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Young et al.

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(54) **LIQUID VAPORIZATION AND PRESSURIZATION APPARATUS AND METHODS**

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(73) Assignee: **Allports LLC International**, Boise, ID (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

(63) Continuation of application No. 08/899,181, filed on Jul. 23, 1997, now Pat. No. 6,162,046, which is a continuation-in-part of application No. 08/439,093, filed on May 10, 1995, now Pat. No. 5,692,095.

(51) **Int. Cl.**[7] **F23D 11/44**; F23L 15/00

(52) **U.S. Cl.** **431/11**; 431/208; 431/241; 126/45; 126/96

(58) **Field of Search** 431/208, 32, 206, 431/11, 243, 102, 344, 241, 259; 123/549; 126/40, 45–47, 96

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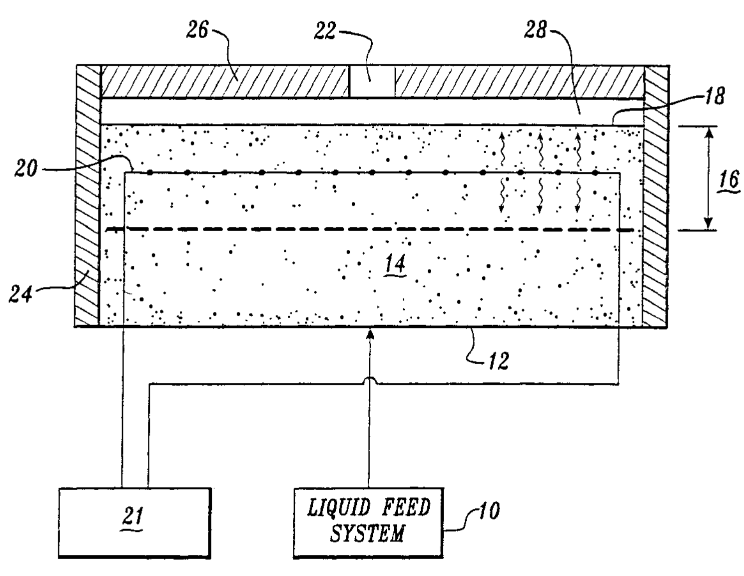
(57) **ABSTRACT**

A vaporization/pressurization module employs a porous member having a low thermal conductivity and a substantially uniform, small pore size. Liquid feed is introduced to the porous member and is heated, vaporized, and pressurized within and/or on a surface of the porous member to produce a vapor jet having a pressure higher than that of the liquid feed. A substantially vapor impermeable barrier facilitates accumulation and pressurization of the vapor, which is released from the module as a pressurized vapor jet from one or more restricted passages. The vaporization/pressurization module is especially useful for liquid fuel combustion applications.

21 Claims, 18 Drawing Sheets



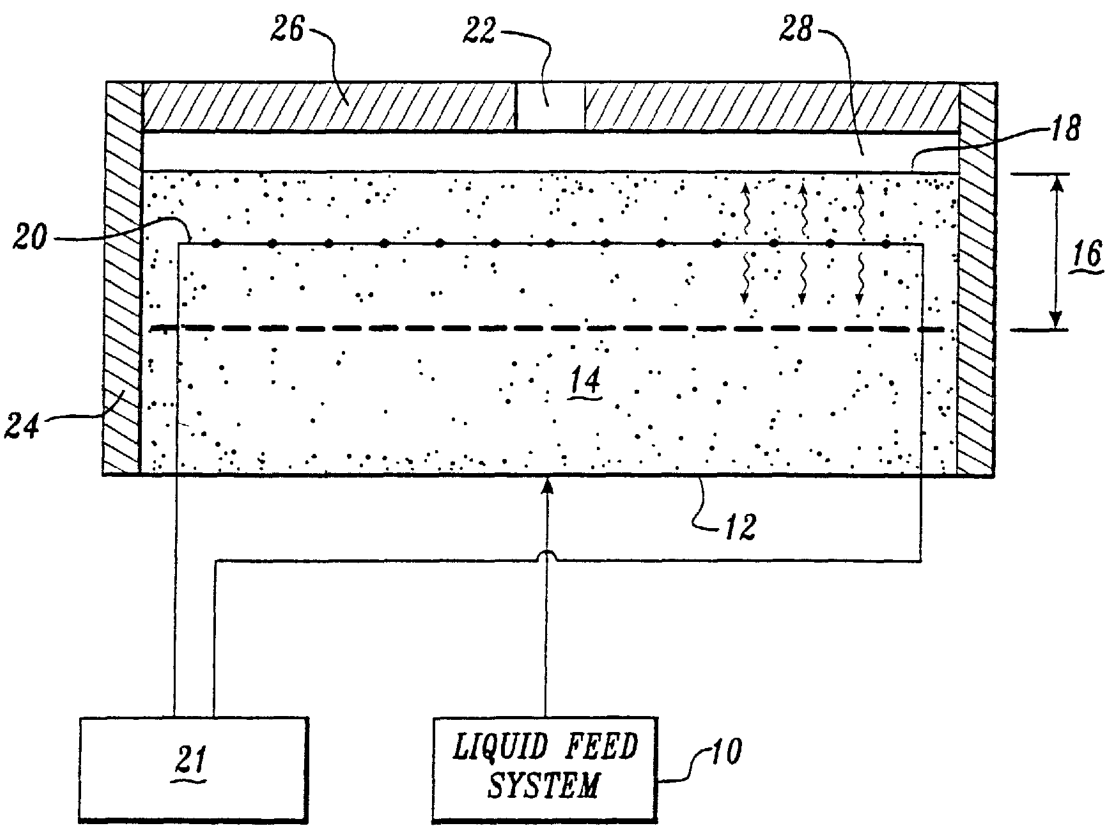


Fig. 1

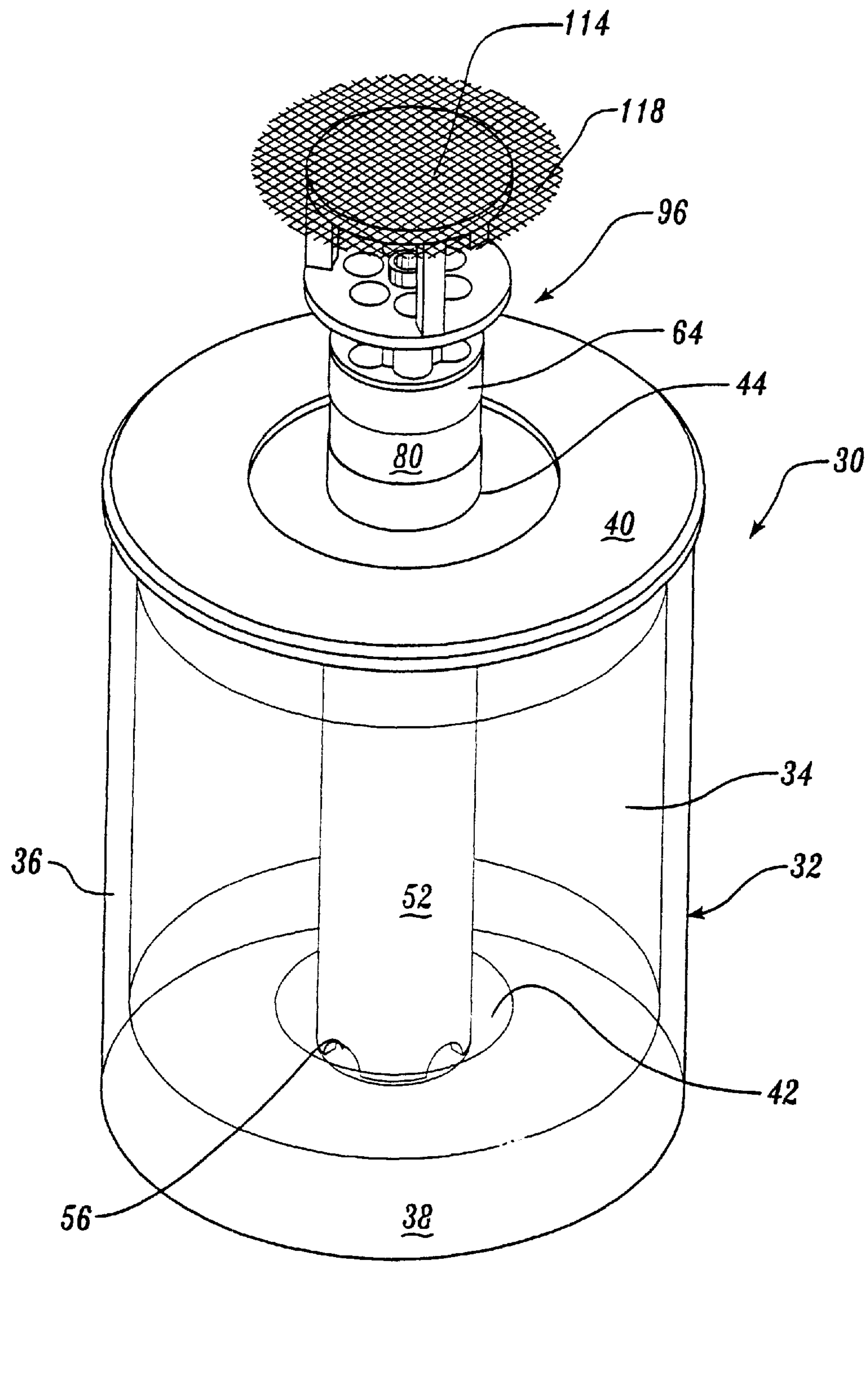


Fig. 2

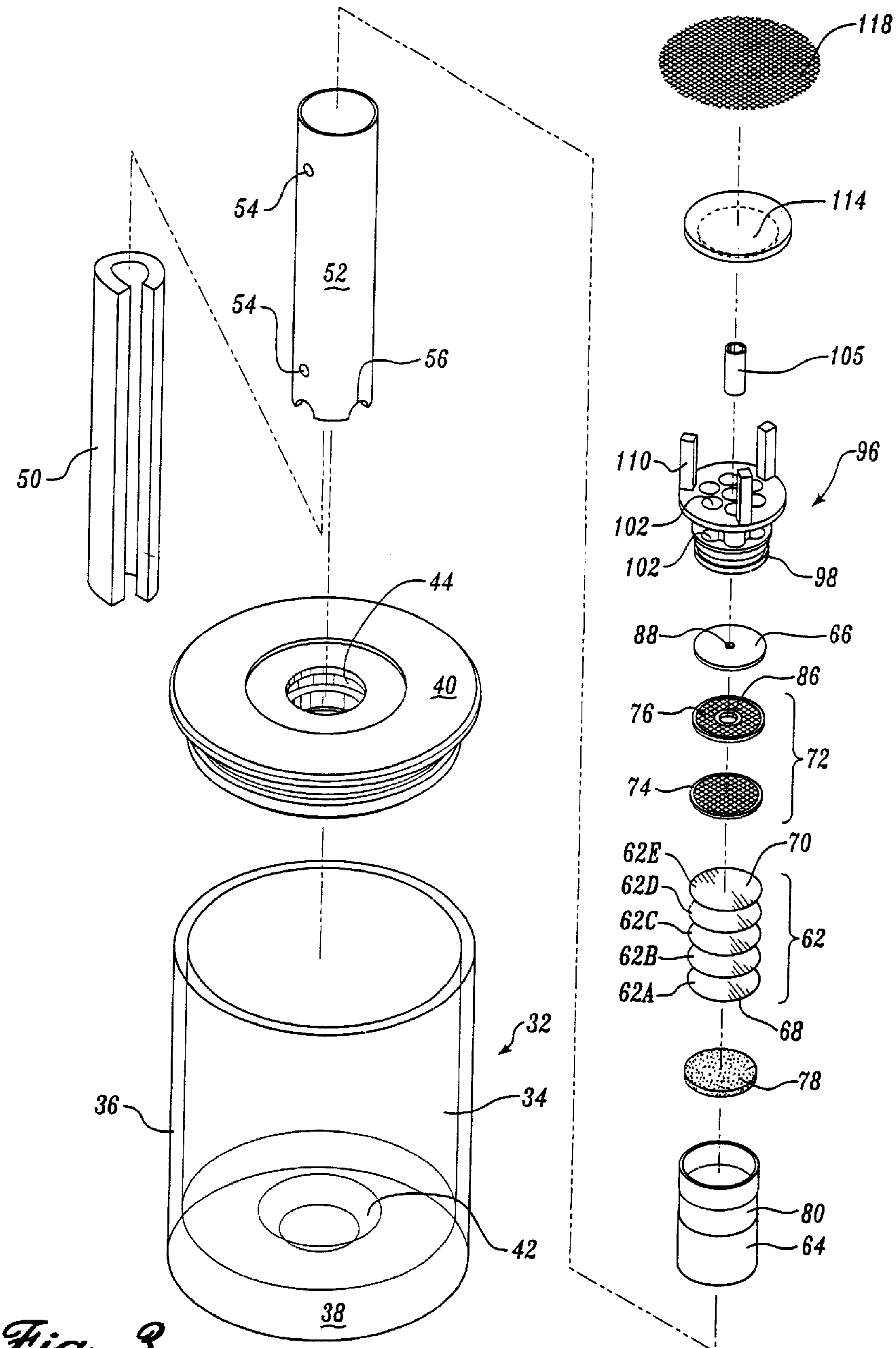

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Fig. 3

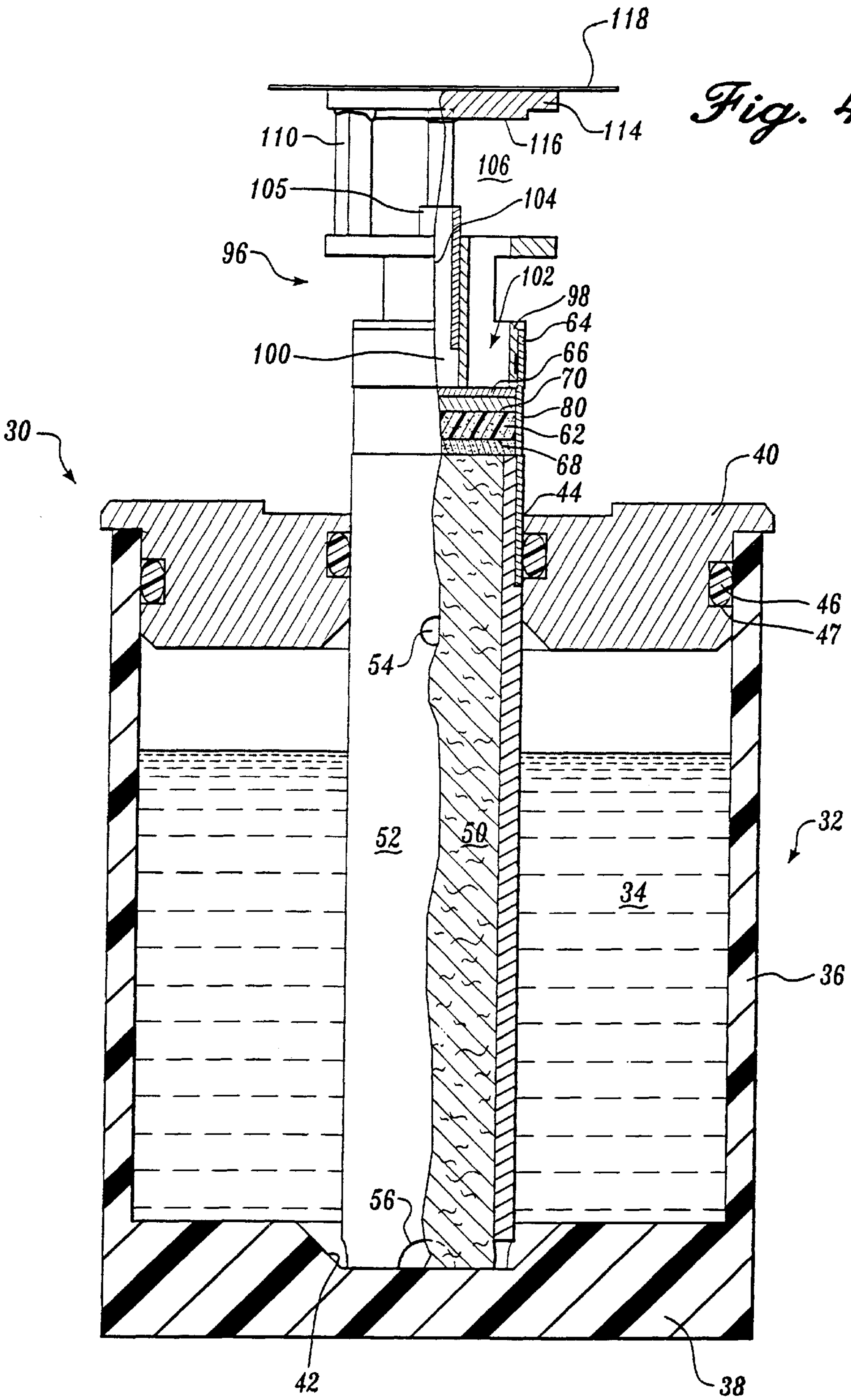
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Fig. 4

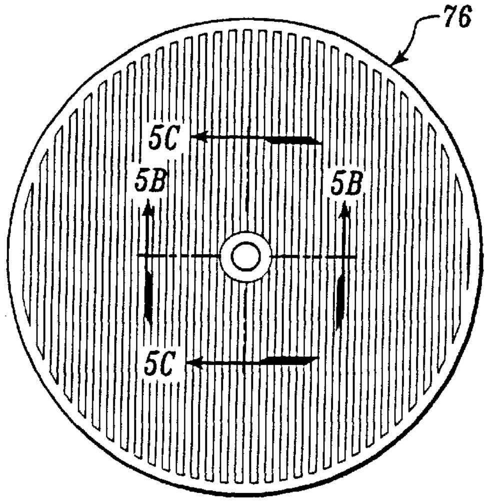

Fig. 5A

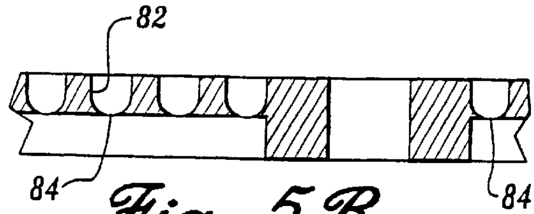

Fig. 5B

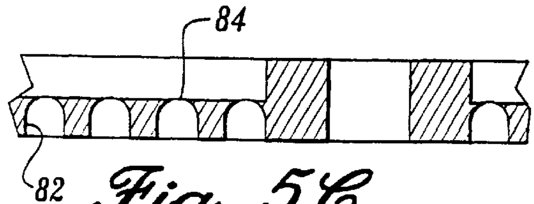

Fig. 5C

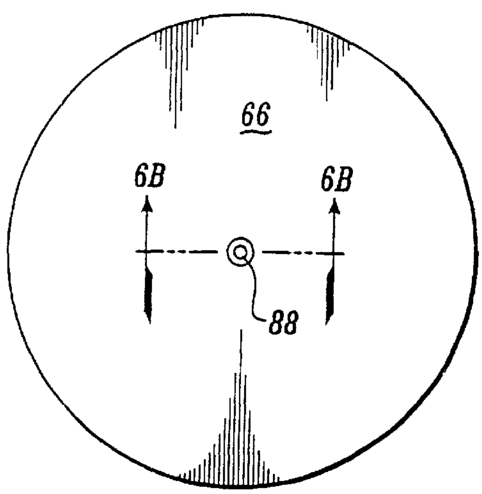

Fig. 6A

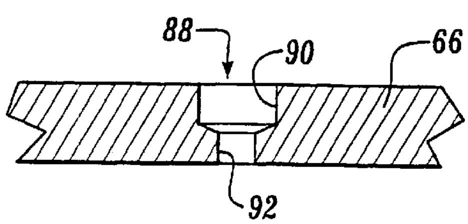

Fig. 6B

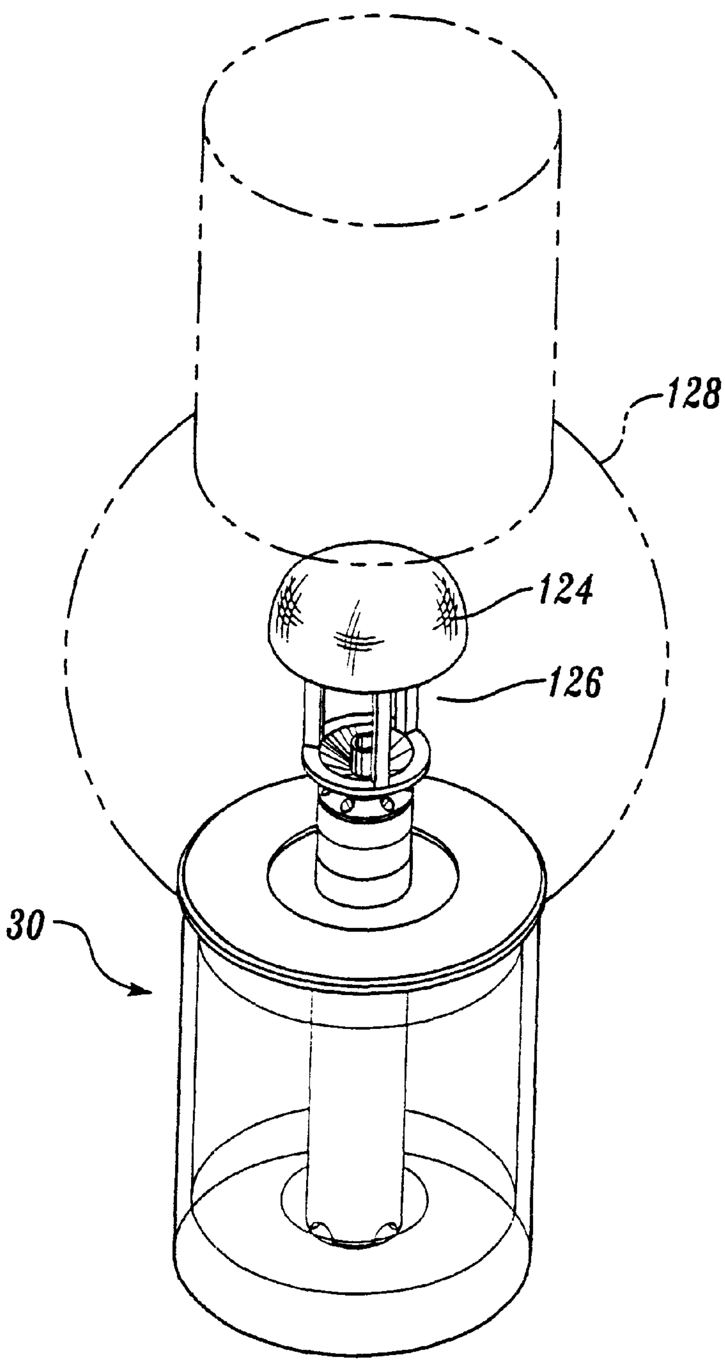

Fig. 7

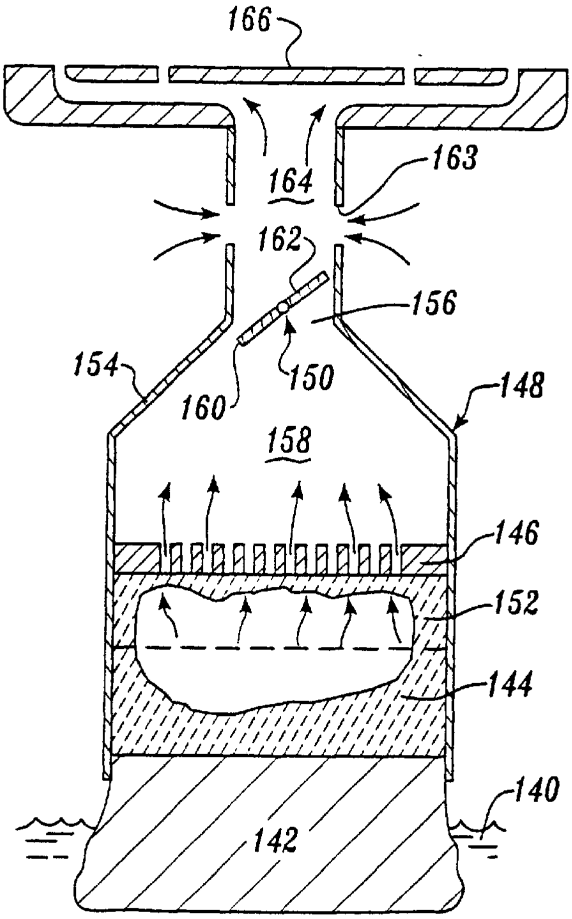
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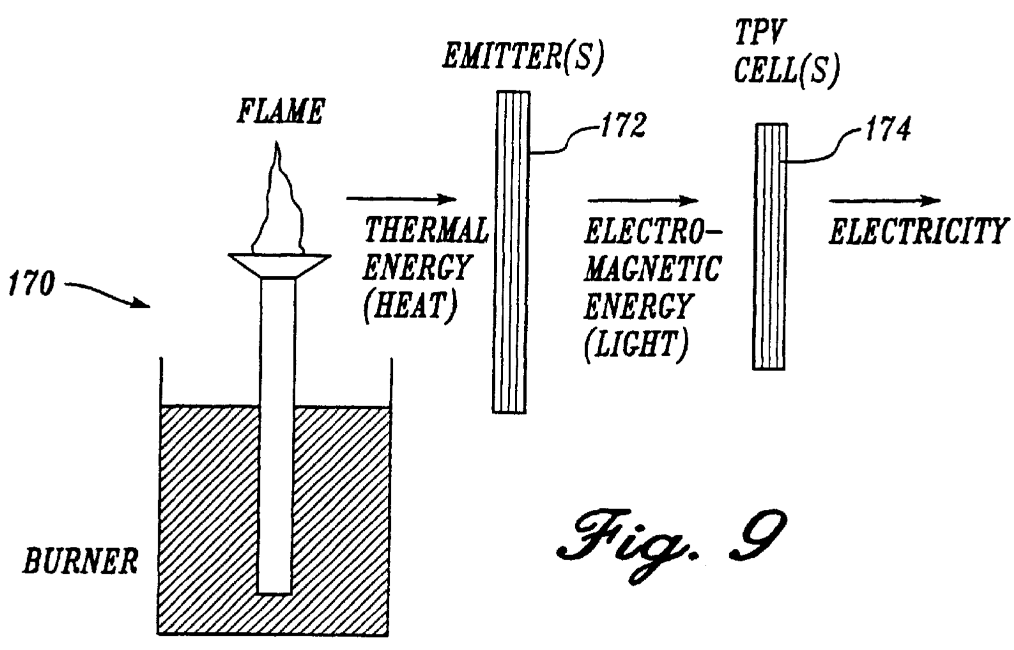
Fig. 8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BURNER

Fig. 9

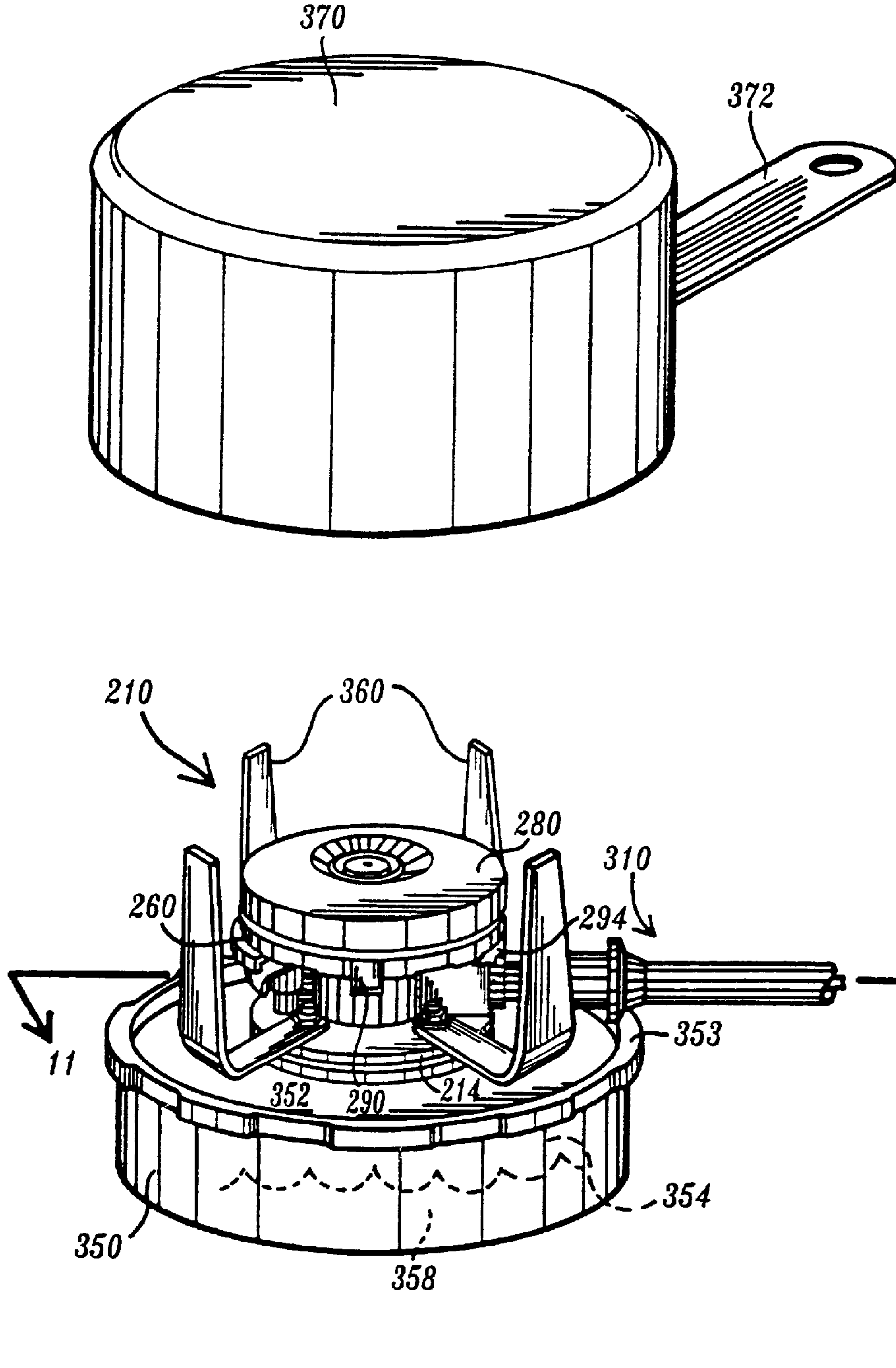

Fig. 10

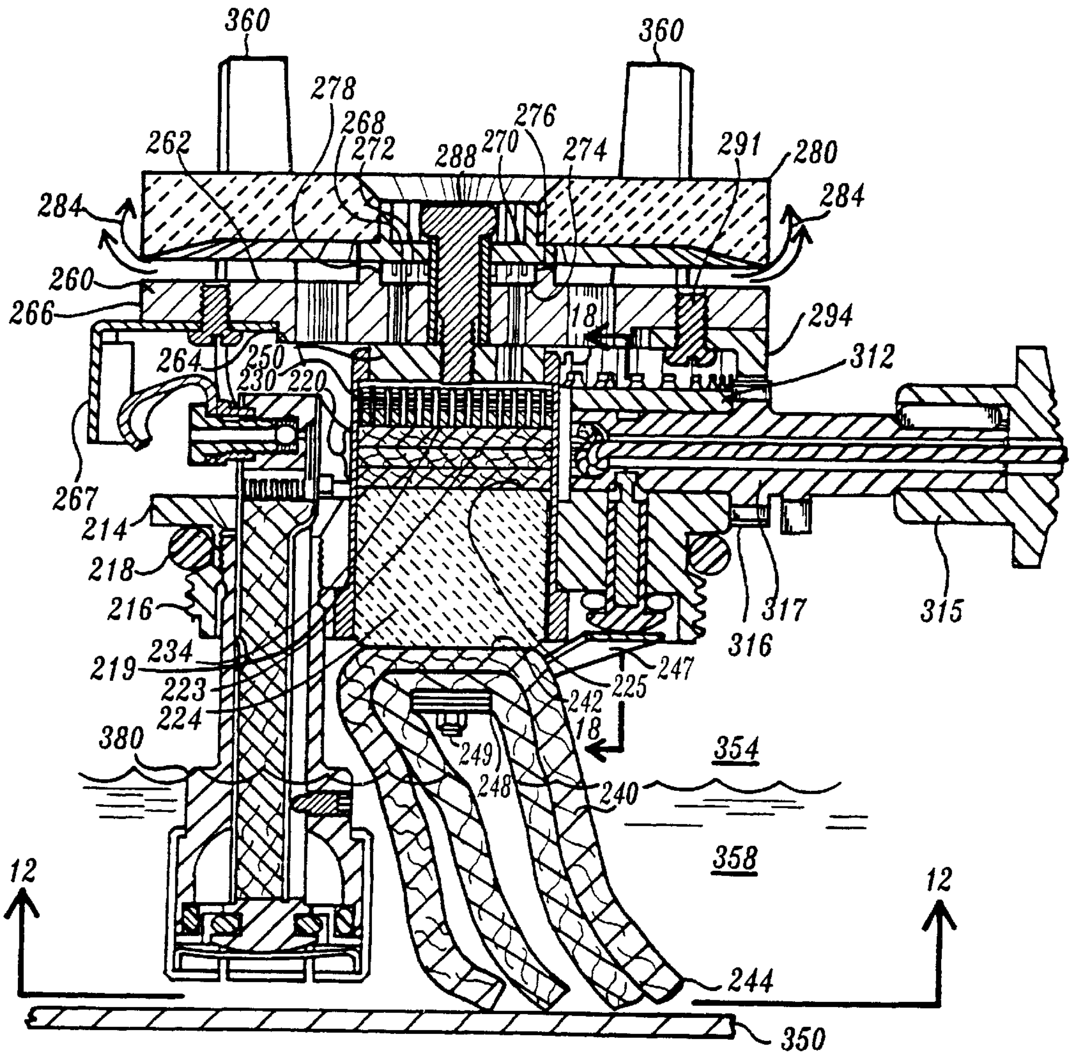
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Fig. 11

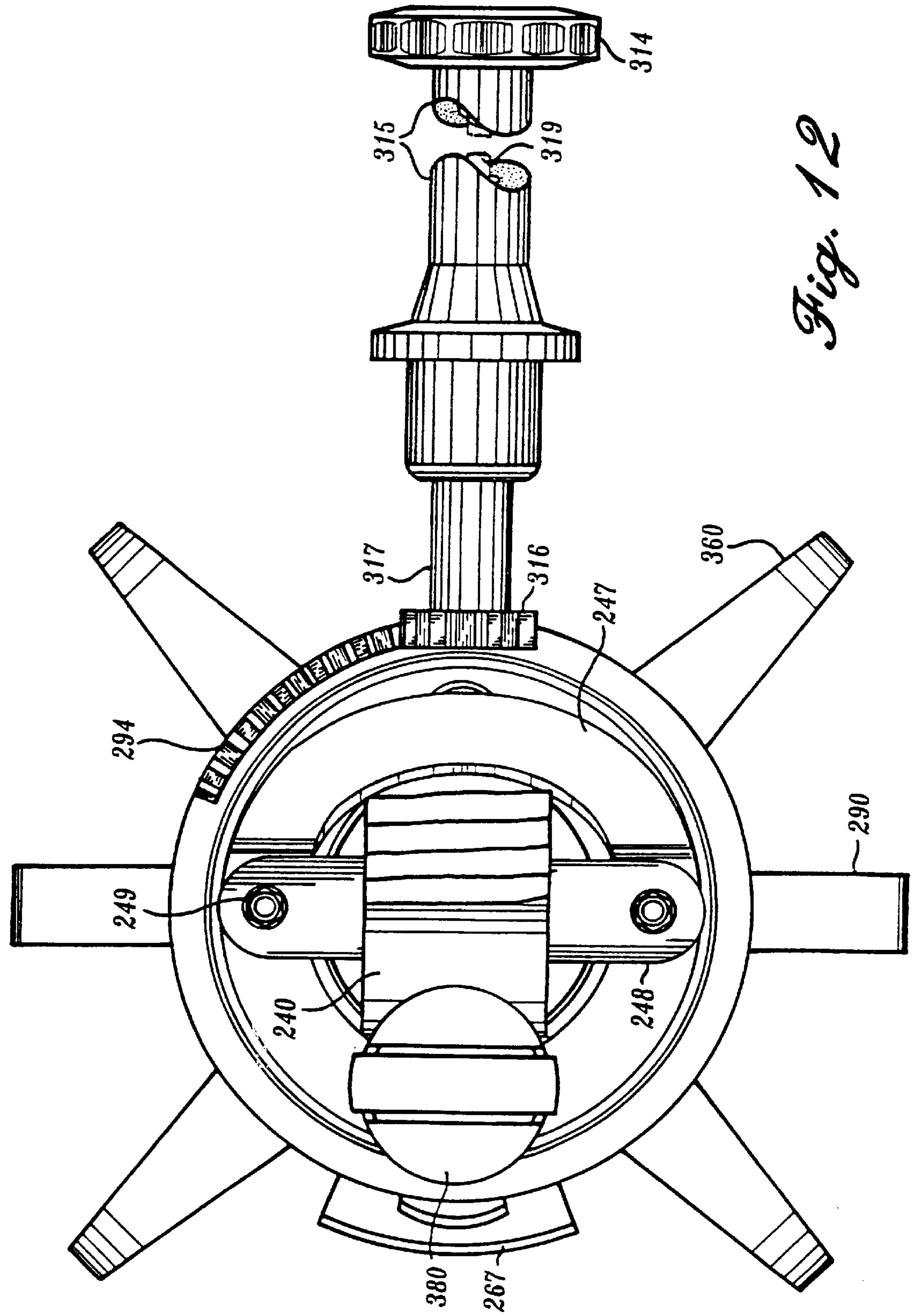

Fig. 12

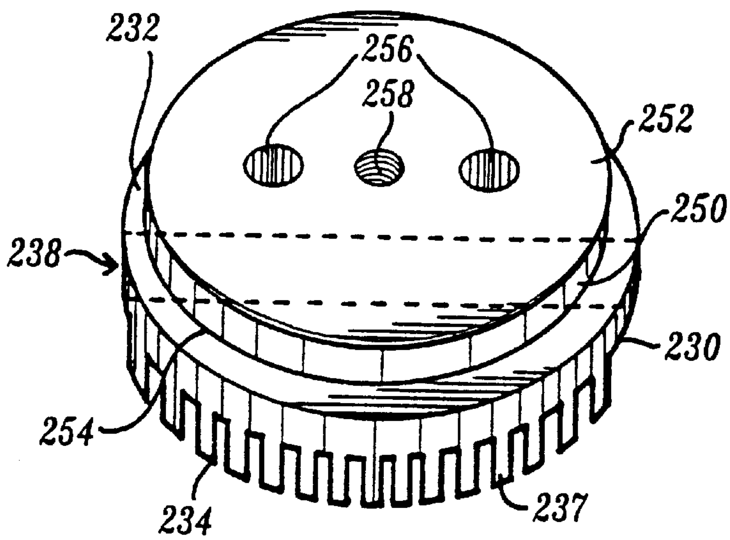
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Fig. 13

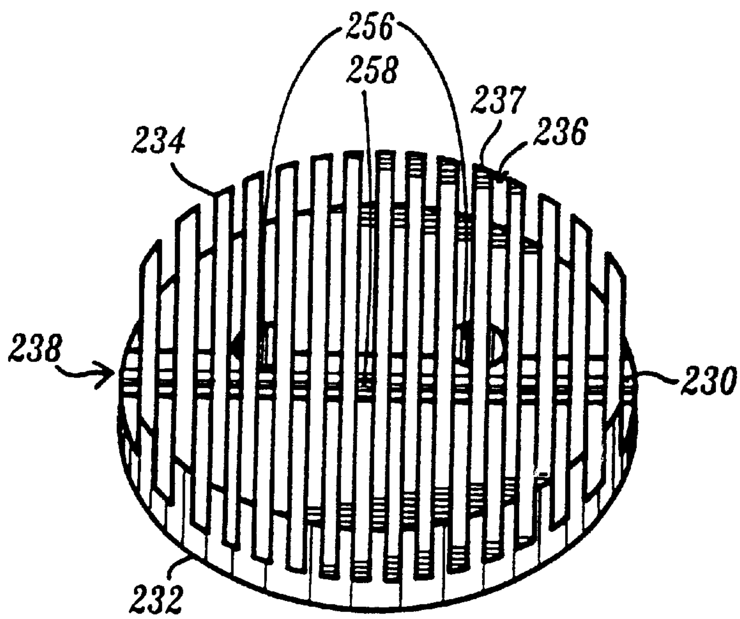
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Fig. 14

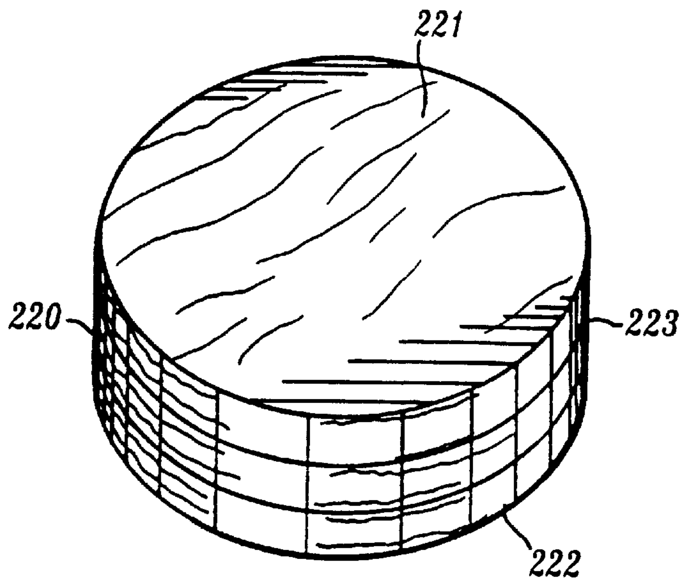

Fig. 15

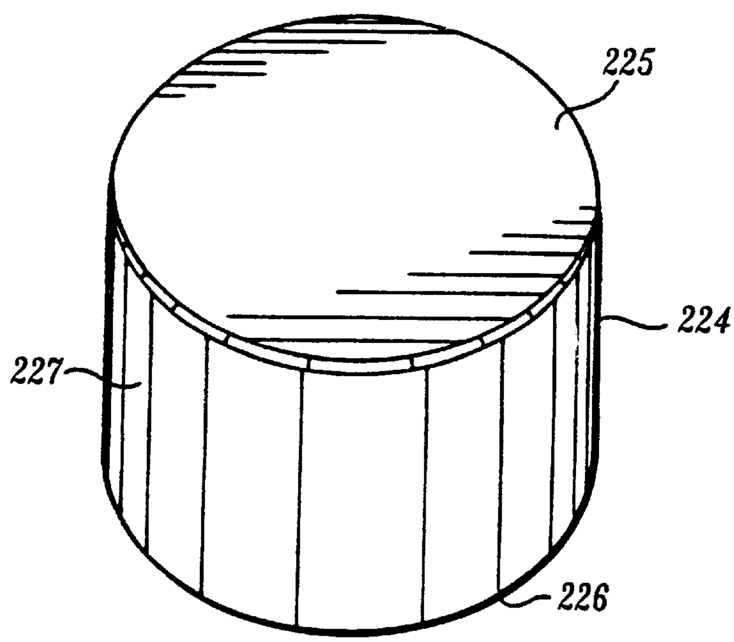

Fig. 16

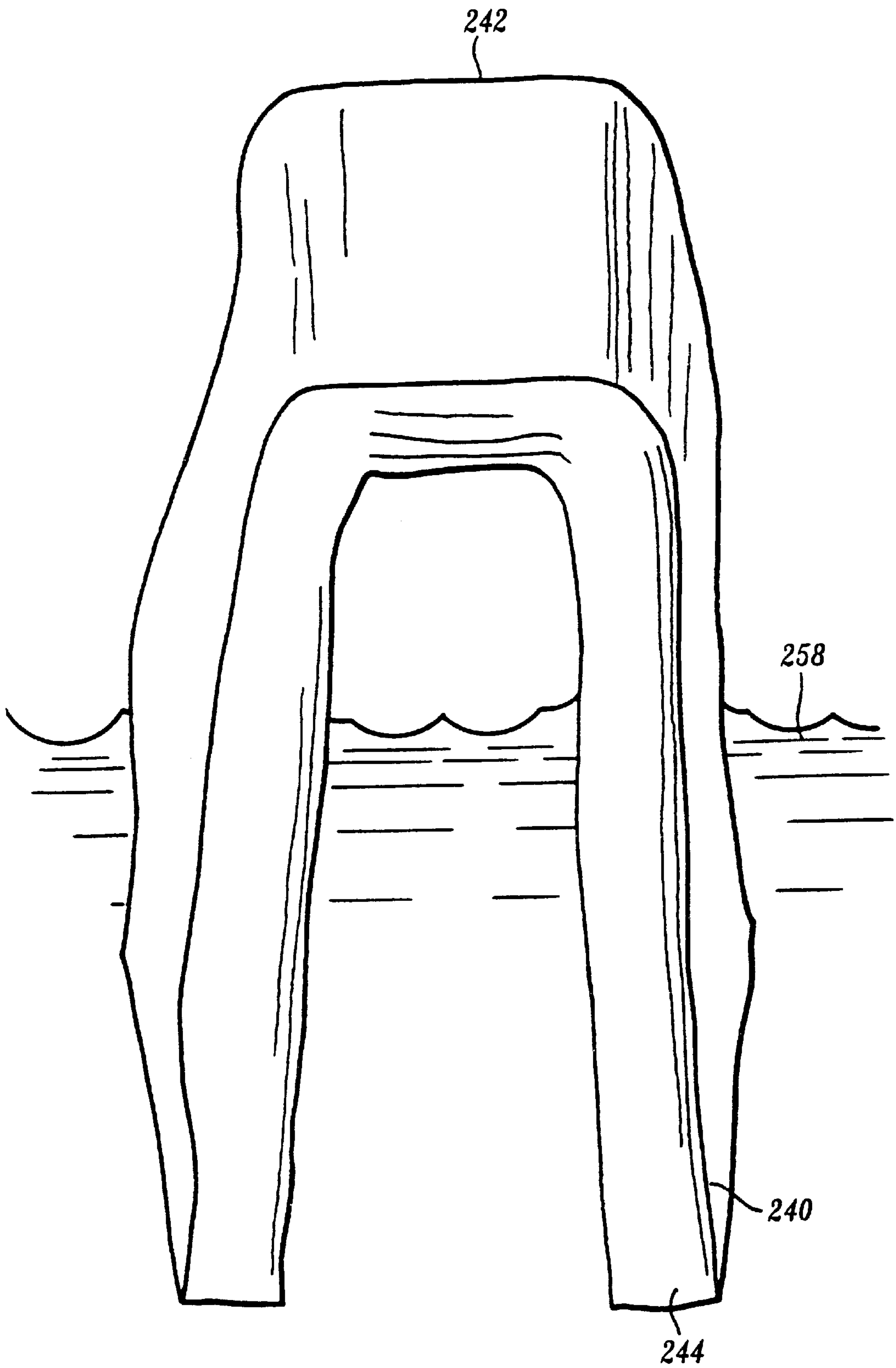

Fig. 17

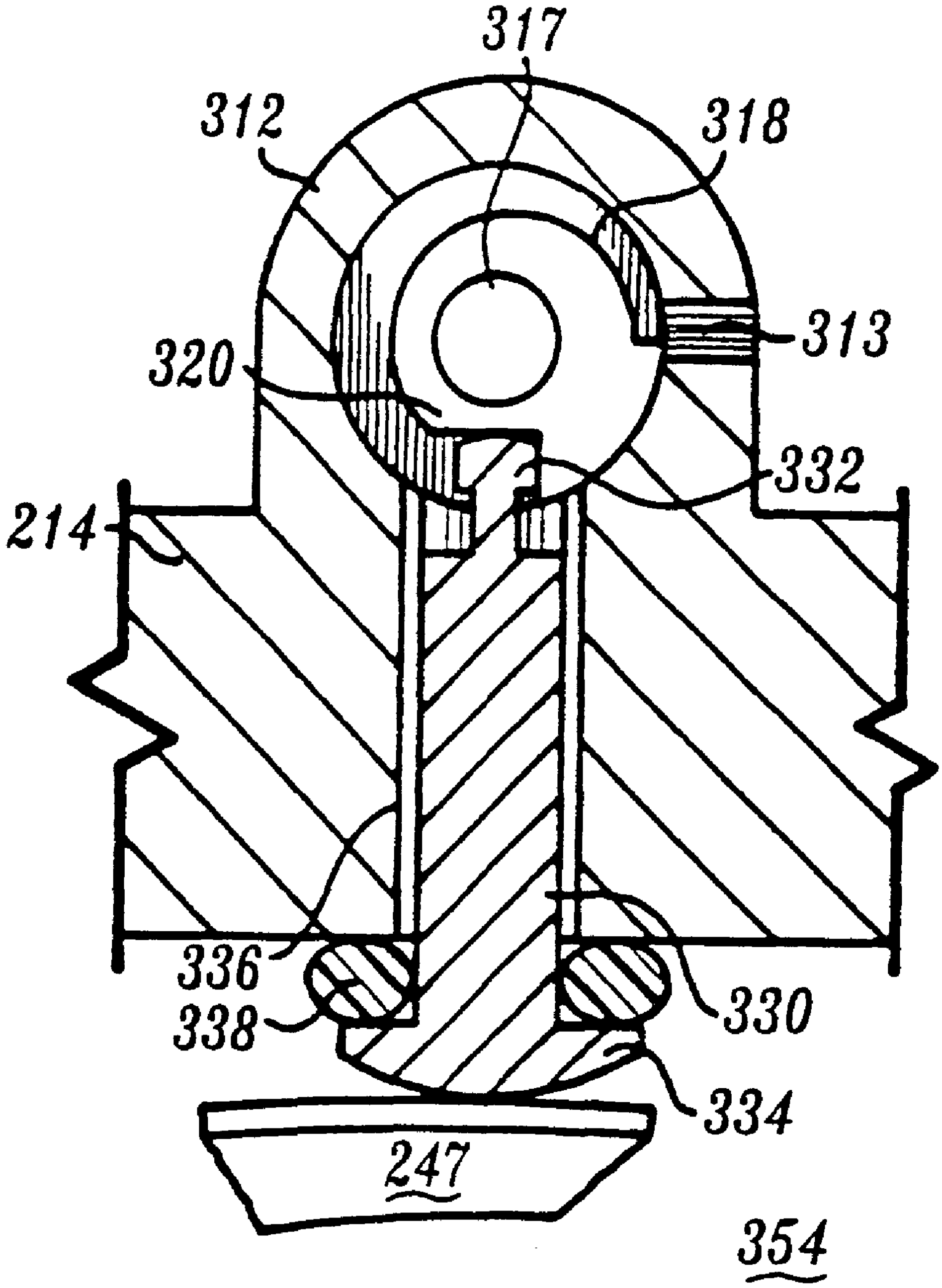

Fig. 18

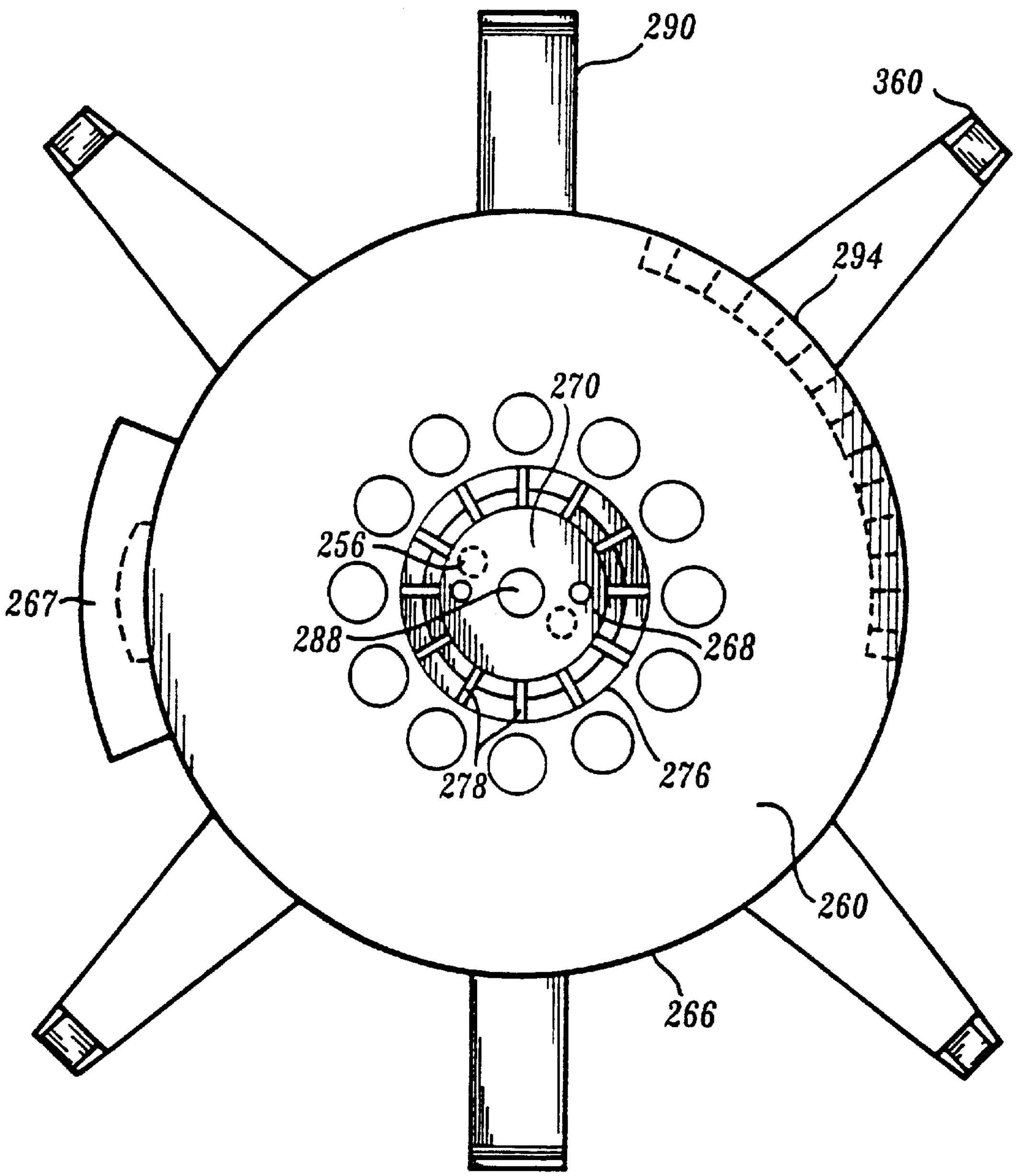

Fig. 19

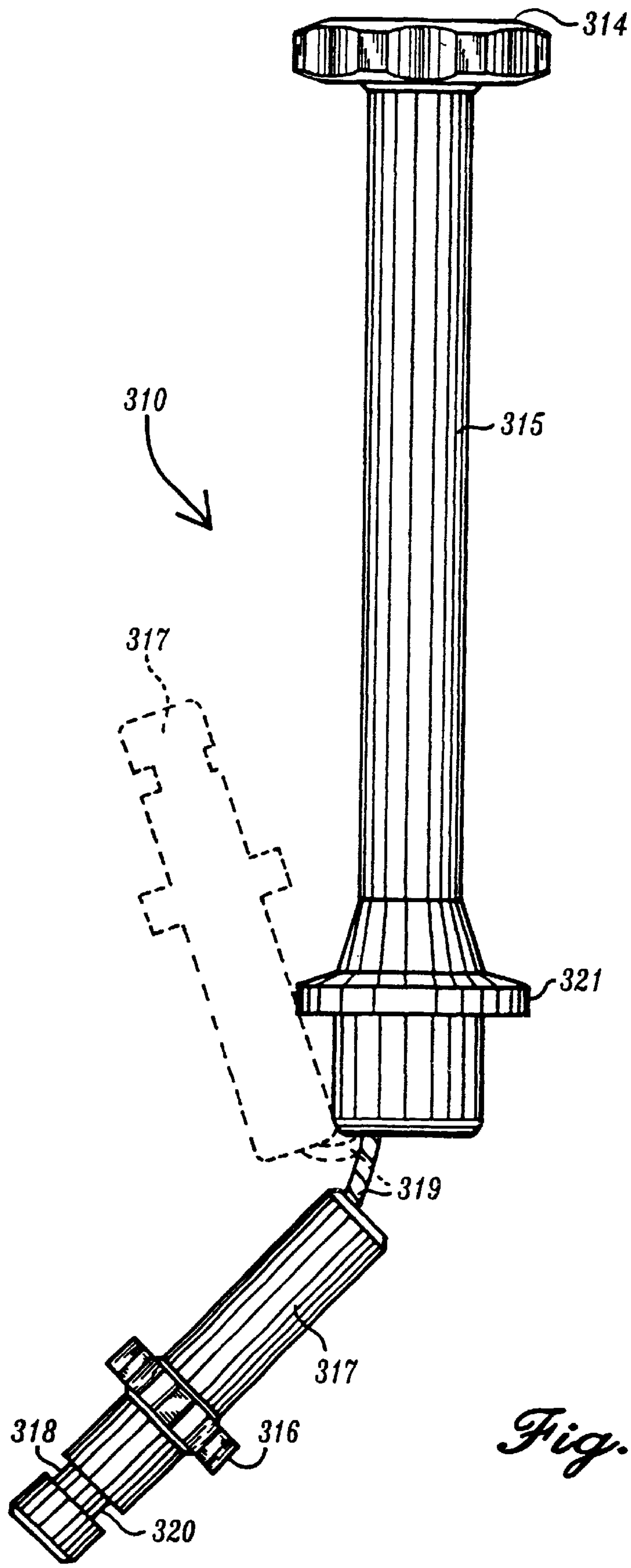

Fig. 20

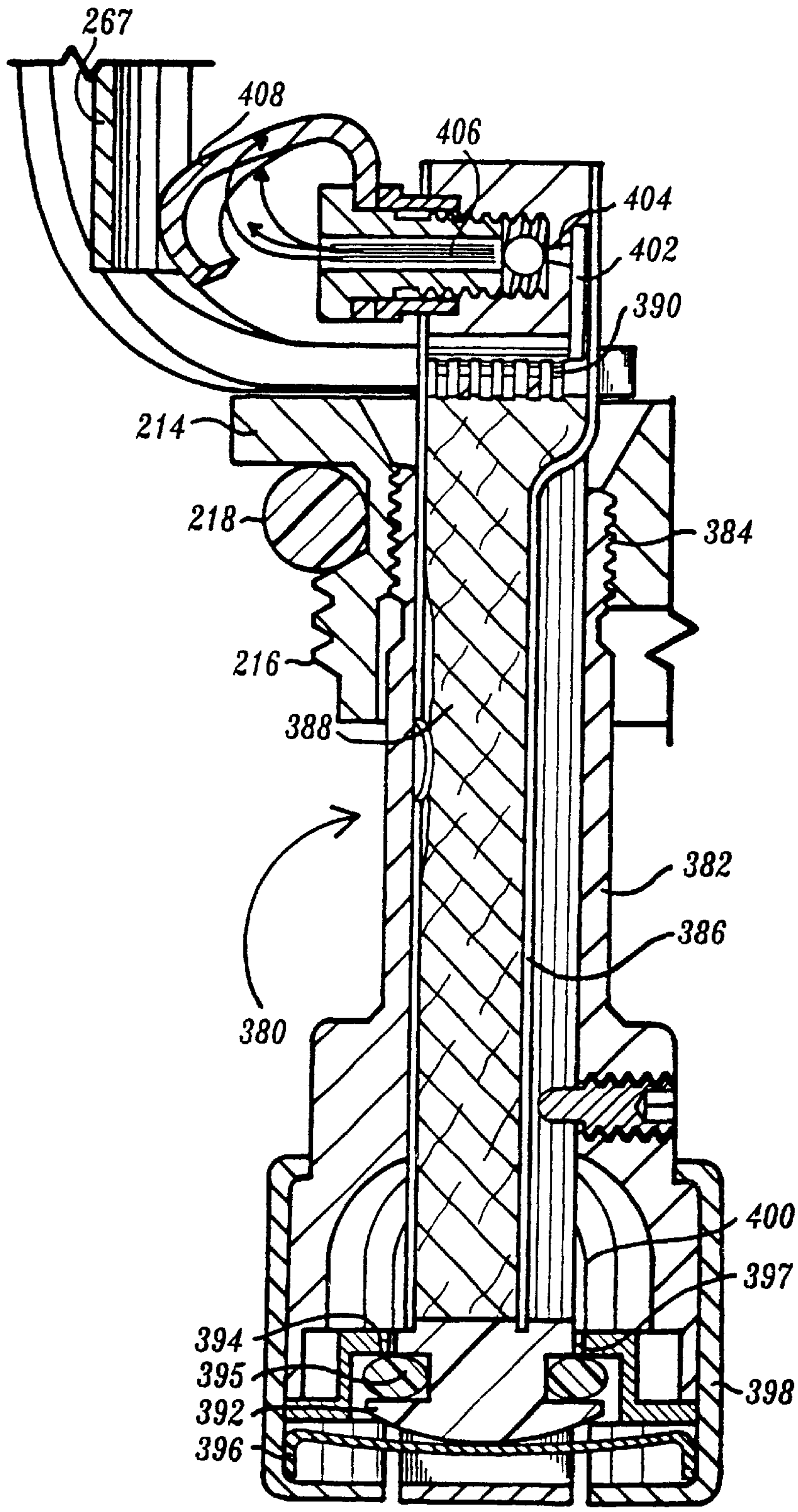
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Fig. 21

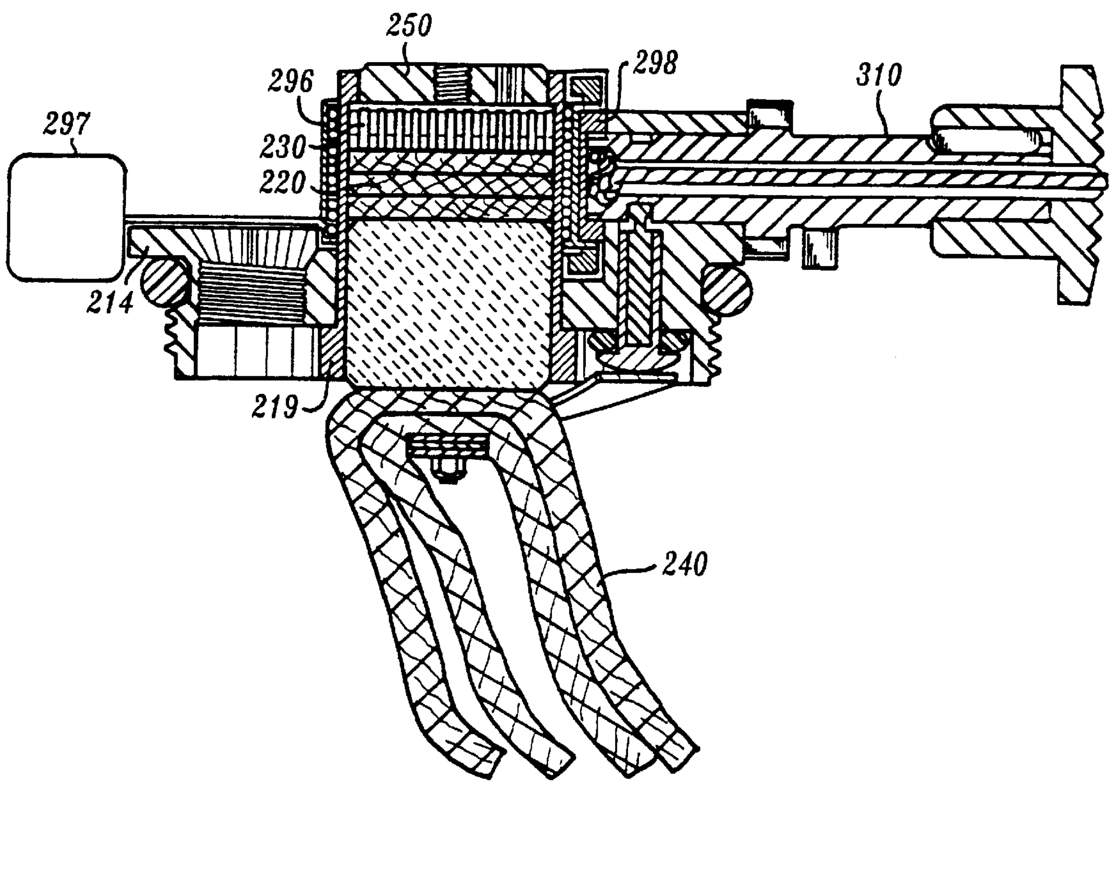

Fig. 22

LIQUID VAPORIZATION AND PRESSURIZATION APPARATUS AND METHODS

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 08/899,181, filed Jul. 23, 1997, U.S. Pat. No. 6,162,046 which is a continuation-in-part of U.S. patent application Ser. No. 08/439,093, filed May 10, 1995, now issued as U.S. Pat. No. 5,692,095, and are incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to methods and apparatus in which liquid is vaporized and pressurized in an enclosed porous member, and relates particularly to methods and apparatus for vaporizing liquid fuels to produce a combustible mixture under pressure. Combustion apparatus employing a vaporization/pressurization module and combustion methods of the present invention are especially suitable for use as light and heat sources for stoves, burners, lamps, appliances, thermal to electric conversion systems and the like.

BACKGROUND OF THE INVENTION

Conventional boilers add heat to a reservoir or inflow of liquid to convert the liquid to vapor. To sustain the inflow of liquid in a pressurized boiler system, the liquid must be supplied under at least as much pressure as that of the outgoing vapor. In a typical industrial boiler, the liquid is pumped into the boiler according to the desired vapor pressure. A throttle controls the flow of vapor from the boiler and, correspondingly, the vapor pressure within the boiler. Feed pumps supply water to the boiler according to the vapor pressure to maintain a constant liquid level in the boiler. If the vapor pressure is increased by reducing flow through the throttle, then the pumping pressure is decreased to maintain the level of liquid hi the boiler. Usually, the throttle is operatively coupled to the feed pump(s) so that the pumping pressure is automatically adjusted according to the flow through the throttle and, correspondingly, the vapor pressure in the boiler. This mechanism of automatically controlling the performance of the feed pumps is commonly referred to as a servomechanism.

In most liquid fuel vaporization applications, liquid fuel is vaporized, then mixed with air or an oxygen-containing gas, and the vaporized fuel/gas mixture is ignited and burned. The liquid fuel is generally supplied under pressure, and vaporized by mechanical means or heated to vaporization temperatures using an external energy source.

Portable burners and light sources that utilize liquid fuels generate liquid fuel vapor, which is then mixed with air and combusted. Combustion devices that burn fuels that are liquids at atmospheric temperatures and pressures, such as gasoline, diesel fuel and kerosene, generally require the liquid fuel to be pressurized by a pump or other device to provide vaporized fuel under pressure. Fuels such as propane and butane, which are gases at atmospheric pressures but liquids at elevated pressures, can also be used in portable burners and light sources. Storage of these fuels in a liquid form necessitates the use of pressurized fuel canisters that are inconvenient to use and transport, are frequently heavy, may he explosion hazards, and require valves which are prone to leaking.

The fuel boiler of propane and butane burners is the reservoir or storage tank itself, from which the gases are released under pressure as vapor. When vapor is withdrawn from the fuel reservoir, the pressurized reservoir acts as a boiler, and draws the required heat of vaporization from ambient air outside the tank. These systems have many disadvantages. The vapor pressure of propane inconveniently depends upon ambient temperature, and the vapor pressure is generally higher than that needed for satisfactory combustion in a burner. While butane fuel has an advantageous lower vapor pressure than propane, burners using butane have difficulty producing sufficient vapor pressure at low ambient temperatures. Burners using a mixture of propane and butane fuel provided under pressure in disposable canisters have also been developed. This fuel mixture performs well at high altitudes, but still does not perform well at low ambient temperatures.

A needle valve can be used to control propane vapor at tank pressure to regulate the fuel flow, and thus the heat output, of a burner. Burner control using a needle valve tends to be delicate and sensitive to ambient temperatures. Alternatively, a pressure regulator can be used to generate a constant and less hazardous pressure of propane that is independent of tank temperature. Propane pressure regulators are commonly used in outdoor grills, appliances for recreational vehicles and boats, and domestic propane installations. Unfortunately, regulators are bulky and are seldom practical for application to small scale portable burner devices.

Despite considerable development efforts and the high market demand for burners for use in stoves, lamps and the like, that operate safely and reliably under a wide variety of ambient temperature, pressure and weather conditions, commercially available combustion devices are generally unsatisfactory.

Wicking systems that use capillary action to convey and vaporize liquid fuels at atmosphenic pressure are known for use in liquid fuel burners. U.S. Pat. No. 3,262,290, for example, discloses a liquid fuel burner in which a wick stone is fastened in a fuel storage container and feeds liquid fuel from the fuel reservoir to the burner. In this system, liquid fuel is provided to the wick stone by an absorbent textile wick, and the wick stone is biased against a burner wick.

U.S. Pat. No. 4,365,952 discloses a liquid fuel burner in which liquid fuel is drawn up from a reservoir by a porous member having a fuel receiving section and a fuel evaporation section. Liquid fuel is supplied by capillary action at a rate matching the rate of evaporation of the fuel. Air is supplied to the fuel evaporation section, and liquid fuel is evaporated from the surface at a rate corresponding to the rate of air supply. The gaseous fuel and air is mixed and jetted from a flame section to a burning section. An externally powered heater maintains the porous member of the fuel evaporation section substantially at a constant temperature irrespective of the rate of evaporation of the liquid fuel.

U.S. Pat. No. 4,421,477 discloses a combustion wick comprising a fuel absorption and a fuel gasifying portion designed to reduce the formation and deposition of tar-like substances in the wick. The wick comprises silica-alumina ceramic fibers molded with an organic binder, with part of the wick provided with a coating of an inorganic pigment, silicic anhydride and a surface active agent. The wick preferably has a capillary bore size of about 1 to 50 microns, with smaller pore size wicks being less prone to accumulation of tar-like substances on the inside.

U.S. Pat. No. 4,465,458 discloses a liquid fuel combustion system in which the liquid fuel is drawn into a porous fiber material or fabric, which is intimately contacted by an externally powered heat generating member to evaporate and vaporize the liquid fuel. Air is introduced to promote vaporization of the liquid fuel and provide an admixed liquid/fuel mixture for burning. Combustion is variable by adjusting the heat input and the air supply.

U.S. Pat. No. 4,318,689 discloses a burner system in which liquid fuel is pumped into a cylindrical chamber having a porous side wall. As a result of the pressure differential, the liquid fuel penetrates the porous wall to form a film on the external surface of the porous chamber wall. Preheated combustion air entrains and vaporizes the liquid fuel film formed on the external wall of the chambers and circulates the fuel/air mixture to a combustion chamber. A portion of the hot exhaust or combustion gases may be returned for countercurrent heat exchange to preheat the combustion air.

Although the prior art discloses numerous types of liquid fuel combustion systems, most liquid fuel vaporizers require the application of energy from all external source, such as heat energy, pressure for pressurizing the liquid fuel and/or vapor, or a blower for jetting an air stream to entrain the vaporized fuel for burning. Prior art liquid fuel combustion systems generally provide vaporization of liquid fuels at atmospheric pressures or, if a pressurized vapor stream is desired, either require the fuel supply to be pressurized or pressurize the vapor by external means. Many of the systems are complex and are not suitable for liquid fuel combustion apparatus that are robust, portable or that are suitable for small scale heating or lighting applications.

It is, therefore, an object of the present invention to provide an apparatus for vaporization and pressurization of liquids, including liquid fuels, within a vaporization/pressurization module having a porous member.

It is another object of the present invention to provide a vaporization/pressurization module that produces a pressurized vapor jet from liquid such as liquid fuel supplied at ambient pressures without requiring the use of pumps or other mechanical means.

It is yet another object of the present invention to provide a vaporization/pressurization module that produces a vapor jet at substantially constant pressures and at a substantially steady flow rate.

It is still another object of the present invention to provide a combustion apparatus employing a vaporization/pressurization module to vaporize liquid fuels, and to produce a pressurized fuel vapor jet.

It is yet another object of the present invention to provide a liquid fuel combustion apparatus that, following ignition, operates in a closed-loop feedback, steady state system that does not require energy input from an external source.

It is still another object of the present invention to provide a liquid fuel combustion apparatus which does not require priming and in which combustion and steady state operation can be conveniently initiated by application of heat from a match or lighter.

It is yet another object of the present invention to provide a liquid fuel combustion apparatus that can operate using any one of two or more different types of liquid fuel.

It is still another object of the present invention to provide a simplified combustion apparatus that generates heat and light by combustion of vaporized, pressurized liquid fuel that can be conveniently provided in a lightweight, portable and/or miniaturized form,

SUMMARY OF THE INVENTION

The liquid vaporization and pressurization apparatus of the present invention utilizes a vaporization/pressurization module employing a porous member having a low thermal conductivity and a substantially uniform, small pore size. The porous member has a liquid feed surface in proximity to a liquid feed system and a vaporization zone in proximity to a heat source. Liquid feed is introduced to the porous member at the liquid feed surface and is heated, vaporized and pressurized within and/or on a surface of the porous member. Egress of vapor to a location remote from the porous member is substantially constrained or is substantially constrainable by means of a substantially vapor impermeable barrier provided in proximity to surfaces of the porous member other than the liquid feed surface. The substantially vvapor impermeable barrier facilitates accumulation and pressurization of the vapor, which is released from the vaporization/pressurization module as a pressurized vapor jet from one or more restricted passage(s) formed in the substantially vapor impermeable barrier.

The barrier is referred to herein as "substantially" vapor impermeablle because it is vapor impermeable except in predetermined locations where egress of one or more pressurized vapor jet(s) is permitted. The substantially vapor impermeable barrier facilitates pressurization of vapor within the porous member and the enclosed space formed by the barrier, and promotes generation of one or more vapor jet(s) at a pressure greater than that of the liquid feed which is generally provided at atmospheric pressure. According to preferred embodiments, egress of vapor is limited by a substantially vapor impermeable barrier having one or more restricted passage(s) permitting egress of pressurized vapor, the passage(s) constituting less than about 5%, more preferably less than 2%, and most preferably less than about 0.5%, of the surface area of the substantially impermeable barrier.

The vaporization/pressurization module of the present invention may be provided as an independent unit for a variety of applications. The vaporization/pressurization module comprises a porous member, a heat source and a substantially vapor impermeable barrier. A liquid feed system provides liquid to the vaporization/pressurization module. Liquid is generally provided at ambient temperatures and pressures to the liquid feed surface of the porous member and is drawn into the porous member and conveyed to a vaporization zone within and/or on a surface of the porous member by capillary forces. During operation, the heat source is used to establish and maintain a thermal gradient within the porous member between the liquid feed surface and the vaporization zone. Liquid drawn into the porous member is heated as it traverses the porous member until it reaches its vaporization temperature in the vaporization zone. Vapor pressure within the vaporization/pressurization module accumulates as liquid is vaporized, and is maintained as a consequence of the substantially vapor impermeable barrier. One or more pressurized vapor jet(s) exit the substantially vapor impermeable barrier only at one or more restricted passage(s).

For liquid fuel combustion applications, a burner assembly is provided in combination with the vaporization/pressurization module and liquid feed system to facilitate mixing, of fuel vapors to form a combustible mixture and to provide a combustion zone. A liquid fuel feed system, such as a gravity-fed system or a capillary feed system employing a porous capillary feed wick or capillary tube(s), conveys liquid fuel from a fuel reservoir to the liquid feed surface of the porous member, which is generally at the "bottom" of the porous member. The liquid fuel feed system may be provided as an integral component of the porous member for certain applications. The heat source may be provided as a heating element using an extenial power source, or a portion of the heat generated by combustion may be retutned to provide the heat required for vaporization. A substantially vapor impermeable barrier may be provided, for example, in the form of: (i) a vapor impermeable shroud positioned in proximity to porous member surfaces adjacent the liquid feed surface; in combination with (ii) a substantially vapor impermeable plate having one or more restricted passage(s) positioned in proximity to a porous member surface opposite the liquid feed surface.

According to especially preferred embodiments, the vapor impermeable shroud has a generally low thermal conductivity, while the substantially vapor impermeable plate has a generally high thermal conductivity. When the porous member is provided as a generally cylindrical or rectangular member, the liquid feed surface is generally the "bottom" surface, a vapor impermeable shroud is positioned in proximity to the porous member sidewalls, and a substantially vapor impermeable plate is positioned in proximity to the porous member "top" surface. The heat source may be provided at or near the "top" of the porous member, for example, as a thermally conductive element deriving heat from a source internal or external to the combustion apparatus. When this arrangement is employed, the vaporization zone of the porous member is in proximity to and generally "below" the heat source. One or more vapor permeable passage(s) are preferably provided in the substantially vapor impermeable plate to permit egress of one or more fuel vapor jet(s) under pressure. Pressurized fuel vapor jet(s) entrain air or another gas or gas mixture to produce a combustible fuel/gas mixture. The combustible fuel/gas mixture may be ignited and burned continuously or intermittently in a combustion zone of the burner assembly.

Certain embodiments of combustion apparatus of the present invention do not require priming or a discrete starter mechanism to initiate liquid fuel vaporization, pressurization and combustion. In one preferred combustion apparatus, heat applied briefly to the burner assembly by a match or lighter is conducted to the porous member and is sufficient to initiate liquid fuel vaporization on or within the porous member, leading to pressurization of the fuel vapor in the vaporization/pressurization module and combustion of the resulting combustible mixture. Once combustion is initiated, the heat for fuel vaporization and pressurization is preferably derived by returning a portion of the heat generated by combustion to the porous member, for example, through conductive elements forming a part of the burner in thermal communication with a hot seat having a high thermal conductivity. The hot seat is preferably located in proximity to and in thermal communication with both the porous member and the burner to transfer the heat energy necessary for fuel vaporization and pressurization from the burner to the porous member. According to preferred embodiments, a steady state condition can be achieved and maintained wherein liquid fuel provided to the liquid feed surface of the porous member at substantially ambient pressures and temperatures is heated and pressurized within the vaporization/pressurization module using a portion of the heat generated in the burner to produce one or more pressurized vapor jet(s), which in turn are used for combustion.

Vaporization/pressurization modules and liquid feed systems of the present invention may be scaled to provide a range of pressurized vapor outputs. For liquid fuel applications, vaporization/pressurization modules may also be used with controllable, variable output combustion apparatus. The combustion output may be varied in numerous ways and is most conveniently varied by adjusting the vaporized, pressurized fuel stream(s) exiting from the module. Adjustment of the vaporized, pressurized fuel stream may be accomplished, for example, by adjusting the amount of heat supplied to the module, by adjusting the flow of liquid fuel to the liquid feed surface of the porous member, or by limiting or adjusting the egress of vaporized fuel from the module. The flow of liquid fuel to the porous member may be regulated by restricting capillary flow through the porous member or, where all assembly of multiple individual modules is used, by removing a selected number of them from the liquid. The flow of pressurized vapor from the module may be regulated by providing a valve or a throttle, or other mechanical means. The quantity of heat supplied to the porous member may be varied, for example, by adjusting the power provided an electrical resistive heating element or by modulating the amount of heat returned to the vaporization/pressurization module from combustion.

Combustion apparatus may incorporate a plurality of individual vaporization/pressurization modules and/or an array of burners, each burner associated with one or more vaporization/pressurization modules, in applications requiring a higher heat or light output than a single module or burner can provide. In addition, modules and/or burners having different capacities may be arrayed together for use separately or in combination.

The vaporization/pressurization module liquid feed system and combustion apparatus may be adapted for use in applications requiring a heat or light source, and are especially suitable for use in applications in which a portable heat and/or light source is required. Such combustion apparatus may be used with a variety of liquid fuels, including fuels such as gasoline, white gas, diesel fuel, kerosene, JP8, alcohols such as ethanol and isopropanol, biodiesel, and combinations of liquid fuels. Vaporization/pressurization modules, liquid feed system, and combustion apparatus of the present invention may be optimized for use with a particular liquid fuel source, or a single module feed system and combustion apparatus may be designed for use with multiple liquid fuels. The system is thus highly versatile and may take advantage of readily available fuels. The vaporization/pressurization module of the present invention may be used in connection with or used to retrofit any type of apparatus that requires the formation of a pressurized vapor jet from a liquid.

Combustion apparatus components other than the burner, the heat source, and the thermal path between the two remain cool to the touch during operation, and the liquid fuel need not be pressurized to provide a substantially continuous vaporized fuel jet during operation. The combustion apparatus of the present invention thus incorporates many safety features not available in other types of combustion apparatus. Moreover, combustion apparatus of the present invention may be miniaturized and constructed from lightweight materials. Simple embodiments of the combustion apparatus employing a vaporization/pressurization module, with or without a separate liquid feed system, may be designed to have few components, and no moving components. Such apparatus may be produced at a low cost and demonstrate improved reliability. They burn efficiently and "clean," and are not prone to clogging as a result of oxidation or pyrolosis of the liquid fuel.

Combustion apparatus incorporating vaporization/pressurization modules and liquid feed systems of the present invention are especially suitable for use as portable heaters, stoves and lamps for indoor, outdoor and/or marine applications, as well as power sources for use in a variety of devices, including absorption refrigerators and other appliances, and thermal to electric conversion systems, such as thermophotovoltaic systems, thermoelectric thermopiles, and alkali metal thermal to electric conversion (AMTEC) systems. Applications including outdoor, camping and marine stoves, portable or installed heaters, lamps for indoor or outdoor use, including mantle lamps, torches, "canned heat" for keeping food or other items warm, "canned light" as a replacement or supplement to candles or other light sources, and emergency heat and light "sticks" are just a few of the many applications for such combustion apparatus. Exemplary non-combustion applications of vaporization/pressurization modules of the present invention include steam generation apparatus and other types of apparatus for providing liquids in a vaporized, aerosol or atomized form.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic cross-sectional diagram illustrating a vaporization/pressurization module of the present invention comprising a porous member, a heat source and a substantially vapor impermeable barrier;

FIG. **2** shows a perspective view of a combustion apparatus utilizing a vaporization/pressurization module and liquid feed system of the present invention;

FIG. **3** shows a perspective, exploded view of the components of the combustion apparatus illustrated in FIG. **2**;

FIG. **4** shows a cross-sectional view of a combustion apparatus utilizing a vaporization/pressurization module and liquid feed system similar to the apparatus shown in FIGS. **2** and **3**;

FIGS. **5**A, **5**B and **5**C show enlarged plan and cross-sectional views of a preferred hot seat for use in the combustion apparatus of the present invention, with FIG. **5**A illustrating an enlarged plan view, FIG. **5**B illustrating a cross-sectional view taken along line **5**B—**5**B of FIG. **5**A, and FIG. **5**C illustrating a cross-sectional view taken along line **5**C—**5**C of FIG. **5**A.;

FIG. **6**A shows an enlarged plan view of a preferred substantially vapor impermeable plate or aperture plate for use in the combustion apparatus of the present invention, and FIG. **6**B shows a cross-sectional view of the aperture plate taken along line **6**B—**6**B of FIG. **6**A;

FIG. **7** shows a schematic perspective view of a combustion apparatus of the present invention in the form of a mantle lamp.

FIG. **8** shows a cross-sectional elevation view of all alternative embodiment of a combustion apparatus employing a vaporization/pressurization module and liquid feed system of the present invention in which the egress of pressurized vapor from the module is variable and controllable;

FIG. **9** schematically illustrates the use of a combustion apparatus of the present invention in a thermophotovoltaic system;

FIG. **10** shows a perspective representational view of another embodiment of a vaporization/pressurization module and liquid feed system of the present invention in a camp stove;

FIG. **11** is a cross sectional view along line **11**—**11** of FIG. **10**;

FIG. **12** is a bottom plan view along line **12**—**12** of FIG. **11**;

FIG. **13** is all isometric representational view of another embodiment of an aperture plate and hot seat of the present invention;

FIG. **14** is an isometric representational view showing the bottom face of one embodiment of a hot seat of the invention;

FIG. **15** is an isometric representational view of one embodiment of a boiler wick of the invention;

FIG. **16** is all isometric representational view of one embodiment of a transfer wick portion of the liquid feed supply of the invention;

FIG. **17** is a perspective representational view of one embodiment of a supply wick portion of the liquid feed supply of the invention;

FIG. **18** is a cross-sectional view along line **18**—**18** of FIG. **11**;

FIG. **19** is a top plan view of one embodiment of a flame plate and aperture and valve plates of the invention;

FIG. **20** is a top plan view of knob and pinion shafts showing a collapsibility feature of one embodiment of the invention;

FIG. **21** is a detail view of a portion of FIG. **11** showing a starter assembly of the invention; and

FIG. **22** is a side sectional elevational view of another embodiment of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

The liquid vaporization and pressurization apparatus and methods for vaporizing and pressurizing liquids of the present invention are described first with reference to the schematic illustration of FIG. **1**. Liquid from a liquid feed system **10** is introduced to a liquid feed surface **12** of porous member **14**. During operation of the vaporization/pressurization module, liquid feed system **10** preferably provides a continuous supply of liquid to liquid feed surface **12**. While liquid feed surface **12** is illustrated in FIG. **1** as the "bottom" surface area of a cylindrical or rectangular porous member, it will be recognized that porous members of the present invention may be provided in a variety of configurations, and that the liquid feed surface may be provided in a variety of configurations as well as locations within or on the surface area of the porous member. Porous member **14** may also incorporate or be provided integrally with a liquid feed system.

As liquid is drawn into porous member **14**, it is heated and vaporized at vaporization zone **16** within or on a surface of porous member **14** where the liquid is heated to its vaporization temperature. A heat source is preferably provided in thermal communication with porous member **14** to provide the heat necessary for liquid vaporization. In the embodiment illustrated in FIG. **1**, the heat source comprises resistive heating element **20** electrically connected to power source **21** embedded porous member **14**. It will be recognized that numerous types of heat sources may be used and that such heat sources may be provided within, on a surface of, or otherwise in proximity to vaporization zone **16** or porous member **14**. Vapor is produced on surfaces of and/or within porous member **14** and, in the embodiment illustrated in FIG. **1**, vapor exits porous member **14** at vapor release surface **18**.

One of the important features of the vaporization/pressurization module of the present invention is that liquid at ambient temperature and pressure is both vaporized and pressurized in the module to produce one or more pressurized vapor jet(s). The produced vapor is pressurized within the module as a consequence of the controlled or controllable egress of vapor from the substantially vapor impermeable barrier provided in proximity to the porous member at surfaces other than the liquid feed surface. The substantially vapor impermeable barrier, as illustrated in FIG. **1**, is located in proximity to the surfaces of porous member **14** adjacent and opposite liquid feed surface **12**, shown as the sidewalls and top of porous member **14**. Egress of pressurized vapor jet(s) from the enclosed space formed by the substantially vapor impermeable barrier takes place at one or more vapor permeable passage(s), such as aperture **22**.

The substantially vapor impermeable barrier illustrated in FIG. **1** is preferably provided as a vapor impermeable shroud **24** located adjacent to the porous member sidewalls and a separate substantially vapor impermeable plate or aperture plate **26**, or similar structure located in proximity to vapor release surface **18**, illustrated as the "top" of porous member **14** in FIG. **1**. The substantially vapor impermeable barrier formed by the combination of shroud **24** and plate **26** isolates the surfaces of porous member **14** other than liquid feed surface **12** in a substantially enclosed or enclosable space. Shroud **24** is preferably vapor impermeable and is preferably arranged closely adjacent, and most preferably contacting the sidewalls of porous member **14**. Plate **26** is preferably provided as a substantially vapor impermeable barrier, is preferably provided with at least one vapor permeable passage, and is preferably in proximity to but spaced a distance from vapor release surface **18** of porous member **14** to form a vapor collection space or plenum **28**.

The substantially vapor impermeable barrier may be provided in a variety of configurations and arrangements, depending upon the configuration and composition of porous member **14** and the environment or application in which the vaporization/pressurization module is used. The substantially vapor impermeable barrier is arranged to provide substantial constraint of porous member **14** and, preferably, to enclose the surfaces of porous member **14** other than liquid feed surface **12** in a substantially vapor impermeable fashion, while permitting egress of generated vapor at one or more predetermined locations at a pressure greater than that of the liquid feed.

According to an embodiment preferred for use in liquid fuel combustional applications, the substantially vapor impermeable barrier is provided as shroud **24**, constructed from a rigid material having a generally low thermal conductivity, and plate **26**, constructed from a rigid material having a generally high thermal conductivity. The generally low thermal conductivity of shroud **24** is sufficiently low to prevent a substantial portion of thermal energy from imigrating from the vaporization zone toward liquid feed surface **12** of porous member **14**. The thermal conductivity of shroud **24** is preferably less than about 200 watts per meter-Kelvin ("W/m K") and more preferably less than about 100 W/m K. The generally high thermal conductivity of plate **26** is sufficiently high to transfer the heat required for vaporization to the vaporization zone of the porous member. The thermal conductivity of plate **26** is preferably greater than about 200 W/m K, and more preferably greater than 300 W/m K. This arrangement promotes heat transfer to and within porous member **14** in proximity to vapor release surface **18** and vaporization zone **16**, yet it advantageously minimizes heat transfer through porous member **14** between vaporization zone **16** and liquid feed surface **12**, and into the liquid feed system and any liquid reservoir.

An important feature of the vaporization/pressurization module of the present invention is the "substantial constraint" of the porous member provided by the substantially vapor impermeable barrier, which facilitates pressurization of vapor generated within and/or on the surface of the porous member. Pressurization of produced vapor within the enclosed space formed by the substantially vapor impermeable barrier and subsequent release through one or more vapor permeable apertures is generally sufficient to form one or more vapor jet(s) having a pressure greater than the pressure at which the liquid was supplied, and is preferably sufficient to form one or more vapor jet(s) having a velocity sufficient to entrain and mix with a gas to form a combustible mixture without requiring introduction of energy from an external source. For most combustion applications, the vaporization/pressurization module produces a vapor jet having a pressure greater than atmospheric using liquid fuel supplied at atmospheric pressure. The vaporization/pressurization module of the present invention may alternatively use liquid supplied at a pressure greater than atmospheric to produce a vapor jet at a higher differential pressure.

"Substantial constraint" of the porous member, as that term is used herein, means that egress of produced vapor to a location remote from the vaporization/pressurization module is limited or controllable to produce one or more vapor jets at a pressure greater than atmospheric. Substantial constraint is generally provided by a substantially vapor impermeable barrier mounted in proximity to surfaces of the porous member other than the liquid feed surface. A substantially vapor impermeable barrier that provides "conistrainable" egress of vapor may incorporate an adjustment feature such as a throttle or valve, or a variable size or number of apertures, or the like, to provide controllable vapor release from the vaporization/pressurization module, while providing constraint sufficient to pressurize vapor enclosed by the substantially vapor impermeable barrier. According to preferred embodiments, egress of pressurized vapor is physically limited by a substantially vapor impermeable barrier having locations permitting egress of pressurized vapor, the vapor permeable locations constituting less than about 5%, more preferably less than about 2%, and most preferably less than about 0.5% of the surface area of the substantially vapor impermeable barrier.

Porous member **14** preferably comprises a material having a low thermal conductivity and a substantially uniform pore size. The thermal conductivity of porous member **14** is preferably sufficiently low to maintain a thermal gradient from ambient temperature of liquid feed surface **12** to the temperature of vaporization at vaporization zone **16**, and to prevent substantial heat transfer out of vaporization zone **16**. Materials having a thermal conductivity of less than about 10 W/m K are suitable for porous member **14**, materials having a thermal conductivity of less than about 1.0 W/m K are preferred, and materials having a thermal conductivity of less than about 0.10 W/m K are especially preferred. Fibrous materials such as fiberglass mats, other types of woven and non-woven fibrous materials, and porous ceramic, low conductivity porous or fibrous metallic materials and porous metal/ceramic composites are suitable. Suitable materials have a porosity sufficient to provide an adequate supply of liquid to the vaporization zone to provide the desired vapor output.

Porous member **14** may alternatively comprise a composite member composed of materials having different thermal conductivities. Such a composite porous member may, for example, comprise a vaporization member having a generally high thermal conductivity in fluid communication with a liquid transfer member having a generally low thermal conductivity. The liquid transfer member in this embodiment may serve as a liquid feed system for the vaporization/pressurization module.

Porous member **14** comprises a material having a relatively small pore size that remains substantially constant during operation of the vaporization/pressurization module.

In general, smaller pore sizes generate greater capillary pressures and, consequently, higher vapor pressures can be generated. The pore size of porous member **14** is sufficiently small to provide an adequate supply of liquid to the vaporization zone to produce the desired vapor output and to provide the capillary forces necessary to maintain a discrete vaporization zone and at the same time, provide a porous environment for vaporization to occur in the vaporization zone. Average pore sizes of from less than 1 micron to about 50 microns are preferred, with average pore sizes of from 0.10 to 30 microns being more preferred, and average pore sizes of about 0.5 to 5 microns being especially preferred.

In the vaporization/pressurization module illustrated in FIG. **1**, resistive heating element **20** is electrically connected to power source **21** and is provided in proximity to vaporization zone **16** of porous member **14**. If a cylindrical or rectangular porous member is used, as shown, vaporization zone **16** is preferably located at or near vapor release surface **18**, shown at the "top" of porous member **14**. Heat source **20** is illustrated as a resistive heating element in communication with external power source **21** to provide a controllable amount of heat to vaporization zone **16**. In alternative embodiments, a heat source may be provided in contact with or in proximity to vapor release surface **18** of porous member **14**. Heat source **20** is preferably capable of providing heat in a generally uniform distribution over a surface or cross section of porous member **14**.

During operation of the vaporization/pressurization module illustrated schematically in FIG. **1**, liquid feed is introduced at ambient temperature and ambient pressure to liquid feed surface **12** of porous member **14** and is drawn into the porous member by capillary action. According to preferred embodiments, in which a substantially continuous pressurized vapor flow is provided during an operating cycle, liquid feed is preferably continuously introduced to liquid feed surface **12**. The vaporization/pressurization module is "started" by activating heat source **20** and heating vaporization zone **16**. As vaporization zone **16** is heated, a thermal gradient is established within porous member **14**, with the hottest areas being in proximity to the heat source and vaporization zone, and the coolest areas being in proximity to liquid feed surface **12**. Capillary forces convey liquid to vaporization zone **16**, where the temperature corresponds to the liquid vaporization temperature. The vaporization zone is generally a locus of points or layer located at or near vapor release surface **18** of porous member **14** and, preferably, is at least partially within porous member **14**.

As the vaporization zone is heated and vapor is generated, vapor pressure accumulates within the enclosed space formed by the substantially vapor impermeable barrier. Vapor is released, as a pressurized vapor jet, from one or more vapor permeable passages, such as aperture **22**. The accumulation of vapor and heat tends to promote migration of the vaporization zone "downwardly" through porous member **14** toward liquid feed surface **12**. Simultaneously, capillary forces draw ambient temperature and pressure liquid into the porous member at liquid feed surface **12** and toward the vaporization zone, thus stabilizing the location of the vaporization zone within porous member **14**. The location of the vaporization zone within porous member **14**, the degree of vapor pressurization, and amount of pressurized vapor released from the vaporization/pressurization module may be modulated, for example, by varying the pore size of the porous member, by providing porous members having different thermal conductivity properties, by changing the configuration or arrangement of porous member **14**, by varying the number, size and/or location of vapor permeable apertures in the substantially vapor impermeable barrier, by modulating the amount of vapor released, and/or by adjusting the amount of heat provided to the vaporization zone. These parameters may likewise be adjusted and modified to provide adaptations that permit vaporization/pressurization modules to efficiently vaporize many different liquids.

One of the important applications for a vaporization/pressurization module of this type is vaporizing and pressurizing liquid fuels to produce a combustible fuel mixture. Several different types of exemplary combustion apparatus are described in detail below. It will be recognized, however, that the vaporization/pressurization module of the present invention may be used in numerous applications that involve liquids other than liquid fuels.

The vaporization/pressurization module and liquid feed system of the present invention and associated combustion apparatus will be described first with reference to FIGS. **2–4**. It will be recognized that the embodiments illustrated and described herein are illustrative, and that the vaporization/pressurization module and liquid feed system of the present invention may be adapted for use with and employed in numerous types of combustion devices.

The combustion apparatus employing the vaporization/pressurization module of the present invention illustrated in FIGS. **2–4** incorporates a liquid fuel reservoir and liquid feed system of the type which is preferred for many applications. Combustion apparatus **30** comprises a liquid fuel container **32** providing an enclosed ambient pressure fuel reservoir **34**. Liquid fuel container **32** may be provided in a variety of configurations, and may be in proximity to or remote from the other combustion apparatus components. Liquid fuel container **32** is preferably vented to the atmosphere to ensure that the pressure within container **32** is equalized with ambient pressure during operation of the combustion device. Venting may be provided in numerous ways which are well known in the art.

According to a preferred embodiment, liquid fuel container **32** is cylindrical and comprises a continuous, cylindrical sidewall **36**, an end wall **38** and an opposite end wall **40**. End wall **38** may incorporate a depression **42**, as shown, to facilitate the flow of liquid fuel to the fuel delivery system. End wall **40** may be provided with an aperture **44** for receiving a liquid fuel feed system or another component of the associated combustion apparatus. Side wall **36** and bottom wall **38** are preferably constructed from a rigid, durable material that is impermeable to liquids and gases, and that does not react with the liquid fuel. According to a preferred embodiment, side wall **36** may be constructed from a material that is transparent or translucent, so that the liquid fuel level is visible to the user. Various types of thermoplastic materials, such as polymeric plastic materials, acrylic, polypropylene, and the like are suitable.

For some combustion applications, a fuel reservoir may be provided remote from the vaporization/pressurization module and combustion apparatus, with a fuel feed line or liquid fuel feed system feeding liquid fuel to the vaporization/pressurization module. For many combustion applications, the fuel reservoir is conversently and desirably in proximity to the vaporization/pressurization module, as shown in FIGS. **2–4**. In either event, means for refillng the fuel reservoir with liquid fuel is generally provided. In a combustion apparatus of the type illustrated in FIGS. **2–4**, a sealable hole may be provided, for example, in end wall **40** of liquid fuel container **32** or, as shown in FIG. **3**, end wall **40** of the liquid fuel container may be threadedly engageable with the fuel reservoir and thus be removable from the rest of the container for refilling fuel reservoir **34** with liquid fuel. Alternatively, end wall **40** may be detachable from and sealable against side wall **36** by means of O-ring **46** retained in groove **47**, as illustrated in FIG. **4**. Various types of refillable containers may be used. For applications where the combustion apparatus is intended to be portable, such as portable heating and lighting applications, the combustion apparatus is preferably designed to prevent or minimize spillage of liquid fuels from the fuel reservoir. This may be accomplished using various techniques which are well known in the art.

In a preferred embodiment, liquid fuel is delivered to the vaporization/pressurization module from liquid fuel reservoir **34** by means of a liquid fuel feed system. The liquid fuel feed system is capable of delivering liquid fuel substantially continuously during operation of the combustion apparatus and at a volume sufficient to sustain the desired level of combustion. Many types of liquid fuel feed systems are known in the art and would be suitable for use in combustion apparatus of the present invention. The liquid fuel feed system may be integral with the vaporization/pressurization module or the porous member, or may be provided as a separate component. Capillary liquid fuel feed system are preferred. The feed system may comprise one or a plurality of capillary tubes, or a porous material, for example, that is immersed in or substantially fills the fuel reservoir. A preferred system, illustrated in FIGS. **2–4**, comprises a porous feed wick **50** having a low thermal conductivity retained in a feed wick shroud **52**. Feed wick **50** absorbs and conveys liquid fuel by capillary action. Numerous absorbent, porous materials, including cotton, fiberglass, and the like, are known in the art and would be suitable. A porous material marketed by E.I. duPont de Nemours & Co., of Wilmington, Del., as "NOMEX" is a preferred material. Porous feed wick **50** has a pore size and porosity to provide a liquid supply to the porous member sufficient to produce the desired vapor output. If porous feed wick **50** is a separate component, it preferably comprises a material having a relatively large average pore size, generally up to at least 10 times greater than the average pore size of the porous member in the vaporization/pressurization module.

Many absorbent porous materials that would be suitable for use as a feed wick stretch to a greater degree in one direction than in others. The low stretch direction of such materials is preferably aligned with the longitudinal axis of the feed wick. The dimensions and placement of feed wick **50** are such that fuel is absorbed and conveyed to the vaporization/pressurization module regardless of the level of liquid fuel in fuel reservoir **34**.

Feed wick **50** is preferably retained in feed wick shroud **52**, which may be separate from or integral with the substantially vapor impermeable barrier that constrains the porous member forming the vaporization/pressurization module. Feed wick shroud **52** is preferably constructed from a rigid, gas and liquid impermeable material that is noncorrosive in liquid fuels and has a generally low thermal conductivity. Aluminum stainless steel, titanium alloys and ceramic materials are preferred. Feed wick shroud **52** is conveniently provided in a cylindrical form and preferably has at least one vent in proximity to each end providing communication between feed wick **50** and liquid fuel reservoir **34**. More particularly, at least one vent is preferably provided in proximity to the interface of the feed wick with the porous member in the vaporization/pressurization module. The vents prevent trapped air and gas pockets from interfering with fuel flow in the feed wick. Vents are conveniently provided as apertures **54** in feed wick shroud **52**, as illustrated in FIG. **3**.

In the combustion apparatus illustrated in FIGS. **2–4**, feed wick shroud **52** is received through aperture **44** in end wall **40** of fuel container **32**. The end of feed wick shroud **52** is positioned in proximity to depression **42**. Cutouts **56** may be provided in feed wick shroud **52**, as shown in FIG. **2**, to facilitate fuel flow to porous feed wick **50**. The other end of porous feed wick **50** is in fluid communication with the vaporization/pressurization module.

Vaporization/pressurization module **60**, as illustrated in FIGS. **3** and **4**, comprises porous member **62**, vapor impermeable shroud **64**, and substantially vapor impermeable aperture plate **66**. Porous member **62** is preferably cylindrical and may comprise a plurality of porous member layers **62A–62E**, as illustrated in FIG. **3**, or a single porous layer **62**, as illustrated in FIG. **4**. If a plurality of layers is employed, each of the layer interface surfaces closely contact(s) the adjacent layer interface surface substantially without gaps or voids. The number and thickness of individual porous member layers may vary, provided that the desired overall porous member thickness and a substantially uniform average pore size is provided. The preferred configuration and dimensions of porous member **62** varies depending, for example, on the desired vapor output.

Porous member **62** has a liquid feed surface **68** and a vaporized fuel exit surface **70**. Liquid feed surface **68** is in fluid communication with the liquid fuel feed system and may contact the liquid fuel feed system directly or through one or more intermediate components. A vaporization zone is established within porous member **62** during operation. The vaporization zone is in thermal communication with a heat source, such as a hot seat, and may contact the heat source directly or through one or more intermediate components. In the embodiment illustrated in FIGS. **3** and **4**, hot seat assembly **72** comprises first vapor permeable member **74** and second vapor permeable member **76**, and is positioned in proximity to vaporized fuel exit surface **70** of porous member **62**. Hot seat assembly **72** is in thermal communication with burner assembly **96** and provides heat to porous member **62** using a portion of the returned combustion heat. Temperature and pressure gradients are maintained across porous member **62** between the liquid feed surface **68** and vaporized fuel exit surface **70** during operation of the module, as described previously with respect to the vaporization/pressurization module illustrated in FIG. **1**.

A glass fiber filter material without binders distributed by Millipore as APFC 090 50 having a pore size of 1.2 μ is an especially preferred material for porous member **62**. Other porous materials having a low thermal conductivity and generally uniform average pore size, such as porous ceramic or porous metallic materials, as well as composites and woven and non-woven fiber materials, would be suitable. The desired configuration, e.g. thickness, of porous member **62** depends upon the desired output capacity of the combustion apparatus, the type of liquid fuel utilized, and the like.

Porous member **62** desirably has a substantially constant and uniform pore size throughout its volume. When porous member **62** comprises a non-rigid material or a material that is prone to stretching or otherwise changing its coformation, a rigid, liquid permeable porous member retainer **78** may be used to provide mechanical support for porous member **62**. When porous member retainer **78** is employed, it is important to maintain efficient fluid communication between the liquid feed system and liquid feed surface **68** of porous member **62**. Porous member retainer **78** preferably contacts the liquid feed surface **68** of porous member **62** closely and substantially without gaps and voids. Porous member retainer **78** comprises a porous, liquid permeable rigid material having a low thermal conductivity. Sintered bronze is an exemplary suitable material.

Porous member **62** is retained within vapor impermeable shroud **64**. The edges of porous member **62** lie closely adjacent and preferably contact the inner surface of shroud **64** substantially without gaps and voids. The space between the edge(s) of porous member **62** and the inner surface of should **64**, at any point along the interface, is desirably not greater than the average pore size of porous member **62**. Shroud **64** comprises a rigid, liquid and gas impermeable material having a generally low thermal conductivity, as described above. In the embodiments shown in FIGS. **2–4**, shroud **64** has a thin-walled section **80** in which the porous member is retained. Thin-walled section **80** is provided to reduce the thermal conductivity of shroud **64** where it interfaces with porous member **62**, thereby reducing and minimizing heat transfer via shroud **64** through porous member **62**. Thin-walled section **80** is desirably as thin as is practical without compromising the structural integrity of shroud **64**. Stainless steel is a preferred material for shroud **64**, although many other materials having a low thermal conductivity, such as titanium alloys, are suitable.

Vaporized fuel exit surface **70** of porous member **62** is preferably in proximity to and in thermal communication with a heat source providing heat energy for vaporizing the liquid fuel in or at the surface of the porous member. The heat source may employ an external power source, such as the electrical heating element illustrated in FIG. **1**. Alternatively and preferably, the heat source utilizes heat energy returned from the heat of combustion without requiring any input from or connection to an external power source.

According to a preferred embodiment illustrated in FIGS. **3** and **4**, the heat source comprises a hot seat assembly **72** comprising a first vapor permeable member **74** and a second vapor permeable member **76**. First vapor permeable member **74** of hot seat assembly **72** is in thermal communication with porous member **62** directly or through one or more intermediate components to deliver heat in a substantially uniform distribution over vaporized fuel exit surface **70** of porous member **62**. Second vapor permeable member **76** is in thermal communication with first member **74** and a heat return means providing heat from combustion of the vaporized fuel.

Hot seat assembly **72** comprises one or more members constructed from a vapor permeable material having a generally high thermal conductivity. In the preferred embodiment illustrated in FIGS. **5A**, **5B** and **5C**, each member of hot seat assembly **72** preferably has a three dimensional surface for rapid and efficient heat and fuel vapor collection and transfer. Each surface of vapor permeable members **74** and **76** has a plurality of parallel grooves **82**. Parallel grooves **82** formed on opposing surfaces are provided at generally right angles to one another. Grooves **82** on each surface penetrate approximately 50% of thickness of members **74** and **76**, such that through holes **84** are formed where the grooves formed on opposing surfaces intersect. Through holes **84** provide the desired vapor permeability and grooves **82** provide a collection area in which vapor is pressurized. Second vapor permeable member **76**, which is in proximity to aperture plate **66**, is preferably provided with one or more apertures **86** that assist in directing vaporized fuel to aperture **88** in aperture plate **66**. Hot seat assembly **72** may be constructed, for example, from copper or a copper alloy, or another material having a high thermal conductivity, using a chemical milling process to form the grooves and through holes providing the desired vapor collection and permeability.

Porous member retainer **78**, porous member **62**, and hot seat assembly **72** are preferably mounted in a fixed position within shroud **64**. Aperture plate **66**, together with shroud **64**, forms the substantially vapor impermeable barrier that substantially constrains egress of vapor and encloses surfaces of porous member **62** other than liquid feed surface **68**. Aperture plate **66** is preferably spaced a distance from the vaporized fuel exit surface **70** of porous member **62** to provide additional space in which vapor is pressurized. Intermediate components, such as hot seat assembly **72**, may occupy all or some of a space or plenum formed between aperture plate **66** and porous member **62**.

Aperture plate **66** is preferably provided in proximity to second vapor permeable member **76** of hot seat assembly **72**. Aperture plate **66** has one or more vapor permeable location (s), such as aperture(s) **88**, through which pressurized fuel vapor passes to produce one or more vaporized fuel jet(s). The size and placement of aperture(s) **88** in aperture plate **66** are important variables affecting the vaporization and pressurization of liquid fuel with the vaporization/pressurization module and desirably vary for different combustion applications, different types of porous members, and different types of fuels. FIGS. **6A** and **6B** illustrate a preferred aperture plate **66** wherein aperture **88** has a larger diameter portion **90** that tapers to form a smaller diameter portion **92** from which the vaporized fuel jet is released. Such tapered orifices generally assist in forming the vaporized fuel jet. Aperture plate **66** is preferably constructed from a rigid material having a generally high thermal conductivity, such as copper or copper alloy.

Burner assembly **96** is mounted in proximity to aperture plate **66** and provides one or more chamber(s) for mixing of air or another combustible gas or mixture with the vaporized fuel. Burner assemblies having various configurations may be used.

Burner assembly **96** illustrated in FIGS. **3** and **4** has a neck **98** which fits within and is retained by shroud **64**. Burner assembly **96** has a mixing chamber **100** penetrated by one or more combustion gas supply channels **102**. For many applications, the combustion gas is simply ambient air. A plurality of combustion gas supply channels **102** are preferably arranged radially in neck **98** for directing air into mixing chamber **100**. Air for mixing with the vaporized fuel may be provided at ambient temperature and pressure or, for particular applications, may be provided at an elevated temperature and/or pressure. The air/vaporized fuel mixture exits mixing chamber **100** through a central passageway **104** and enters combustion zone **106**. A mixer tube **105** may be provided in connection with central passageway **104** to direct the flow of the air/vaporized fuel mixture. Burner assembly **96** preferably supports two or more heat conductive posts **110**. Apertures facilitate the flow of air into and through supply channels **102** and facilitate the flow of the air/vaporized fuel mixture to mixing chamber **100**. Burner assembly **96** is preferably constructed from a rigid material having a generally high thermal conductivity, such as copper or a copper alloy. Burner assemblies of various configurations may be used.

Additional mixing of the air/vaporized fuel mixture takes place in combustion zone **106**. Burner cap **114** is preferably mounted on conductive posts **110**, and collision and ignition of the air/vaporized fuel mixture takes place on underside **116** of burner cap **114**. Burner cap **114**, in combination with flame spreader **118**, spreads and distributes the flame. Burner cap **114** is preferably constructed from a rigid, substantially non-porous material such as stainless steel, and flame spreader **118** may comprise a stainless steel wire screen. In the combustion apparatus **30** illustrated in FIGS. **2–4**, feed wick **50**, porous member retainer **78**, porous member **62**, hot seat assembly **72**, aperture plate **66**, and burner assembly **96** all have a generally cylindrical or circular configuration and are arranged in a vertically stacked arrangement, aligned on a common central axis.

Combustion apparatus of the type illustrated in FIGS. **2–4** return a portion of the heat generated by combustion to the porous member to sustain vaporization of the liquid fuel and production of one or more vaporized fuel jet(s) to provide continuous, steady state operation of the combustion apparatus. According to this preferred embodiment, heat from combustion is conducted to porous member **62** firm flames or heat generated on burner cap **114** through heat conductive posts **110**, through burner neck **98** to aperture plate **66** and hot seat assembly **72**. All of these components are constructed from materials having a high thermal conductivity. In this fashion, following initial vaporization and ignition of the combustible mixture, the combustion apparatus operates in a continuous, steady state mode without requiring introduction of heat or energy from any source external to the apparatus. Numerous other means for returning a portion of the heat generated by combustion to the vaporization/pressurization module are known in the art and would be suitable for use in connection with combustion apparatus of the present invention.

The combustion apparatus illustrated in FIGS. **2–4** does not require priming or any starter or discrete ignition mechanism to initiate combustion. Heating the burner assembly for a few seconds using a match or a lighter provides sufficient heat transfer to the hot seat and porous member to initiate vaporization and pressurization of fuel in the porous member, produce a vaporized fuel jet, and initiate combustion. This system has many advantages for portable burner applications. Various ignition systems, including catalytic ignition systems, may alternatively be adapted for use in combustion apparatus of the present invention.

Combustion apparatus of the type illustrated in FIGS. **2–4** may additionally incorporate an adjustable combustion output feature. The combustion output is generally modulated by increasing or decreasing the flow of vaporized and pressurized fuel into the burner assembly. Adjusting the fuel output may be accomplished in numerous ways. A preferred system for modulating the vaporized fuel output involves modulating the heat flux in the combustion apparatus, and more particularly involves modulating the amount of heat energy returned to the vaporization/pressurization module. Modulating the amount of heat returned may be accomplished, for example, by increasing or decreasing the number or capacity of heat return elements, such as conductive posts; by adjusting the position of the heat return elements with respect to the flame generated; by adjusting the flame pattern and/or content relative to the heat return element(s); by adjusting the amount of heat conducted by heat return elements, for example, by employing duty cycles, diverting a portion of the heat, or cooling a portion of the heat return elements; or by other methods that are known in the art.

FIG. **7** schematically illustrates a combustion apparatus **30** of the present invention in the form of a mantle lamp. The mantle lamp comprises a combustion apparatus of the general type shown in FIGS. **2–4** with a mantle **124** mounted on a mantle support **126** in proximity to the flame. The shape of the flame may be adjusted by modifying, the configuration of the burner, for example, to provide optimal mantle illumination output. Various types of mantles, such as "bag" mantles produced and sold by Coleman Co., Inc. of Witchita, Kans., rare earth doped rigid ceramic durable mantles, and the like, are suitable. Substantially rigid mantles are preferred due to their resistance to shock and handling. The combustion output, and thus the illumination output, may be varied, for example, as described above. In addition, the mantle may be movable with respect to the burner and flame to modulate illumination output. A chimney **128**, reflectors, and other types of accessories may also be incorporated.

FIG. **8** illustrates another embodiment of a combustion apparatus of the present invention wherein the flow of vapor from the vaporization/pressurization module is adjustable by mechanical means. Liquid fuel **140** is conveyed from a reservoir through a capillary feed member **142** to a lower surface of porous member **144**. Vapor permeable hot seat **146** is provided in proximity to an upper surface of porous member **144** for heating liquid fuel to its vaporization temperature. Hot seat **146** may be controllably heatable by an external energy source or may be heated from a portion of the returned combustion heat.

In the combustion apparatus illustrated in FIG. **8**, porous member **144** is substantially constrainable at surfaces other than the liquid feed surface by means of substantially vapor impermeable shroud **148** and throttle **150**. Shroud **148** comprises a cylindrical portion **152** and a conical portion **154** that tapers to form a vapor release aperture **156**. Shroud **148** in communication with throttle **150** forms an enclosable space **158** which facilitates the accumulation and maintenance of vapor pressure during operation of the combustion device. Release of pressurized fuel vapor through vapor release aperture **156** is preferably adjustable by means of throttle **150**, which may conveniently comprise a plate **160** matching the configuration of vapor release aperture **156**, plate **160** being pivotable about pivot axis **162** to adjust the flow of vapor from enclosed space **158**.

During operation of the combustion apparatus shown in FIG. **8**, liquid fuel is vaporized in porous member **144** and fuel vapor exits the porous member, travels through hot seat **146**, and collects in enclosed space **158**. Adjustment of throttle **150** varies the flow and velocity of vapor to mixing chamber **164** and consequently varies the pressure at which vapor is released. Vaporized fuel mixes with air introduced through apertures **163** in mixing chamber **164** to form a combustible mixture that may be ignited and burned in burner **166**.

FIG. **9** schematically illustrates a liquid fuel burner apparatus of the present invention in a thermal to electric conversion system employing a thermophotovoltaic system to convert thermal energy to electrical energy. Liquid fuel combustion apparatus **170** employs a vaporization/pressurization module of the present invention to produce thermal energy, which is converted to radiant electromagnetic energy by emitter(s) **172**. Suitable emitters are generally ceramic and may be doped with rare earth oxides. Electromagnetic energy emitted from emitter(s) **172** is converted to electricity in suitable thermophotovoltaic cell(s) **174**. Suitable thermophotovoltaic cells include, for example, crystalline silicon cells, gallium antimonide (GaSb) infrared-sensitive cells, cells employing germanium, certain Group III-V materials such as gallium indium arsenide, and the like.

Alternative embodiments of the vaporization/pressurization module, liquid feed system and combustion apparatus and accessory components arranged to provide a stove are illustrated in FIGS. **10–22**. Referring fist to FIGS. **10** and **11**, fuel reservoir **350** is a tank for holding liquid fuel **358**. Fuel reservoir lid **352**, having lip **353** and carrying boiler frame **214** and associated apparatus, provides an air-tight closure to fuel reservoir **350**. Boiler frame **214** screws into fuel reservoir lid **352** by means of threads **216**, with resilient O-ring **218** providing a fluid tight seal between boiler frame **214** and fuel reservoir lid **352**. In the preferred embodiment, fuel reservoir **350**, fuel reservoir lid **352**, and boiler frame **214** are made of aluminum, which provides a light, sturdy structure. However, in other embodiments these parts could be formed of other materials.

Shroud **219** is an elemental cylindrical member which passes vertically through, and is supported by, boiler frame **214**. Shroud **219** is made of a thin wall of solid material which is a poor conductor of heat. Shroud **219** houses fuel transfer wick **224**, fuel boiler wick **220**, hot seat **230**, and aperture plate **250**.

Referring now to FIGS. **10** through **16**, the top **242** of supply wick **240** is pressed against the lower surface of transfer wick **224** by means of clips **248** and nuts **249**. The ends **244** of supply wick **240** dangle freely submersed in liquid fuel **358**. Supply wick **240** is made of Kevlar felt in the preferred embodiment, though other porous flexible materials or rigid porous materials, such as glass frit or ceramic may be utilized. Whatever material is used for supply wick **240**, the pores should be of appropriate size to wick fuel **358** from fuel reservoir **350** from supply wick ends **244** Lip and out the top **242** through transfer wick **224** under capillary action and provide liquid fuel **358** to boiler wick **220** at the appropriate boiling pressures. It should be noted that in alternative embodiments, a portion of transfer wick **224** could be directly submerged in liquid fuel **358**, obviating the need for supply wick **240**.

Fuel boiler wick **220** is a disk shaped member compressed between the upper surface **225** of transfer wick **224** and the lower surface **234** of hot seat **230**. In the preferred embodiment, boiler wick **220** is made of three discs of Kevlar felt. However, in other embodiments, boiler wick **220** may be made of other porous materials, such as ceramic, of appropriate pore size. Also, in other embodiments, boiler wick **220** may be of unitary, versus laminar, constriction. Boiler wick **220** is designed to fit snugly within shroud **219** so that a seal is formed between circular edge **223** of boiler wick **220** and the inner surface of shroud **219**, so that fluid flow will be through the pores through wicking and not through any edge gaps exceeding the average pore size of the boiler wick. Boiler wick **220** must be of appropriate pore size and material so that capillary action provides a supply of liquid fuel and so that heat transferred from hot seat **230** to the boiler wick provides for a boiling transition from liquid to fuel vapor over an appropriate range of temperatures and pressures. If the boiler wick **220** is made of a rigid, porous material, such as a ceramic or metal, a vapor tight seal between edge **223** and shroud **219** may be accomplished by precise manufacture, isometric seals, or by the use of caulking type adhesives. However, it may be more practical to construct boiler wick **220** of a pliable soft material such as plastic foam, conformable bat or felt, as in the preferred embodiment, which can be compressed into the needed sealing contact.

Transfer wick **224** is a generally cylindrical rigid member made of porous material with pore size compatible with that of supply wick **240** and boiler wick **220**. In the preferred embodiment, transfer wick **224** is made of ceramic, though it may also be made of metal.

Referring specifically to FIG. **13**, hot seat **230** and aperture plate **250** are generally cylindrical members formed or assembled as a unit. In the preferred embodiment, they are unitary in construction. The upper surface **232** of hot seat **230** forms an interface with the lower surface **254** of aperture plate **250**. Both are formed of heat conductive materials, such as metals, for conducting heat from heat returns **290** through valve plate **260**, and into boiler wick **220** for boiling the liquid fuel. Hot seat **230** and aperture plate **250** may be made of different materials, but in the preferred embodiment both are tanned of aluminum

Referring now specifically to FIG. **14**, in the preferred embodiment the lower surface **234** of hot seat **230** is provided with a series of narrow slots or grooves cut into the lower surface and extending approximately half of the vertical, or axial, length of hot seat **230**. The material between the notches **236** form a series of parallel varies **237** which contact the upper surface **221** of boiler wick **220**. The vanes **237** provide a means of conducting heat from the hot seat to the boiler wick, while the notches **236** between the vanes provide flow passages for the vapor boiling out of boiler wick **220**. The upper surface **232** of hot seat **230** is provided with a channel **238** extending sufficiently deep into the vertical length of the hot seat, so that fluid communication is provided from lower surface **234** through notches **236** and through channel **238** for boiling fuel vapors escaping from boiler wick **220** and on to aperture plate **250**.

Referring again specifically to FIG. **13**, aperture plate **250** is a generally cylindrical disk having upper and lower surfaces **252** and **254**, respectively. Lower surface **254** mates with upper surface **232** of hot seat **230**, and in the preferred embodiment is formed integrally therewith. Aperture plate **250** is provided with apertures **256** extending through the plate from upper surface **252** to lower surface **254** which provide fluid communication and flow passages for boiled fuel vapor from hot seat **230** to valve plate **260**. Screw hole **258** in aperture plate **250** receives screw **288**, as shown in FIG. **11**, for holding valve plate **160** and additional portions of the apparatus in place.

Referring again to FIGS. **10** and **11**, valve plate **260** is a generally cylindrical member having upper and lower surfaces **262** and **264**, respectively, and generally circular edge **266**. Valve plate **260** provides the dual functions of conducting heat from heat return tabs **290** to aperture plate **250** and thence to hot seat **230**, and a means for throttling the flow of fuel vapor out of apertures **256** in aperture plate **250** and on to jet former **270**. Heat return tabs **290** extend from edge **266** of valve plate **260**, and may be formed integrally therewith. In the preferred embodiment, however, heat return tabs **290** are made of copper and attached to valve plate **260** by means of screws **291**.

Starter guard **267**, fixedly attached to valve plate **260**, prevents operating starter assembly **380** unless valve plate **260** is rotated to align the boiler system for operation, as described below. Ports **268** extend generally vertically through valve plate **260** from lower surface **264** to upper surface **262**, and when valve plate **260** is properly aligned, provide fluid communication for fuel vapor between apertures **256** in aperture plate **250** and jet former **270**.

Upper surface **262** of valve plate **260** fixedly mates with lower surface **274** of jet former **270**. Lower surface **264** of valve plate **260** closely and rotatably contacts upper surface **252** of aperture plate **250**. By rotating valve plate **260** about screw **288** through action of control shaft **310**, ports **268** in valve plate **260** can be made to come into varying alignment with apertures **256** in aperture plate **250**, and thereby adjustably throttling the flow of fuel vapor exiting aperture plate **250** and escaping into jet former **270**. In this way, the flame strength, and consequently the heat output, of the stove, may be regulated. In the preferred embodiment, valve plate **260** is made of aluminum though in other embodiments it may be made of any heat conducting material.

Referring now to FIGS. **11** and **19**, jet former **270** is a generally cylindrical member forming a generally cylindrical hollow chamber, and having upper and lower surfaces **272** and **274**, respectively, and an outer edge **276**. A series of jet orifices **278** cut through outer edge **276** provide fluid paths for fuel vapor escaping from the central chamber of jet former **270**. Jet orifices **278** are sized to form jets of escaping fuel vapor which mix with ambient air, the mixture being then burned to form flames **284**. In the preferred embodiment, jet orifices **278** are narrow elemental slots. In the preferred embodiment, jet former **270** is integral with the upper surface **262** of valve plate **260**. Jet former **270** rotates about screw **288** along with valve plate **260**.

Flame plate **280** is a generally circular disk which sits atop, and is in taxed contact with upper surface **272** of jet former **270**. Flame plate **280** rotates about screw **288**, along with jet former **270** and valve plate **260**. Flame plate **280** is sized in diameter to divert flames **284** horizontally outward from jet orifices **278** and form an essentially circular flame ring, suitable for cooking and heating purposes. In the preferred embodiment, flame plate **280** is made of ceramic, but in other embodiments it could be made of any suitable flame and heat proof material.

Referring specifically to FIG. **19**, heat return tabs **290** are fixedly attached to, and extend horizontally outward from, edge **266** of valve plate **260** at equal intervals. The purpose of heat return tabs **290** is to transfer a portion of heat from flames **284** back to hot seat **230**. Heat return tabs **290** are empirically sized and shaped to transfer the appropriate amount of heat through valve plate **260** and aperture plate **250** on to hot seat **230**. At high vapor flow, a high heat flow is required to vaporize fuel in the boiler, while at low vapor flow, only a little heat is required to vaporize fuel in the boiler. Heat return tabs **290** are shaped and arranged to intercept a portion of flames **284**. The size and location of flames **284** depends upon the setting of valve plate **260** relative to aperture plate **250**. Therefore, the portion of flames **284** intercepted by heat return tabs **290** varies with the amount of the vapor throttling. This action provides a heat flow into heat return tabs **290** which is appropriate to any setting of the stove. As can be seen in the figures, heat return tabs **290** are angled upward from the horizontal at their ends, such that the larger flames **284** at lighter burner settings will impinge upon the upturned ends of the heat return bars. In this way, more of the flames' heat is transferred to heat return tabs **290** and on to hot seat **230** for increased boiling rate. In the preferred embodiment, heat return tabs **290** are made integral with the valve plate **260**.

Referring now to FIGS. **11** and **20**, control shaft **310** interfits within, and extends from, shaft housing **312**, which itself sits atop boiler frame **214**. Control shaft **310** is comprised of two portions, knob shaft **315** and pinion shaft **317**, one end of pinion shaft **317** being received within one end of knob shaft **315**. Knob shaft **315** and pinion shaft **317** are generally cylindrical, hollow members tied together by internal resilient shock cord **319**. This arrangement permits quick reassembly after collapsing the two shafts into a smaller length for ease of portability. Flange **321** of knob shaft **315** is specially shaped to prevent its sliding past fuel reservoir lid lip **353** and detaching from pinion shaft **315** unless control shaft **310** is in a position to shut all valves, thereby providing a stowage interlock.

Control shaft **310** is used to manually control the heat output of the stove by varying the angular position of valve plate **260** relative to aperture plate **250**. This is achieved by means of pinion **316** on pinion shaft **317**. Pinion **316** interfits with face gear **294**, which extends down from valve plate **260**. When knob **314** is rotated by hand, causing pinion **316** to rotate and face gear **294** to translate relative to pinion **316**, valve plate **260** is caused to rotate about screw **288**, thus changing the throttling between aperture plate **250** and valve plate **260**, and hence the vapor escaping to jet former **270** and the size of flames **284** exiting jet ports **278**. Referring to FIG. **18**, pinion shaft **317** is provided with slot **318** and detent **320** within slot **318**. Slot **318** is an annular cut extending for 270° rotation of pinion shaft **317**. Detent **320** is a flattened, slightly deeper section at one end of slot **318**. Slot **318** and detent **320** control the position of vent piston **330** to provide an air path from vent hole **313** into gas space **354** within fuel reservoir **350**, as described below.

Referring now to FIGS. **11** and **18**, vent piston **330**, having tip **332** at its upper end and head **334** at its lower end, is slidably received into vent hole **336** in boiler frame **214**. Spring **247** is a resilient, thin metallic semicircular member, the ends of which are fixed by nuts **249**. Spring **247** acts on head **334** of vent piston **330**, both to hold vent piston **330** in place, and to provide a positive, generally upward force on the piston to force tip **332** into positive engagement with slot **318** of control shaft **310**. The diameter of the central portion of vent piston **330** is designed so that there is sufficient clearance between the piston and the inner walls of vent hole **336** to permit the passage of air. Tip **332** of vent piston **330** rides in slot **318** of control shaft **310** as control shaft **310** is rotated to control the heat output of the stove. Slot **318** is designed so that all angular positions of control shaft **310**, except when tip **332** is seated in detent **320**, vent piston **330** will be in a downward "open" position, permitting the passage of air from atmosphere through vent hole **313** into shaft housing **312**, through vent hole **336** along the gap between vent piston **330** and the inner wall of vent hole **336** into gas space **354** of fuel reservoir **350**. This air path prevents the drawing of a vacuum in gas space **354** as fuel is consumed and the level of liquid fuel **358** in fuel reservoir **350** decreases.

Slot **318** and detent **320** are placed so that when control shaft **310** has been rotated to close off the fuel vapor escape path through apertures **256** in aperture plate **250**, and thus shut down the stove, tip **332** on vent piston **330** will be engaged in detent **320**. Detent **320** is cut deeper into pinion shaft **317** than is slot **318**, so that when detent **320** engages tip **332** of vent piston **330**, vent piston **330** will slide higher into vent shaft **336**, seating O-ring **338** at the lower end of vent shaft **336** to seal off the air flow path from atmosphere to gas space **354** and fuel reservoir **350**. In this way, when the stove is shut down, fuel reservoir **350** is sealed closed to allow for the stove to be transported in any position relative to horizontal without the danger of leaking or spilling liquid fuel.

Referring now to FIGS. **11** and **21**, starter assembly **380** is comprised of a generally cylindrical sheath **382** attached to boiler frame **214** by means of threads **384**, and extending down into fuel reservoir **350**. Generally cylindrical wick tube **386** is slidably disposed within, and extends a distance above sheath **382**. Plunger **392**, fixedly attached to the lower end of wick tube **386**, moves vertically with wick tube **386**. Spring bar **396** applies a generally upward force on plunger **392** and wick tube **386**. O-ring **394**, disposed within groove **395** in plunger **392**, seals shut fuel inlet **397** when plunger **392** is in its uppermost position. Fuel chamber **400** communicates with fuel reservoir **350** when fuel inlet **397** is not blocked by **020** ring **394**. Starter hot seat **390** is fixedly disposed within wick tube **386** near its upper end. Starter hot seat **390** is a vane, channeled disc similar to hot seat **230** described above. Starter wick **388** is disposed within sheath **382** and extends from fuel chamber **400** up to the lower surface of starter hot seat **390**. Starter wick **388** is made of Kevlar felt in a preferred embodiment, though other porous, flexible materials, or rigid porous materials, such as glass frit or ceramic, may be utilized. Whatever material is used for starter wick **388**, the pores should be of appropriate size to wick fuel **358** from fuel chamber **400** up to starter hot seat **390** through capillary action and provide liquid fuel **358** to its upper end at the appropriate boiling pressures. The upper end of starter wick **388** is designed to be at its upper end pressed firmly against the lower surface of starter hot seat **390** and the inner surface of wick tube **386**. With wick tube **386** acting as a shroud, starter hot seat **390** and the adjacent portion of starter wick **388** are designed to function as a capillary feed boiler for boiling liquid fuel **358** transferred by the starter wick **388** from fuel chamber **400**. Heat transferred from starter hot seat **390** to the upper portion of starter wick **388**, provides for a boiling transition from liquid to fuel vapor over the appropriate range of temperatures and pressures.

Boiled fuel vapor from starter hot seat **390** flows upward through passageway **402**, through orifice **404**, and out through jet tube **406**, where the fuel vapor is mixed with air. A combustible mixture of air and fuel vapor exits jet tube **406** while flowing toward the left as shown in FIG. **11** and impinges upon flame shaper **408**. Flame shaper **408** divides this gas flow into two equal portions to either side, and generally reverses its direction so that the flow moves toward the right as shown in FIG. **11**. After division and redirection, the flow of combustible mixture burns and makes flames which heat the lower surface **264** of valve plate **260**. At the same time, flame shaper **408**, fixedly connected to the upper end of wick tube **386**, captures some of the heat from the combusted starter fuel vapor and returns it back to starter hot seat **390**. Retaining clip **398** holds spring bar **396**, plunger **392**, and wick tube **386** in place relative to sheath **382**.

Operation of starter assembly **380** is as follows: After rotating control shaft **310** to rotate valve plate **260**, and with it starter guard **267** away from flame shaper **408**, flame shaper **408** is depressed momentarily. Depressing flame shaper **408** will cause wick tube **386**, and with it plunger **392**, to move downward within sheath **382** against the resistance offered by spring bar **396**. When plunger **392** is moved downward, O-ring **394** will no longer block fuel inlet **397**, thus allowing fuel **358** from fuel reservoir **350** to flow upward into fuel chamber **400**. Once flame shaper **408** is released, wick tube **386** and plunger **392** will return upward, sealing O-ring **394** against fuel inlet **397** and trapping a predetermined amount of fuel into fuel chamber **400**. The fuel trapped in fuel chamber **400** will be transported upward under capillary action by starter wick **388**, until the liquid fuel reaches the upper end of starter wick **388** in the vicinity of starter hot seat **390**.

A flame source is then directly applied to flame shaper **408**, which transfers the heat of the flame source to starter hot seat **390**. Starter hot seat **390** will transfer the heat to the upper portions of starter wick **388**, increasing the temperature of the transported liquid fuel contained within the upper portion of starter wick **388**. When the temperature of this liquid fuel reaches the boiling point for the prevailing pressure, the liquid fuel begins to boil. The fuel vapor produced will travel upward through the slots and channel in starter hot seat **390**, through passageway **402** and orifice **404**, and out through jet tube **406**, whereupon it will mix with air and be ignited by the external flame source being applied to flame shaper **408**. Once this ignition occurs, the flame source being applied to flame shaper **408** can be removed, since a portion of the heat released by the ignited fuel vapor will be returned through the flame shaper **408** back to starter hot seat **390** to produce a self sustaining capillary feed boiling action.

Flame shaper **408** is designed to direct the flame produced by the combusted starter fuel vapor upward on to valve plate **260**, which will transfer the heat through aperture plate **250** to hot seat **230** to begin the main capillary feed boiling action in boiler wick **220**. Once the fuel vapor produced by boiler wick **220** exits jet orifices **278**, that fuel vapor will mix with air and be ignited by the flame from starter assembly **380** being directed upward by flame shaper **408**. Heat return tabs **290** will return sufficient heat from the flames produced at jet orifices **278** to sustain the capillary feed boiling action in boiler wick **220**. Once the liquid fuel in fuel chamber **400** has been exhausted by the combustion in the starter assembly **380**, starter assembly combustion will cease. Fuel chamber **400** is designed to provide sufficient fuel for commencing a self-sustaining capillary feed boiling action in boiler wick **220** before the combustion in starter assembly **380** ceases.

Referring again to FIG. **10**, support prongs **360** provide a surface for setting the cooking pan or other item to be heated by the stove. Support prongs **360** are bent metal tabs fixedly attached to boiler frame **214**. Top **370** is also provided and sized to accommodate the outer circumference of fuel reservoir **350** forming an enclosure for easy transportation of the stove. Handle **372** permits top **370** to function as a cooking pot when inverted. The operation of the stove is as follows: first, liquid fuel **258** is added to fuel reservoir **350** by unscrewing boiler frame **214** and associated apparatus from fuel reservoir lid **352** at threads **216** to expose the interior of fuel reservoir **350**. Liquid fuel may be added through the void left in lid **352** by the removed boiler frame **214**. A sufficient amount of liquid fuel **358** is added so that when boiler frame **214** is reinstalled, ends **244** of supply wick **240** and plunger **444** will be submerged in fuel. Boiler frame **214** is then screwed back into place in lid **352** of fuel reservoir **350** until O-ring **218** is firmly compressed between boiler frame **214** and fuel reservoir lid **352**, providing a tight seal between the interior of the fuel reservoir and atmosphere.

Knob **314** is then turned counter clockwise to rotate control shaft **310**, and with it pinion gear **316** so that face gear **294**, and with it valve plate **260**, rotate clockwise as seen from above about screw **288** to open a fluid communication path between boiler wick **220** and jet former **270**. As valve plate **260** rotates, starter guard **267** will move with it to expose flame shaper **408** on starter assembly **380**. As control shaft **310**, and with it pinion shaft **317**, rotate, tip **332** of vent piston **330** disengages from detent **320** and moves counter clockwise along concentric cam slot **318** in pinion shaft **317**. This movement causes vent piston **330** to move downward against spring clip **247** and open an air path from atmosphere through vent shaft **336** and into gas space **354** of fuel reservoir **350**. The fluid communication path thereby created provides a means for air from the atmosphere to move into gas space **354** to fill the void created by the liquid fuel, which is consumed as the boiler operates.

Next, flame shaper **408** of starter assembly **380** is depressed through wick tube **386**, plunger **392** and associated components downward against the resistive force of spring bar **396**. This action will open fuel inlet **397** and allow liquid fuel **358** in fuel reservoir **350** to flow upward into fuel chamber **400**. Flame shaper **408** is held down momentarily to allow fuel chamber **400** to fill. When flame shaper **408** is released, it, along with wick tube **386**, plunger **392**, and associated apparatus will move upward, sealing off fuel inlet **397** with O-ring **394**. A few seconds delay is here necessary to give time for the liquid fuel in fuel chamber **400** to be transported via capillary action by starter wick **388** upward into the vicinity of starter hot seat **390**. Then, an external flame source is applied to flame shaper **408** to heat it and concomitantly starter hot seat **390** to begin the boiling of the liquid fuel in starter wick **388**. When fuel vapor exits jet tube **406** and mixes with air, it will be ignited by the external flame source to begin self sustaining combustion and capillary feed boiling of the starter assembly **380**.

The combustion-flame produced by starter assembly **380** is directed upward and inward by flame shaper **408** and impinges against the adjacent portions of valve plate **260**, heating it. This heat is transferred through valve plate **260**, aperture plate **250**, and hot seat **230** into boiler wick **220**.

When the liquid fuel within boiler wick **220** is heated to its vaporization temperature for the extant capillary pressure, the fuel boils and the released fuel vapor escapes upward through the remainder of boiler wick **220**, through notches **236** and channel **238** in hot seat **230**, through apertures **256** and aperture plate **250**, through ports **268** and valve plate **260** and into jet former **270**, where it finally escapes through jet port **278**. Upon exiting jet port **278** and mixing with air, the released fuel vapor is ignited by the flame from starter wick **340**, thus starting the stove. Once the stove has been started, some of the heat from flames **284** is transmitted via valve plate **260**, aperture plate **250** and hot seat **230** to boiler wick **220** to sustain the boiling process.

At higher stove outputs, determined by the position of valve plate **260** relative to aperture plate **250**, flames **284** will extend a sufficient horizontal distance from jet port **278** to impinge upon heat return tabs **290** and thus provide additional heat transfer back to boiler wick **220** to sustain higher boiling rates necessary for higher fuel vapor production rates. As noted above, heat return tabs **290**, as well as the other transfer components of the device, are constructed so than an empirically correct amount of heat is transferred to boiler wick **220** to sustain the boiling.

Once the stove is operational, a cooking pan or other item to be heated may be placed atop spider **360**. As the cooking or other heating progresses, knob **314** may be used to rotate control shaft **310** as appropriate to throttle the flow of fuel vapor through valve plate **260** and into jet former **270**, thus regulating the output of the stove. As different amounts of fuel vapor flow are demanded from the boiler, the heat transfer through hot seat **230** and into boiler wick **220** will automatically adjust to sustain boiling.

Another embodiment of the liquid fuel stove employing a capillary feed boiler is depicted in FIG. **22**. In this embodiment, heat return bars **290** are replaced by resistive heat elements **296** attached to shroud **219**, and powered by battery **297**. Other embodiments may employ a variety of other electrical power sources. In this embodiment, some heat from combustion inadvertently reaches the boiler by stray conductive, convective, and radiative heat paths. Resistive heat elements **296** add to this stray heat enough to maintain vapor flow. The electrical heat is controlled electronically to maintain the hot seat at a controllable temperature. The temperature of hot seat **230** is sensed by the resistance of the heat elements**296** using well-known electronic control techniques. With a knob, this temperature is controlled manually.

This embodiment of the invention does not require a vapor valve. Vapor flows unimpeded from the boiler to the jet forming orifices. The vapor flow depends upon the heat input to the boiler, which in turn depends upon the temperature of the hot seat. Therefore, the combustion output depends upon the controllable temperature of the hot seat.

In the embodiment described previously, control of the combustion output is achieved by throttling the fuel vapor flow by changing the relative positions of aperture plate **250** and valve plate **260**. In this alternative embodiment, once valve plate **260** is rotated into an open position relative to aperture plate **250**, valve plate **260** remains fixed, and stove output is controlled by controlling the heat output of resistive heat elements **296** and hence the boiling rate in boiler wick **220**. Rheostat **298**, attached to and manually controlled by the rotation of control shaft **310**, varies the electrical supply to resistive heat elements **296**, and hence the heat output of the heat elements. This arrangement provides an exacting method of controlling the output of the stove for applications in which accurate control is desired. Remaining portions of the camp stove of this alternative embodiment, such as jet former **270**, vent piston **330** and starter wick **340**, are similar to those of the previously described embodiment.

The following Example describes certain preferred embodiments of a combustion apparatus employing the vaporization/pressurization module of the present invention. While certain configurations, dimensions and materials are described, it will be understood that these are exemplary and the apparatus and methods of the present invention are not limited to these embodiments.

EXAMPLE

A combustion apparatus employing the vaporization/pressurization module of the present invention designed to burn white gas similar to that shown in FIGS. **2–4** was assembled. The liquid feed reservoir had the configuration illustrated in FIGS. **2–4** and was constructed from acrylic.

The feed wick shroud and porous member shroud comprised a unitary tubular member constructed from stainless steel. The overall length of the shroud was 2.0 inches; the outer diameter was 0.375 inch; the wall thickness was 0.010 inch; and the thin-walled portion of the should had a wall thickness of 0.004 inch. NOMEX was used as a feed wick and configured as shown in FIG. **3**. Two vent apertures were provided as shown in FIG. **3**.

A sintered bronze porous member retainer having a diameter of 0.357 inch and a thickness of 0.060 inch was baked to a golden brown color after machining, and then mounted in the shroud near the top of the feed wick. The porous member was composed of 15 discs of Millipore APFC 090 50 glass fiber filter material having a pore size of 1.2 μ, each disc having a diameter of 0.375 inch. The porous member was designed to fill the thin walled shroud section having a length of 0.112 inch, and the discs were slightly compressed as they were positioned in contact with the porous member retainer. The discs were in contact with the inner shroud wall. A hot seat assembly having the configuration shown in FIGS. **5A**, **5B** and **5C** was positioned in contact with the upper Millipore disc. The hot seat assembly was constructed from a tellurium-copper alloy and the grooves were chemically milled as described above.

The aperture plate was constructed as illustrated in FIGS. **6A** and **6B** from a tellurium copper alloy as a 0.375 inch diameter plate having a thickness of 0.020 inch. The diameter of the smaller diameter jet releasing aperture in the aperture plate was 0.009 inch. This aperture was the only vapor permeable aperture in the shroud/aperture plate combination forming the substantially vapor impermeable barrier.

The burner apparatus was similar to the burner illustrated in FIGS. **2–4** and was constructed from a tellurium-copper alloy. The burner had a central air passageway aligned with the central axis of the combustion apparatus and six air passageways having longitudinal axes parallel to the longitudinal axis of the central air passageway and provided in a radial arrangement with respect to the central air passageway. Three heat conductive posts were mounted in a radial arrangement near the outer rim of the burner apparatus as illustrated in FIGS. **2–4** and were also constructed from a tellurium-copper alloy. The burner cap was constructed from stainless steel, 300 series, and had an overall diameter of 0.500 inch. A flame spreader comprising stainless steel wire screen having an overall diameter of 0.750 inch; a wire diameter of 0.009 inch, and a pitch of 0.024 inch was used, as illustrated in FIGS. **2–4**.

White gas was introduced into the fuel reservoir. A flame from a lighter was held near the burner cap for two to three seconds to initiate combustion. Following ignition, the combustion apparatus produced a very hot flame that burned steadily for minutes to hours, depending on the level of fuel provided in the fuel reservoir. The flame could be extinguished by inhibiting air flow to the burner apparatus or removing the feed wick from the fuel.

We claim:

1. A vaporization/pressurization module comprising:

a porous member composed of a material having a thermal conductivity of less than 10 W/m K and having a liquid feed surface, a liquid vaporization zone, a vapor release surface generally opposite the liquid feed surface, and sidewalls;

a heat source in thermal communication with the porous member; and

a substantially vapor impermeable barrier contacting the porous member sidewalls and in proximity to the porous member vapor release surface, the substantially vapor impermeable barrier having one or more vapor permeable locations permitting egress of pressurized vapor.

2. A vaporization/pressurization module according to claim 1, wherein, the one or more vapor permeable locations permitting egress of pressurized vapor further comprises an adjustment feature to provide controllable vapor release.

3. A vaporization/pressurization module according to claim 1, wherein, the one or more vapor permeable locations comprise less than about 5% of the surface area of the substantially vapor impermeable barrier.

4. A vaporization/pressurization module according to claim 1, wherein the substantially vapor impermeable barrier comprises a vapor impermeable shroud contacting the porous member sidewalls and an aperture plate having one or more vapor permeable apertures in proximity to the porous member vapor release surface, and wherein said vapor impermeable shroud has a thermal conductivity of less than 200 W/m K.

5. A vaporization/pressurization module Comprising:

a porous member comprising a ceramic material having a substantially uniform small pore size, the porous member having a liquid feed surface, a liquid vaporization zone, a vapor release surface generally opposite the liquid feed surface, and sidewalls;

a heat source in thermal communication with the porous member; and

a substantially vapor impermeable barrier contacting the porous member sidewalls and in proximity to the porous member vapor release surface, the substantially vapor impermeable barrier having one or more vapor permeable locations permitting egress of pressurized vapor.

6. A vaporization/pressurization module comprising:

a porous member comprising a material having a low thermal conductivity and an average pore size of from 0.5 to 5 microns, the porous member having a liquid feed surface, a liquid vaporization zone, a vapor release surface generally opposite the liquid feed surface, and sidewalls;

a heat source in thermal communication with the porous member; and

a substantially vapor impermeable barrier contacting the porous member sidewalls and in proximity to the porous member vapor release surface, the substantially vapor impermeable barrier having one or more vapor permeable locations permitting egress of pressurized vapor.

7. A vaporization/pressurization module according to any of claims 1, 5 or 6, wherein the material comprising the porous member has an average pore size of from 0.10 to 30 microns.

8. A vaporization/pressurization module according to claim 1 or 5, wherein the porous member has an average pore size of from 0.5 to 5 microns.

9. A vaporization/pressurization module according to any of claim 1, 5 or 6, wherein the porous member has a composite construction and comprises materials having different thermal conductivities.

10. A vaporization/pressurization module according to any of claims 1, 5 or 6, additionally comprising a resistive heating element provided in proximity to a vaporization zone of the porous.

11. A vaporization/pressurization module according to any of claims 1, 5 or 6, wherein the porous member is cylindrical.

12. A combustion apparatus comprising the vaporization/pressurization module of any of claims 1, 5 or 6, and additionally comprising a liquid fuel reservoir and a liquid feed system for providing liquid fuel to the liquid feed surface of the porous member.

13. A combustion apparatus according to claim 12, wherein the liquid fuel reservoir is vented so that the pressure in the liquid fuel reservoir during combustion is equalized with ambient pressure.

14. A combustion apparatus according to claim 12, wherein the liquid fuel reservoir is cylindrical.

15. A combustion apparatus according to claim 12, wherein the liquid feed system is a capillary feed system.

16. A combustion apparatus according to claim 12, wherein the capillary feed system comprises an absorbent, porous material having a pore size larger than the pore size of the porous member.

17. A combustion apparatus according to claim 12, additionally comprising a hot seat assembly constructed from a vapor permeable material mounted in proximity to and in thermal communication with the vapor release surface of the porous member.

18. A combustion apparatus according to claim 12, additionally comprising a burner assembly providing at least one chamber for mixing a combustible gas with vaporized fuel.

19. A combustion apparatus according to claim 12, wherein the burner assembly is in thermal communication with the hot seat assembly by means of heat conductive posts.

20. A combustion apparatus according to claim 12, additionally comprising an adjustment mechanism for modulating the flow of vaporized and pressurized fuel into the burner assembly.

21. A combustion apparatus according to claim 12, additionally comprising an adjustment mechanism for modulating the heat flux in the combustion apparatus.

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