comprises at least one lower insert slot sized and
configured to allow passage of the quenching airflow therethrough to join and mix with the
combustion discharge and the dilution airflows to form the combustion discharge stream.

2. The heater of claim 1, wherein the heater is adapted to receive gaseous fuel into the
   burner inlet at a plurality of pressures from an external gaseous fuel supply.

3. The heater of claim 1, wherein the heater is adapted to receive gaseous fuel into the
   burner inlet at a lower pressure from an external gaseous fuel supply.
4. The heater of claim 1, wherein the airflow assembly is mounted to the lower insert in spaced relationship from the outer wrapper, the airflow assembly comprising:
   a fan motor having a shaft, a motor mount, a fan wheel attached to the shaft, an inner scroll disposed between two end panels, the end panels each having an entrance, one entrance facing the heat chamber and being configured to receive the combustion discharge stream and the other entrance facing away from the heat chamber and being configured to receive the fan wheel within the inner scroll, the inner scroll and the two end panels cooperating to define a combustion discharge stream opening that is aligned with the air housing exit when the airflow assembly is mounted within the housing.

5. The heater of a claim 4, further comprising a gas control assembly adapted for connection to the gaseous fuel supply, the gas control assembly being comprised of:
   a pressure regulator through which gaseous fuel enters the gas control assembly; a manual shutoff valve; a sediment trap; a gas control valve; a burner manifold having a burner orifice.

6. The heater of claim 5, wherein the burner orifice has a burner orifice area and the inlet has a inlet area, and the lower insert slot has a slot area, and the inlet matrix has an inlet matrix area.

7. The heater of claim 6, wherein gaseous fuel is propane, the burner orifice has a burner orifice area of about 0.00013 in² per 1000 BTUH to about 0.00014 in² per 1000 BTUH; the inlet has an inlet area of about 0.9 in² per 1000 BTUH to about 1.2 in² per 1000 BTUH; the lower insert slot has a slot area of about 0.28 in² per 1000 BTUH to about 0.31 in² per 1000 BTUH, and the inlet matrix has an inlet matrix area of between about 0.008 CFM per BTUH to about 0.009 CFM per BTUH.
8. The heater of claim 6, wherein gaseous fuel is natural gas, the burner orifice has a burner orifice area of about 0.00025 in² per 1000 BTUH to about 0.00027 in² per 1000 BTUH; the inlet has an inlet area of about 0.9 in² per 1000 BTUH to about 1.2 in² per 1000 BTUH; the lower insert slot has a slot area of about 0.28 in² per 1000 BTUH to about 0.31 in² per 1000 BTUH, and the inlet matrix has an inlet matrix area of between about 0.008 CFM per BTUH to about 0.009 CFM per BTUH.

9. The heater of claim 1, wherein the airflow assembly is mounted in spaced relationship from the outlet of the heat chamber, the space between the airflow assembly and the heat chamber exit defining a mixing zone where dilution airflows, combustion discharge and quenching air flows are intermingled to begin forming the combustion discharge stream.

10. The heater of claim 9, further comprising a gas control assembly adapted for connection to the gaseous fuel supply, the gas control assembly being comprised of:

   a pressure regulator through which gaseous fuel enters the gas control assembly; a manual shutoff valve; a sediment trap; a gas control valve; a burner manifold having a burner orifice.

11. The heater of claim 10, wherein the burner orifice has a burner orifice area and the inlet has a inlet area, and the lower insert slot has a slot area, and the inlet matrix has an inlet matrix area.

12. The heater of claim 11, wherein gaseous fuel is propane, the burner orifice has a burner orifice area of about 0.00013 in² per 1000 BTUH to about 0.00014 in² per 1000 BTUH; the inlet has an inlet area of about 0.9 in² per 1000 BTUH to about 1.2 in² per 1000 BTUH; the lower insert slot has a slot area of about 0.28 in² per 1000 BTUH to about 0.31 in² per 1000 BTUH, and the inlet matrix has an inlet matrix area of between about 0.008 CFM per BTUH to about 0.009 CFM per BTUH.
13. The heater of claim 11, wherein gaseous fuel is natural gas, the burner orifice has a burner orifice area of about 0.00025 in\(^2\) per 1000 BTUH to about 0.00027 in\(^2\) per 1000 BTUH; the inlet has an inlet area of about 0.9 in\(^2\) per 1000 BTUH to about 1.2 in\(^2\) per 1000 BTUH; the lower insert slot has a slot area of about 0.28 in\(^2\) per 1000 BTUH to about 0.31 in\(^2\) per 1000 BTUH, and the inlet matrix has an inlet matrix area of between about 0.008 CFM per BTUH to about 0.009 CFM per BTUH.

14. The heater of any one of claims 1-13, the heater further comprising an electronic controller for regulation of heater operational parameters.

15. The heater of any one of claims 1-13, the heater further comprising a control box, the control box comprising a panel, an ignition controller, a transformer, a power cord, and a harness.

16. The heater of claim 15, wherein the control box is in electronic communication with one or more components selected from the group consisting of the gas control valve, fan motor, an air proving switch, an igniter, a temperature limit switch, a fan motor switch, a shutter assembly, and an exhaust fan motor.

17. The heater of claim 1, wherein the heater is mounted within an enclosed structure.

18. The heater of claim 1, wherein the heater is mounted exterior to an enclosed structure.

19. The heater of claim 17 or 18, wherein the enclosed structure further comprises a shutter assembly.

20. The heater of claim 19, wherein the shutter assembly is motor actuated.

21. The heater of claim 17, wherein the enclosed structure further comprises an exhaust fan.
FIG. 5

SUBSTITUTE SHEET (RULE 26)