

## Pulse combustion apparatus

This invention relates to pulse combination apparatus and to heaters of the pulse combustion type.

A pulse combustion apparatus conventionally includes a combustion chamber and an exhaust pipe which forms a resonant system with the combustion chamber. At each cycle of the apparatus, a fuel charge is admitted to the combustion chamber and is ignited. The charge expands into the exhaust pipe causing a partial vacuum transient in the combustion chamber which both assists in drawing in a fresh charge, and causes high temperature gas to be drawn back into the combustion chamber from the exhaust pipe. The fresh fuel charge spontaneously ignites, establishing the next cycle and the apparatus is self-sustaining after initial ignition. In a heater of the pulse combustion type, a fluid to be heated is brought into heat exchange relationship with the exhaust pipe.

My United States Patent No. 3,267,985 discloses a pulse-combustion-type heater in which the combustion chamber has substantially the shape of two conical shells joined together at their major diameters along a common line of junction. An inlet is at one end of the chamber and successive fuel charges are admitted to the chamber through it. Five exhaust pipes are coupled tangentially to the combustion chamber for heating and are disposed in a chamber through which water is circulated. They communicate with the chamber through at least one exhaust gas outlet. While this form of combustion chamber and exhaust system has been found to provide a very stable combustion cycle, the present invention is aimed at providing further improvements intended to enhance performance.

According to one aspect of the present invention the combustion chamber has an internal cavity of a shape which extends about a median plane, which is circular in said plane, and which curves generally inwardly from both sides of said plane around its entire periphery, towards first and second ends of the cavity. The exhaust pipe extends from the median plane of the combustion chamber. As a result of the combustion chamber shape and the arrangement of the exhaust pipe, combustion gases returning to said combustion chamber under the effect of a vacuum transient in the chamber are caused to flow into said cavity in a double toroidal flow pattern into which a subsequent fuel charge enters generally centrally from said combustion chamber inlet.

Other aspects of the invention relate to improvements in the arrangement of heat exchange coils opening from a manifold positioned where gas combustion is at least substantially complete (claim 6); to forming a housing for the chamber and pipe from three stacked sections the top and bottom ones of which are concrete castings (claim 11); and to

improved valving and inlet arrangements for air ingress into the chamber (claim 13).

In order that the invention may be more clearly understood, reference will now be made to the accompanying drawings which illustrate a number of preferred embodiments of the invention by way of example, and in which:

Figure 1 is a vertical sectional view through a pulse combustion heater according to the invention;

Figure 2 is a vertical sectional view through the combustion chamber of the apparatus shown in Figure 1;

Figure 3 is a transverse sectional view on line III—III of Figure 2;

Figure 4 is a perspective view, partly in section and partly exploded, showing the valve means of the combustion chamber of Figures 2 and 3;

Figure 5 is a vertical sectional view of part of Figure 4;

Figure 6 is a perspective view of the exhaust system of the apparatus of Figure 1;

Figure 7 is a plan view corresponding to Figure 6;

Figure 8 is a diagrammatic illustration of the gas flow pattern in the combustion chamber of the apparatus shown in Figure 1;

Figures 9 and 10 are views corresponding to Figures 2 and 3 respectively showing modified combustion chamber;

Figure 11 is a vertical sectional view partly exploded, of a pulse combustion heater according to a further embodiment of the invention;

Figure 12 is a transverse sectional view on line XII—XII of Figure 11;

Figure 13 is a perspective view of the gas cushion chamber of the apparatus shown in Figures 11 and 12; and,

Figure 14 is an exploded perspective view of the impeller assembly of the apparatus of Figures 11 and 12;

Referring first to Figure 1, a pulse combustion heater is generally indicated at 20 and includes a combustion chamber 22, valve means 24 at the top of the chamber for admitting fuel charges thereto, and an exhaust system 26. The components of the apparatus are disposed within a housing 28 which is designed to be self-standing on a suitable support surface. Reference numeral 30 indicates a control box which is disposed at one side of the housing and which houses suitable control equipment including an ignition transformer connected by a high tension lead (not shown) to a spark plug in the combustion chamber. The spark plug is used for starting only.

Housing 28 is divided internally as will be described to define, from top to bottom, an air inlet chamber 32, an air cushion chamber 34, a heat exchange chamber 36, a muffler chamber

38 and an exhaust chamber 40. The housing is defined by inner and outer casings denoted 42 and 44 respectively. The inner casing is made of high strength concrete, while the outer casing is made of steel. At the position of the air cushion chamber 34, the inner casing is fitted with a liner 46 of galvanized steel. The top of chamber 34 is defined by a plate 48 which separates the air cushion chamber 34 from the air inlet chamber 32. Supporting structure above plate 48 is generally indicated at 50 but will not be described in detail. Also, it should be noted that suitable sound insulating material is incorporated in the top of the housing and in the inner casing, but has not been shown, again because it forms no part of the invention.

Air inlet chamber 32 communicates with the exterior of the housing by way of an air inlet 52 which extends through the inner and outer casing. This allows ambient air or air from a supply pipe to be drawn into the housing for combustion as required. A fan unit generally denoted 54 is suspended below plate 48 and has an inlet 56 within chamber 32. The fan unit includes an electric motor 58 driving fan blades 60 arranged within a fan chamber 62 which discharges into the air cushion chamber 34. This chamber provides a reservoir of combustion air. Air is drawn from chamber 34 into the combustion chamber 22 as required under the control of the valve means generally indicated at 24. Fan unit 54 is used only for starting; after ignition, the combustion process is self-aspirating.

Heat exchange chamber 36 is defined by a liner assembly generally denoted 64, which, in effect, forms a boiler inside housing 28. Thus, it will be seen that the liner assembly includes a cylindrical portion 65 and top and bottom closures or "heads" 66 and 68 respectively at opposite ends of the heat exchange chamber and that the chamber is provided with an inlet 70 and an outlet 72 which extend through housing 28. Each of these components is in the form of a tubular sleeve which passes through the housing 28 and communicates with an associated pipe connection which mates with a corresponding opening in the relevant closure member of liner assembly 64. In Figure 1, the pipe connection associated with inlet 70 is denoted 76 and the associated opening in the top closure 66 is indicated at 78. The corresponding pipe connection for outlet 72 is denoted 80 and the corresponding opening is indicated at 82. The inlet and outlets are coupled to external equipment (not shown) for circulating water through a heat exchange chamber 36 for heating. The combustion chamber 22 is mounted in an opening 74 in the top closure 66 of the liner assembly 64 so that water entering the heat exchange chamber 36 through inlet 70 will flow around the combustion chamber for transfer of heat from the chamber to the water. Similarly, as the water flows down in chamber 36

towards outlet 72, it will flow around the exhaust system 26 and receive heat therefrom.

Muffler chamber 38 is defined between the lower closure member 68 of liner assembly 64 and a plate 84 which extends transversely inside housing 28 at a spacing below the bottom closure member 68. The exhaust system 26 discharges generally vertically downwards into chamber 38 as will be described and a heat shield 86 is attached to the upper surfaces of plate 84. A muffler tube 88 extends generally vertically through plate 84 at a position spaced laterally from the position at which the exhaust system discharges into chamber 38. Thus, exhaust gases entering chamber 38 from the exhaust system 26 will pass into exhaust chamber 40 by way of muffler pipe 88. Chamber 40 has an exhaust outlet pipe 90 through which the exhaust gases leave housing 28 and from which the gases may be vented to atmosphere or otherwise disposed of as appropriate. A narrow condensate drain tube 92 is provided at the bottom of chamber 40 and is inclined downwardly so that any liquid which may collect in the chamber will drain to the outside.

Reference will now be made to Figure 2 and 3 in describing the combustion chamber 22 of the apparatus. Combustion chamber 22 is in the form of a one-piece bronze casting, denoted 94, at the top of which the valve means 24 is located. The combustion chamber has an internal cavity 96 which is generally of flattened spherical shape. Thus, cavity 96 extends about a median plane 98, on which plane section III—III is taken. The cavity is of a shape which is circular in said plane, and which curves generally inwardly from both sides of said plane around its entire periphery towards first and second ends 100 and 102 of said cavity. Casting 94 defines an inlet 104 at the first end of the cavity through which successive fuel charges can enter the combustion chamber cavity, while the second end 102 of the cavity is closed and generally flat. An exhaust outlet 106 is provided in the wall of the combustion chamber and is located in median plane 98. An integral sleeve 108 extends from the combustion chamber generally tangentially with respect to cavity 96 and a pipe 110 of the exhaust system (see later) is coupled to the sleeve.

The combustion chamber inlet 104 is in the form of a passageway which extends through casting 94 from a top flange 112 to cavity 96 and includes three portions 114, 116 and 118 of progressively reducing diameter considered in the direction of fuel charge flow. As will be seen from Figure 4, the flange 112 and passageway portions 114, 116 and 118 are of circular shape in plan. The center passageway portion 116 receives a flame trap 120 for preventing blow-back of burning gases through the combustion chamber inlet. Flame trap 120 is in the form of an outer tubular retainer 122

and a core 124 formed of a spiral of corrugated stainless steel strip; the corrugations leave openings between the turns of the spiral through which fuel charges can flow. A screw threaded opening 125 adjacent inlet 104 receives a spark plug (not shown) for initiating the combustion process.

Referring now more particularly to Figures 4 and 5, valve means 24 includes a valve plate 126 mounted on the top surface of the flange 112 of casting 94. Plate 126 is provided with a number of sets of openings for admitting charges of air and fuel such as natural gas to the combustion chamber. In Figure 4, the sets of openings are denoted by reference numeral 128 and it will be seen that five such sets are visible; in fact, plate 126 is provided with seven sets of valve openings although two of the sets do not appear in Figure 4. Each set of openings includes a central opening 130 for admitting natural gas and a plurality of openings 131 distributed around opening 130 and through which air is admitted to the combustion chamber. Each central opening 130 is fitted with an inlet tube 132 which extends vertically upwardly from plate 126. Referring back to Figure 1 the tubes 132 communicate with a gas cushion chamber defined by a casing 134 which in this case is made of sheet brass. The gas cushion chamber is of generally cylindrical shape with domed ends (although the particular shape is not critical) and is fitted at one end with a corrugated fuel inlet tube 136 which extends through housing 28 and communicates outside the housing with a source of natural gas (not shown). Thus, the gas cushion chamber 134 will provide the combustion chamber with what is, in effect, a reservoir of gas at source pressure for admission to the chamber through the fuel inlet tubes 132. Air cushion chamber 34 provides a similar reservoir of combustion air. A pressure sensing tube 138 is shown adjacent the air cushion chamber 134 in Figure 1 and can be connected to switch in control box 30 for indicating when combustion has been established. Means (not shown) may also be provided for maintaining a substantially constant air/fuel ratio as described by my United States Patent No. 3,267,985.

Referring back to Figures 4 and 5, the sets 128 of openings in plate 126 are controlled by individual valves, each of which includes a light and freely movable valve disc such as those shown in exploded positions at 140 in Figure 4. In this particular embodiment, the discs are made of Dacron (T.M.) fabric coated with polychlorotrifluorethylene sold under the trade mark Kel-F by M. W. Kellogg Co. Each disc 140 is retained below the associated set of openings by a support plate 142 suspended from valve plate 126. Each support plate 142 is of circular shape and is formed with a set of openings corresponding generally to the opening in plate 126. Three integral lugs 144 project upwardly from plate 142 for suspending the plate. The

lugs extend through opening in plate 126 and are bent over and sealed by silver brazing as can best be seen in Figure 5. Thus, it will be appreciated that each valve disc 140 is supported by the associated plate 142 and is trapped against lateral movement by lugs 144. The openings in plate 142 permit pressure waves from the combustion chamber to force the valve disc 140 upwardly to close off the associated openings in valve plate 126. When the pressure decreases, the discs will move down and admit fuel to the combustion chamber.

Figures 6 and 7 show the exhaust system of the heater and will now be more particularly described. The system includes a single primary exhaust pipe 110 part of which is visible in Figures 3 and 4. This primary exhaust pipe has an inlet end coupled to the combustion chamber so as to extend outwardly from the chamber tangentially with respect to its circular configuration. Pipe 110 is of relatively substantial length (see later) and is shaped to define a generally circular loop portion which extends around the combustion chamber (see Figure 1), and an end portion which is bent downwardly and connected to a manifold 146. Manifold 146 has a single central inlet to which the primary exhaust pipe 110 is coupled. In this embodiment the inlet is defined by a sleeve 148 which projects upwardly from a main body portion 150 of the manifold and which is angled to correspond with the inclination of outlet end portion of the primary exhaust pipe 110. Pipe 110 is received in and welded to sleeve 148. The body portion 150 of the manifold 146 is generally cylindrical in shape and is formed with a plurality of outlets in the form of openings in its outer surface, which communicate with the single central inlet. The outlet openings are arranged in pairs in equally spaced relationship around the body portion 150 of manifold 146 with the outlets in each pair spaced vertically from one another and staggered laterally to a slight extent as can clearly be seen in Figure 6 in the case of one pair of outlet openings (denoted 152a and 152b). A plurality of heat exchange coils generally denoted 154 are provided for connecting manifold 146 with the muffler chamber 38 (Figure 1). Each coil is in the form of a hollow tube shaped to define a helix of substantially constant diameter extending about a longitudinal axis and having an inlet coupled to one of said manifold outlets, and an outlet which communicates with the muffler chamber 38 of the heater. The heat exchange coils are arranged in pairs around manifold 146 and each pair comprises one left hand wound coil and one right hand wound coil of identical shape and size. Referring to Figure 6, reference numeral 154L denotes the left hand coil of a pair while 154R denotes the corresponding right hand coil. The corresponding pair of coils are similarly designated in Figure 7. Five such pairs of coils are provided around manifold 146.

It will be apparent from Figures 6 and 7 that,

by virtue of the vertically staggered arrangement of the manifold outlets 152a and 152b the coils in each pair can "mesh" with or be interleaved with one another so that the turns of one coil fit between the turns of the corresponding coil. Similarly, adjacent coils of different pairs can be meshed or interleaved with one another. This provides for a very compact heat exchange unit having large capacity. A further advantage of this arrangement is that it can be readily fabricated using conventional coil winding equipment and with minimum bending of the pipes. Thus, successive coiled sections can be taken directly from a coil winding machine and fitted into the manifold without the need for special fabrication techniques.

A still further advantage of this heat exchanger construction is that heat exchangers having even more coils can be readily fabricated by enlarging the manifold and adding coils around the periphery of the existing coils as indicated in chain dotted line at 154' in Figure 7. These additional coils may be arranged in pairs of left and right hand coils interleaved with one another in the same fashion as the center coils. The inlet ends of the coils would be extended inwardly as shown in Figure 7 and connected into the larger manifold in a second row of staggered manifold outlets above the outlets shown in Figure 6.

A still further advantage of the heat exchange structure shown in the drawings derives from the fact that curved pipes are used. Thus, in a heat exchanger having straight pipes, the boundary layer effect produces, in effect, an insulating layer of stagnant air which tends to inhibit heat transfer from the pipes and reduces the efficiency of the heat exchanger. In the present application in which high velocity gas flows are encountered, the use of curved pipes minimized the boundary layer effect and increases the efficiency of the heat exchanger compared with a conventional unit having straight pipes. Curved pipes also have the advantage that they are capable of accommodating thermal expansion and contraction without the need for special precautions in the construction of the heat exchanger.

Referring back to Figure 6, it will be seen that the outlet end portion of each of the heat exchange tubes is shaped to define an axially parallel end portion 154a which extends through the bottom boiler head 68 of the heat exchange liner assembly 64 (see Figure 1).

The operation of the heater will now be described initially with reference to Figure 1 of the drawings. As indicated previously, the apparatus is designed to be self-sustaining after initial starting. Thus, a supply of fuel and air is delivered to the combustion chamber from the gas cushion chamber 134 and from the fan 54 respectively and is ignited by the spark plug in the combustion chamber. The pressure rise

which occurs in the chamber upon ignition causes the valve discs 140 (Figure 4) to be propelled upwardly and close off the air and gas inlet openings in the valve plate 126. The combustion gases expand and enter the primary exhaust pipe 110, causing a vacuum transient in the combustion chamber itself. This allows the valve discs 140 to move downwardly under the effect of the pressurized air and fuel acting on the discs from above so that a fresh fuel charge enters the combustion chamber. The vacuum transient also has the effect of causing combustion gases in the exhaust system to return to the combustion chamber.

The combustion chamber has been designed so that this returning pressure wave of combustion gases entering the combustion chamber is caused to flow in a double toroidal flow pattern as indicated diagrammatically in Figure 8. In that view, the wall of the combustion chamber cavity is indicated by a chain dotted outline denoted 96 and a tangential portion of the primary exhaust pipe is indicated at 110. By virtue of the tangential arrangement of this pipe and its position on the median plane of the combustion chamber cavity, the returning gases meet the combustion chamber wall generally in the region of the median plane. Since the wall curves inwardly at both sides of that plane, the gases are caused to flow inwardly both above and below the median plane in addition to being caused to follow the curvature of the wall around the circumference of the cavity. This generates the double toroidal flow pattern. Next the succeeding fuel charge enters the combustion chamber from inlet 104 generally centrally of the chamber and thus enters the center of the toroidal flow pattern of the combustion gases. In Figure 8, the flow path of the fuel charge is indicated generally at 158.

It has been found that the flame in the combustion chamber is not extinguished at any time during the cycle of the apparatus. During the low pressure part of the cycle (that is during the vacuum transient — generally about one third to one half of the cycle time depending on cycle strength) the gases in the combustion chamber are relatively stagnant and a number of flame fronts persist throughout the mixture. This low pressure draws the next fuel charge into the center of the combustion chamber with very little turbulence. The combustion gases returning to the combustion chamber through the primary exhaust pipe 110 are delayed due to the length of the pipe, but enter the combustion chamber at a very high velocity. These gases may be well below ignition temperature (since the exhaust system is water cooled); however, while the temperature will have an effect on the operating frequency of the apparatus, it has not been found to cause instability in the combustion cycle. In any event, as these returning gases enter the combustion chamber the residual gases containing the flame fronts are rapidly mixed with the fresh

charge due to the double toroidal flow pattern described above. There is a rapid increase of temperature and pressure and gases again start to flow out of the combustion chamber through the exhaust pipe. Complete ignition and pressure rise has been found to occur within approximately one tenth of the cycle time. This double toroidal turbulence pattern in the combustion chamber is very consistent with virtually no stray tails of flame which could cause pre-ignition of the charge and produce a pressure rise at the wrong time in the cycle. Thus, it will be understood that ignition of the incoming charge should be kept to a minimum until the high velocity combustion gases return to the combustion chamber. Ignition will then take place at a rate which is related to the gas velocity and the turbulence pattern.

An additional advantage derived from the combustion chamber design shown in the drawings is that the outside dimension of the combustion chamber can be minimized for a given volume, substantially reducing the space required to accommodate the combustion chamber. Another advantage is that the ratio of surface area to volume of the combustion chamber is at a minimum so as to reduce any quenching effect on the burning gases in the combustion chamber due to the presence of cooling water in the heat exchange chamber 36.

It has also been found that the design of the exhaust system has a significant impact on the operation of the apparatus. Thus, it will be noted that the system includes a primary exhaust pipe (110) which is of relatively large diameter and is of a significant length. These characteristics are selected with the aim of ensuring that combustion is completed in the primary exhaust pipe 110 and is not carried through into the heat exchange portion of the exhaust system. Thus, it has been found that, even with the improved combustion chamber design provided by the invention, some combustion occurs in the exhaust system. The high velocity of the gases entering the exhaust system results in a high rate of heat transfer to the surrounding water which, with the temperature drop which occurs due to expansion, results in some carbon monoxide in the gases. By providing an exhaust system in which substantially all of the combustion takes place upstream from the heat exchange coils this cooling effect on the gases and hence the high carbon monoxide content of the exhaust is minimized, while at the same time achieving efficient heat exchange to the water in the heat exchange chamber 36 through the medium of the heat exchange coils 154. A thin layer of an insulating material may even be applied to the primary exhaust pipe 110 in an effort to maintain the temperature of the combustion gases in the pipe and thereby to reduce the carbon monoxide content of the gases. In practice, it has been found that an increase in surface temperature of even about 55°C will make a significant difference to the

percentage of carbon monoxide in the exhaust.

A further expedient which may be adopted in the interest of minimizing carbon monoxide emission is to provide a restrictor or nozzle (not shown) in the exhaust pipe at its connection to the combustion chamber. Thus, since the combustion cycle is dependent upon the high velocity of the gases returning to the combustion chamber during the low pressure part of the cycle for providing fast ignition, a restrictor or nozzle provides for a larger volume for secondary combustion and at the same time gives the returning pressure wave a high velocity as it enters the combustion chamber (for rapid ignition). In practice, it has been found that, for optimum results, the inside diameter of the combustion chamber cavity in the median plane should be equal to or less than three times its height. Also, it has been found that the inside diameter of the primary exhaust pipe should be at least about 2 cm and that the pipe should be not less than about 25 cm in length.

It has been found that a single pipe is suitable for an apparatus having a relatively small heat output rating and that, for a larger apparatus the number of pipes may be multiplied in proportion to the increase in output rating. For example, in practical tests, an apparatus rated at 100,000 B.t.u. per hour required a single pipe of about 2.5 cm internal diameter and a 400,000 B.t.u. apparatus required four such pipes. In a multiple pipe installation they will be equally spaced around the combustion chamber and will each be disposed tangentially thereto. A more complex manifold (as manifold 146) is obviously required in such cases.

Reference will finally be made to Figures 9 and 10 which illustrate a modified form of combustion chamber which may advantageous in certain applications. Primed reference numerals have been used in Figures 9 and 10 to illustrate parts which correspond with Figures 2 and 3. The combustion chamber shown in Figures 9 and 10 has, in fact, been designed primarily for use in a pulse combustion apparatus in which the combustion chamber is air cooled; that is, where the apparatus is either an air cooled engine or is being used for heating air. For this reason, the combustion chamber is shown as having external fins denoted 160 for promoting heat transfer from the combustion chamber to the surrounding air. However, it should be noted that this is only one example of an application of this form of combustion chamber and that, in other applications, the fins might well be omitted.

The primary difference between the combustion chamber of Figures 9 and 10 and that shown in the previous views is that the inner wall of the combustion chamber is contoured to define an inwardly protuberant surface portion around the inner periphery of the combustion chamber in its median plane 98'. The effect of this protuberant portion is to positively separate

the returning combustion gases which enter the chamber cavity into two distinct flow paths. Thus, the flow pattern in the chamber of Figures 9 and 10 is essentially the same as that which occurs in the combustion chamber of Figures 2 and 3, but is somewhat more discrete. This form of flow pattern may be desirable in some situation although it should be emphasized that, in practice, it has not generally been found essential to provide for physical separation of the returning gases in this fashion in order to achieve satisfactory combustion.

Reference will now be made to Figures 11 to 14 in describing a pulse combustion heater according to a further embodiment of the invention.

In principle, the heater shown in these views is similar to the heater described above with reference to Figures 1 to 7. Thus, the heater includes a housing, generally indicated at 200, which defines internally, an air inlet chamber 202, an air cushion chamber 204, a heat exchange chamber 206, a muffler chamber 208 and an exhaust chamber 210. A fan unit 212 is positioned between the air inlet chamber 202 and the air cushion chamber 204 although the unit is shown in a partly exploded position in Figure 11. A gas cushion chamber 214 is disposed within the air cushion chamber 204 and a gas supply pipe 216 is coupled to chamber 214. The chamber 214 forms part of a sub-assembly which is illustrated in detail in Figure 13, and which includes valve means of the same form as that described previously in connection with Figure 4.

A combustion chamber 218 is disposed in the heat exchange chamber 206 and supports the gas cushion chamber sub-assembly as will be described. An exhaust system 220 is associated with combustion chamber 218 and discharges into the muffler chamber 208. The combustion chamber and exhaust system are of the same form as the combustion chamber 22 and exhaust system 26 described with reference to the previous views.

A primary difference between the heater being described and the heater of Figures 1 to 7 resides in the construction of the housing 200. As in the first embodiment, housing 200 includes inner and outer casings, denoted 222 and 224 respectively. The outer casing 224 is in the form of a one piece steel shell of cylindrical form and the inner casing 222, while also of generally cylindrical form, is an assembly of three generally cylindrical casing sections, namely an air cushion chamber section 226, a boiler section 228, and an exhaust chamber section 230. The sections are bolted together as will be described to form the inner casing 222 and are designed to provide a gas-tight assembly in which there can be no leakage of gases between the exhaust or muffler chambers of the heater and the air cushion chamber. This form of inner casing also has the advantage that the heater can be manufactured as three sub-assemblies

(an air cushion chamber sub-assembly, a boiler sub-assembly, and an exhaust chamber sub-assembly) which can be easily bolted together in assembling the heater.

The air cushion chamber section 226 and exhaust chamber section 230 of the inner casing 222 are cast in concrete. The castings may be manufactured by any appropriate concrete casting technique, e.g. by rotational moulding. In this particular embodiment, the sections are designed to be made by a technique in which a steel shell is employed for forming the outer surface of each section and remains associated with the concrete casting after the casting operation has been completed. Thus, as shown in Figure 11, steel shells 226a and 230a remain around the respective castings 226 and 230 of the inner casing. The casting which makes up the air cushion chamber section 226 is of generally cylindrical shape but is formed within its ends with upper and lower recesses 232 and 234 of annular form. The space between the recesses defines the air cushion chamber 204 of the apparatus. Recess 232 is of significant depth compared with recess 234 and is dimensioned to define the air inlet chamber 202. Recess 232 has an annular face 236 which is disposed normal to the longitudinal axis of section 226 and which forms a support for the fan unit 212 of the apparatus. A cast concrete lid 238 is provided for fitting over the open upper end of section 226 and is held in place by four screw threaded studs, two of which are indicated at 240 which are cast into section 226 so as to extend upwardly from the top end face of the section. The lid 238 is formed with openings to correspond with the three studs so that the lid can be fitted over the studs and secured in place by nuts and washers such as those indicated at 244. Four similar studs 242 are provided at the lower end of the section.

A steel air inlet tube 248 is fitted into an opening which extends through casting 226 at a position above the end face 236 of recess 232. Tube 48 is secured in place by a suitable epoxy adhesive. Casting 226 is also formed with suitable openings for the gas supply pipe 216 and for other necessary external connections (see later). All of these openings are air-tightly sealed with respect to ambient air.

The exhaust chamber casting 230 is also of generally cylindrical shape but includes an integral wall 250 at its lower end. At its upper end, section 230 is formed with a recess 252 generally similar to and of the same diameter as the recess 234 at the lower end of the air cushion chamber sections 226. Four equally spaced screw-threaded studs, two of which are visible at 254 and 256 are cast into section 230 so as to extend vertically upwardly from the top edge of the section. Internally, section 230 is shaped to define a narrow annular shoulder 258 which supports a metal muffler plate 260. Plate 260 is secured in place using a suitable silicon

sealer and divides the interior of section 230 into the muffler chamber 208 and the exhaust chamber 210. Plate 260 is made of steel and is fitted with a heat shield 262 and a muffler tube 264 generally similar to the structure described in connection with the first embodiment. An exhaust outlet pipe 266 extends through the wall of casting 230 below plate 260 and is secured in place by an epoxy adhesive. A condensate drain outlet 268 is similarly secured in an opening in the casting but below pipe 266.

The boiler section 228 of the inner casing of the heater is in the form of a cylindrical steel shell having an external diameter selected so that the shell can be fitted between the upper and lower casing sections 226 and 228 respectively with the respective ends of the shell received in recesses 234 and 252 of the other two sections as shown. Beads of a suitable silicon sealer are introduced into the recesses before assembly to ensure gas-tight sealing. The casing sections are then assembled and clamped together in gas-tight fashion by means of the screw-threaded studs 242 and 254 which respectively project downwardly from section 226 and upwardly from section 230. Angle section brackets such as that indicated at 272 are welded to the external surface of shell 270 in positions to correspond with the positions of the studs 242 and 254. Each bracket has a limb, as limb 272a, which projects outwardly from the external surface of shell 270 and which is formed with an opening for receiving the relevant stud. Thus, the studs 242 and 254 project through the openings in the brackets and are fitted with suitable nuts and washers for clamping the shell 270 between the casing sections 226 and 230. A suitable silicon sealer is used to coat the bottom faces of the recess 234 and 252 to ensure gas-tight sealing.

Shell 270 forms part of a boiler sub-assembly of the heater and is provided at its upper and lower ends with respective boiler heads 274 and 276 which are welded inside the ends of the shell in accordance with conventional boiler manufacturing practice. Head 274 is formed with an opening 278 and the combustion chamber 218 is bolted to head 274 so as to protrude upwardly through opening 278. Thus, it will be noted that the combustion chamber includes an integral flange 218a which fits against the under surface of head 274 and by which the combustion chamber is bolted to the head. The exhaust system 220 of the heater will not be described in detail since it is essentially the same as the exhaust system previously described with reference to the first embodiment. For present purposes, it is sufficient to note that the exhaust system is disposed inside shell 270 and extends from the combustion chamber 218 to the bottom head 276. Suitable openings are provided in head 276 for receiving the lower end portions of the heat exchange coils of the exhaust system.

Shell 270 is also provided with internally

screw-threaded water inlet and outlet couplings 280 and 282 which are located in openings in the shell and are welded in place. These couplings will receive external pipe work to be connected to the interior of the "boiler" represented by shell 270 and heads 274 and 276 for circulation of water around the combustion chamber and exhaust system. A third, similar coupling 284 is provided adjacent the lower end of shell 270 and is fitted with a plug 286 for clean out purposes.

It will be appreciated that the inner casing construction as described above has a significant advantage in that the air cushion chamber section 226 and the exhaust chamber section 230 are essentially isolated from one another by a sealed boiler section 228. As a result, there is virtually no risk of leakage of exhaust gases from the muffler chamber 208 or the exhaust chamber 210 to the air cushion chamber 204. Additionally, this form of construction has the advantage that the heater can be constructed as three sub-assemblies which can be assembled individually and then bolted together as described. The assembly is then fitted into the outer casing 224 and the space between the two casings is filled with fiberglass insulation.

Figure 13 illustrates the gas cushion sub-assembly of the heater, which is generally designated 288. This assembly includes cushion chamber 214 itself and the valve means associated with the combustion chamber 218. The valve means is essentially the same as that previously described with reference primarily to Figures 4 and 5 and will not therefore be described again in detail. It is sufficient to note that the valve means includes a valve plate 290 which is coupled to the gas cushion chamber 214 by a series of gas inlet tubes 292. The tubes 292 communicate with the interior of the gas cushion chamber 214 and with gas inlet openings in plate 290. At its lower end, each tube is surrounded by a series of air openings in plate 290 which allow air from the air cushion chamber 204 to enter the combustion chamber. Also associated with each series of openings is a valve comprising a valve retainer plate 294 and a valve disc (not shown) all as previously described with reference to Figures 4 and 5.

A pressure sensing tube 296 also extends upwardly from plate 290 and is fitted with coupling 298 at its outer end. Tube 296 communicates at its lower end with an opening in plate 290 which provides communication with the interior of the combustion chamber 218 when the gas cushion chamber sub-assembly is in place on the combustion chamber. Thus, by means of tube 296 a signal can be obtained as an indication of the pressure in the combustion chamber. This signal is used as an indication of whether or not combustion has been satisfactorily established in chamber 218.

When the gas cushion chamber sub-

assembly is fitted to the combustion chamber, valve plate 290 is disposed on top of the chamber and is held in place by a clamping ring 300 which extends around the gas inlet tubes 292 above plate 290. Ring 300 is formed with four equally spaced openings 302 which match both with corresponding openings 304 in plate 290 and with four externally screw-threaded studs 306 which project upwardly from the top of combustion chamber 218. Thus, sub-assembly 288 is mounted on the combustion chamber by fitting the valve plate 290 and the clamping ring 300 over the studs 306 and fitting suitable nuts and washers to the studs. One of these nuts is indicated at 306 in Figure 11 and the nuts associated with all four studs are similarly designated in Figure 12. In order to provide for ease of access to the nuts 306 for fitting of sub-assembly 288 to the combustion chamber (and subsequent removal thereof if necessary) gas cushion chamber 214 is specially designed to provide recessed areas 308 in its external surface. Referring back to Figure 13, the gas cushion chamber 214 is assembled from two substantially identical shell sections 310 and 312 which meet in a horizontal median plane of the chamber. Both sections are of oval shape in said plane and have side walls which are progressively shaped in moving away from said plane to define arcuate section troughs which form the recesses 308 referred to above. As a result, the top wall of each shell has the general appearance of an oval which has been inwardly constricted at both sides of a center section. The upper shell 312 is formed around its lower margin with an outwardly stepped portion 312a which defines a recess receiving the upper marginal portion of the lower shell section 310.

The gas cushion chamber sub-assembly 288 has been designed so that its component parts can be assembled or stacked together generally in the positions in which they are shown in Figure 13 and passed through a furnace brazing oven for brazing of the parts to one another. In this connection, it will be recalled that the valve disc retaining plates of the valve arrangement (as plate 294) are designed to be secured in place by brazing. The design of the gas cushion chamber sub-assembly also has the advantage that it can be bolted onto the combustion chamber of the heater as a unit. The design of the gas cushion chamber also allows ready access to the mounting studs 306 (Figure 11) using a socket wrench as discussed previously.

Referring back to Figures 11 and 12, it will be remembered that gas is delivered to the gas cushion chamber 214 through a gas supply pipe 216 which extends through the wall of the air cushion chamber section 226 of the inner casing. Externally of both the inner and outer casing, pipe 266 is fitted with a gas pressure regulator 314 which has a control port 316 for receiving an air pressure signal by which the regulator 314 is biased to vary the gas

pressure delivered to the gas cushion chamber 214 according to the air pressure in chamber 226. This signal is provided by way of a pressure sensing tube 318 which extends from port 316 through the inner and outer casings 222 and 224 and which is secured in place by a suitable adhesive. Regulator 314 is designed to control the pressure of the gas supplied to chamber 214 in accordance with the air pressure in air cushion chamber 204 so as to maintain a substantially constant air/gas pressure ratio. This has been found to be advantageous from the viewpoint of improving reliability of the heater.

Upstream of the gas pressure regulator 314, the gas supply line includes a solenoid operated gas valve for controlling delivery of gas to the combustion chamber. The valve is a conventional on/off valve and has not been shown in detail.

The fan unit 212 of the heater is shown in an exploded position in Figure 11. The unit includes an electric motor 320 and a shrouded impeller enclosed within a housing indicated at 322 in Figure 11. The housing includes a peripheral flange 324 which rests on the bottom face 236 of the recess 232 in the air cushion chamber section 226 when the fan unit is in its installed position. A foam rubber gasket 326 is secured to flange 324 by adhesive for sealing with face 236. The impeller casing 322 includes an upwardly extending, central air inlet 328 and a helical compression spring 330 extends around inlet 328 and is dimensioned to fit between the portion of the impeller casing around the inlet and the underside of the lid 238 of the inner casing. Thus, when the fan unit is in its installed position, flange 324 rests on the end face 236 in recess 232 and the lid 238 is bolted onto the top of the air cushion chamber section 226. In this condition, spring 230 is under slight compressive loading and serves to urge the impeller casing 322 against face 236.

Figure 14 is an exploded view of the impeller and housing. Housing 322 made in two parts, comprising an upper housing part 322a and a lower housing part 322b. The two parts have flattened peripheral portions which cooperate to define flange 324. Housing part 322a has the general shape of a shallow dome with a generally cylindrical upward extension as its center which defines air inlet 328. The lower housing part 322b is generally dish-shaped and includes a recessed central region 332 of circular shape surrounded by an annular wall 334. Wall 334 is formed with a series of circular air outlet openings 336. An impeller 338 is shown positioned between the two parts of the housing in Figure 14. The impeller includes a disc-shaped main portion 340 surrounding a central boss 342 and having on its upper surface a plurality of arcuate shaped vanes 344 which radiate outwardly from boss 342. Boss 342 has a central bore which receives the drive shaft of motor 320 (not shown) and the boss is

clamped to the drive shaft by a set screw (not shown).

A thin aluminum shroud 346 of slightly discsd circular shape is fitted to the tops of the as 344 so that open ended air passageways are defined between the vanes. At their outer ends, the vanes extend above the main portion of 340 of the impeller so that the passageways are open at their outer ends. At their inner ends, the vanes 344 are cut away to define an air inlet region around boss 342. Shroud 346 is held in place by a number of relatively fine pins or studs which are formed on certain of the vanes which project through holes in the shroud and are peened over to hold the shroud in place.

The main portion 340 of the impeller is dimensioned to be accommodated within the recessed central portion 332 of lower housing part 322b so that the open outer ends of the air passageways defined between the vanes 344 discharge generally in the direction of the air outlet openings 336.

The form of impeller shown in Figure 14 has been found to provide increased pressure output compared with a conventional impeller of comparable size. By way of example, a shrouded eight inch diameter impeller has been found eminently satisfactory for a heater of 100,000 B.t.u. output. A relatively high impeller output pressure has been found particularly desirable for ensuring reliable combustion cycle initiation where hot return water is present in the heat exchange chamber.

It should be noted that the preceding description relates to specific embodiments of the invention only and that many modifications are possible. For example, the specific materials referred to herein are not to be considered as essential, but rather as indicating materials which have been found satisfactory in practice. Also, it should be noted that the apparatus described has been designed primarily for burning gaseous fuels such as natural gas or propane although the principles of the invention are applicable to an apparatus for burning other fuels, for example, fuel oil or coal dust. For this reason, the term "fuel charge" has been used to denote any appropriate combustion medium and is intended to include a gas-air mixture. Of course, where different fuels are used, different expedients would undoubtedly be required for delivering the fuel charge to the combustion chamber. Fuel delivery may be effected in the manner disclosed in my United States patent aforesaid.

With reference to the valve means specifically disclosed in this application, it is to be understood that the number of valves will vary according to the size of the apparatus. Seven valves have been found appropriate to a 100,000 B.t.u. unit, but a larger number would be required for a larger apparatus.

Also, while the preceding description relates specifically to a heater, it is to be noted that the invention is not limited in this regard. For

example, a pulse combustion apparatus of the form provided by the invention could be used as an engine for the recovery of mechanical or electrical energy.

With reference to the exhaust system of the apparatus, it should be noted that the primary exhaust pipe could be omitted in some applications and heat exchange coil(s) connected directly to the combustion chamber (without a manifold). Of course the heat exchange pipes are also exhaust pipes whether or not a primary exhaust pipe (jet pipe) is present.

The primary exhaust pipe and/or the heat exchnge coils may be internally coated with lead for corrosion protection and long life. The lead coating may be applied by conventional techniques to a suitable thickness. A small percentage of tin or other material may be included with the lead for improved adhesion.

## Claims

1. A pulse combustion apparatus including a combustion chamber (22, 22', 218), at least one exhaust pipe (110, 110') forming a resonant system with said chamber, means (24, 24') for admitting successive fuel charges to said chamber and ignition means operable to initiate combustion in said chamber; the combustion chamber (22, 22', 218) having an internal cavity (96, 96') which extends about a median plane (98, 98'); the combustion chamber (22, 22', 218) further including an inlet (104) at one of its said ends, through which successive fuel charges can enter said combustion chamber (22, 22', 218) from said fuel charge admitting means (24, 24') in a direction normally to said median plane (98, 98') of the combustion chamber; and at least one exhaust gas outlet (106, 106') disposed in said median plane (98, 98'); an exhaust pipe (110, 110') being coupled to a said exhaust gas outlet (106, 106') and extending from the combustion chamber (22, 22', 218) generally tangentially with respect to said cavity (96, 96'); characterized in that the combustion chamber (22, 22', 218) has an internal cavity (96, 96') which extends about said median plane (98, 98') and which is of a shape which is circular in said plane (98, 98') and curves generally inwardly from both sides of said plane around its entire periphery towards the first (100) and secnd (102) ends of said cavity (96, 96'), and the exhaust pipe (110, 110') extends in the median plane from the outlet (106, 106') whereby combustion gases returning to said combustion chamber (22, 22', 218) under the effect of a vacuum transient in the chamber (22, 22', 218) at each cycle of the apparatus are caused to flow in a double toroidal flow pattern in said cavity (96, 96') and a subsequent fuel charge enters said flow generally centrally from said combustion chamber inlet (104).

2. An apparatus as claimed in Claim 1, wherein the combustion chamber cavity (96) is



clamped to the drive shaft by a set screw (not shown).

A thin aluminum shroud 346 of slightly disc'd circular shape is fitted to the tops of the vanes 344 so that open ended air passageways are defined between the vanes. At their outer ends, the vanes extend above the main portion of 340 of the impeller so that the passageways are open at their outer ends. At their inner ends, the vanes 344 are cut away to define an air inlet region around boss 342. Shroud 346 is held in place by a number of relatively fine pins or studs which are formed on certain of the vanes which project through holes in the shroud and are peened over to hold the shroud in place.

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The form of impeller shown in Figure 14 has been found to provide increased pressure output compared with a conventional impeller of comparable size. By way of example, a shrouded eight inch diameter impeller has been found eminently satisfactory for a heater of 100,000 B.t.u. output. A relatively high impeller output pressure has been found particularly desirable for ensuring reliable combustion cycle initiation where hot return water is present in the heat exchange chamber.

It should be noted that the preceding description relates to specific embodiments of the invention only and that many modifications are possible. For example, the specific materials referred to herein are not to be considered as essential, but rather as indicating materials which have been found satisfactory in practice. Also, it should be noted that the apparatus described has been designed primarily for burning gaseous fuels such as natural gas or propane although the principles of the invention are applicable to an apparatus for burning other fuels, for example, fuel oil or coal dust. For this reason, the term "fuel charge" has been used to denote any appropriate combustion medium and is intended to include a gas-air mixture. Of course, where different fuels are used, different expedients would undoubtedly be required for delivering the fuel charge to the combustion chamber. Fuel delivery may be effected in the manner disclosed in my United States patent aforesaid.

With reference to the valve means specifically disclosed in this application, it is to be understood that the number of valves will vary according to the size of the apparatus. Seven valves have been found appropriate to a 100,000 B.t.u. unit, but a larger number would be required for a larger apparatus.

Also, while the preceding description relates specifically to a heater, it is to be noted that the invention is not limited in this regard. For

example, a pulse combustion apparatus of the form provided by the invention could be used as an engine for the recovery of mechanical or electrical energy.

With reference to the exhaust system of the apparatus, it should be noted that the primary exhaust pipe could be omitted in some applications and heat exchange coil(s) connected directly to the combustion chamber (without a manifold). Of course the heat exchange pipes are also exhaust pipes whether or not a primary exhaust pipe (jet pipe) is present.

The primary exhaust pipe and/or the heat exchange coils may be internally coated with lead for corrosion protection and long life. The lead coating may be applied by conventional techniques to a suitable thickness. A small percentage of tin or other material may be included with the lead for improved adhesion.

## Claims

1. A pulse combustion apparatus including a combustion chamber (22, 22', 218), at least one exhaust pipe (110, 110') forming a resonant system with said chamber, means (24, 24') for admitting successive fuel charges to said chamber and ignition means operable to initiate combustion in said chamber; the combustion chamber (22, 22', 218) having an internal cavity (96, 96') which extends about a median plane (98, 98'); the combustion chamber (22, 22', 218) further including an inlet (104) at one of its said ends, through which successive fuel charges can enter said combustion chamber (22, 22', 218) from said fuel charge admitting means (24, 24') in a direction normally to said median plane (98, 98') of the combustion chamber; and at least one exhaust gas outlet (106, 106') disposed in said median plane (98, 98'); an exhaust pipe (110, 110') being coupled to a said exhaust gas outlet (106, 106') and extending from the combustion chamber (22, 22', 218) generally tangentially with respect to said cavity (96, 96'); characterized in that the combustion chamber (22, 22', 218) has an internal cavity (96, 96') which extends about said median plane (98, 98') and which is of a shape which is circular in said plane (98, 98') and curves generally inwardly from both sides of said plane around its entire periphery towards the first (100) and second (102) ends of said cavity (96, 96'), and the exhaust pipe (110, 110') extends in the median plane from the outlet (106, 106') whereby combustion gases returning to said combustion chamber (22, 22', 218) under the effect of a vacuum transient in the chamber (22, 22', 218) at each cycle of the apparatus are caused to flow in a double toroidal flow pattern in said cavity (96, 96') and a subsequent fuel charge enters said flow generally centrally from said combustion chamber inlet (104).

2. An apparatus as claimed in Claim 1, wherein the combustion chamber cavity (96) is



of flattened, generally spherical shape with its maximum diameter disposed in said median plane (98).

3. An apparatus as claimed in Claim 1, wherein said combustion chamber cavity (96') is defined by a wall of said combustion chamber which includes a protuberant surface portion encircling said cavity (96') in said median plane (98') and arranged to positively separate combustion gases returning to said chamber into two discrete toroidal flow paths.

4. An apparatus as claimed in any one of the preceding claims, wherein said exhaust pipe or pipes (110, 110') is or are of a length selected so that, in use, combustion of gases is at least substantially complete before the gases leave said pipe(s) (110, 110').

5. An apparatus as claimed in Claim 4, wherein said exhaust pipe (110, 110') forms a primary pipe of an exhaust system (26, 220) further comprising: a manifold (146) having an inlet (148) to which the primary exhaust pipe (110, 110') is coupled, and a plurality of outlets (152a, b) spaced around the manifold; and a corresponding plurality of heat exchange coils (154) each in the form of a hollow tube shaped to define a helix of substantially constant diameter extending about a longitudinal axis and having an inlet coupled to one of said manifold outlets (152a, b), and an outlet (154a); said coils (154) being arranged around said manifold (146) with their longitudinal axes generally parallel to one another.

6. A pulse combustion apparatus which is a heater comprising: a housing (28, 200), a combustion chamber (22, 22', 218) within the housing (28, 200) having an inlet (104) and an outlet (106, 106'), means (24, 24') for admitting successive fuel charges to said chamber (22, 22', 218) through said inlet (104), ignition means operable to initiate combustion in said chamber (22, 22', 218); a heat exchange chamber (36, 206) in the housing (28, 200) and having an inlet (70, 280) and an outlet (72, 282) for fluid to be heated; and an exhaust system (26, 220) forming a resonant system with the chamber (22, 22', 218), and disposed in the heat exchange chamber (36, 206); characterized in that a primary exhaust pipe (110, 110') having first and second ends is coupled to the combustion chamber (22, 22', 218) at its first end so as to extend generally tangentially from the combustion chamber (22, 22', 218), and is of a length selected so that combustion of gases is at least substantially complete before the gases leave said pipe (110, 110'); a manifold (146) has an inlet (148) to which the second end of the primary exhaust pipe is coupled and a plurality of outlets (152a, b) spaced around the manifold (146); and a corresponding plurality of heat exchange coils (154), each in the form of a hollow tube shaped to define a helix of substantially constant diameter extending about a longitudinal axis and having an inlet coupled to one of said

manifold outlets (152a, b), an outlet (154a), and are arranged around said manifold (146) with their longitudinal axes generally parallel to one another within the heat exchanger (36, 206); and an exhaust chamber (40, 210) in the housing (28, 200) communicates with the outlets (154a) of said heat exchange coils and has an outlet (90, 266) for exhaust gases.

7. An apparatus as claimed in Claim 5 or Claim 6, wherein said heat exchange coils (154) are arranged around said manifold (146) in pairs with the turns of the respective coils in each pair in vertically staggered relationship and interleaved with one another so that the heat exchanger formed by said coils (154) occupies minimum space.

8. An apparatus as claimed in Claim 7 wherein the coils (154) in each pair are formed as respective left and right hand windings (154L, 154R) of identical shape, and wherein the manifold outlets (152a, b) to which the coils (154) are coupled are vertically staggered to provide for said interleaving of the turns of the respective coils (154).

9. An apparatus as claimed in Claim 8 wherein the exhaust system includes first and second series of said coils (154, 154'), the coils in each said series being arranged in an annular configuration with the coils (154') of said second series surrounding the coils (154) of said first series and connected to said manifold (146) by inwardly extended inlet end portions of the relevant coils.

10. An apparatus as claimed in any one of Claims 5—9 wherein each of said primary exhaust pipes (110, 110') and said heat exchange coils (154) is internally coated with lead.

11. A pulse combustion heater comprising a combustion chamber (22, 22', 218) with ignition means associated therewith, at least one exhaust pipe forming a resonant system with the chamber (22, 22', 218) and a housing (200);

characterized in that the housing (200) includes three housing sections (226, 228, 230) of tubular form coupled together in a vertically stacked arrangement and comprising a top housing section (226) defining an air cushion chamber (204), a centre housing section (228) defining a heat exchange chamber (206), and a bottom housing section (230) defining an exhaust chamber (210);

the or each exhaust pipe (110, 110') is disposed in said heat exchange chamber (206) and communicates with the exterior of said housing (200); and

said top and bottom sections (226, 230) are in the form of concrete castings closed at their upper and lower ends respectively, and said center sections (228) forms part of a boiler sub-assembly further comprising top and bottom boiler heads (274, 276) closing opposite ends of said center housing section (228).

12. A heater as claimed in Claim 11, charac-



terized in that each of said housing sections (226, 228, 230) is of hollow cylindrical form, and wherein said top and bottom sections (226, 230) are formed with annular recesses (234, 236) in lower and upper ends thereof respectively, and wherein said center section (228) is of a diameter such that its upper and lower ends fit into said recesses (234, 252) the housing (200) further including clamping means (242, 254) coupling said sections (226, 228, 230) together and arranged to maintain gas-tight sealing between the sections (226, 228, 230).

13. A pulse combustion apparatus comprising:

a housing (28, 200) defining an air cushion chamber (34, 204);

a combustion chamber (22, 22', 218) having an inlet (104) communicating with said air cushion chamber (34, 204), and an outlet (106, 106');

ignition means operable to initiate combustion in said combustion chamber (22, 22', 218); and,

at least one exhaust pipe (110, 110') forming a resonant system with said combustion chamber (22, 22', 218);

characterized in that the apparatus further comprises a unitary gas cushion chamber sub-assembly (288) disposed in said air cushion chamber (34, 204) and including:

a hollow gas cushion chamber (214) coupled to a supply of a combustible gas;

a valve plate (290) extending across and closing said combustion chamber inlet (104);

a plurality of gas inlet tubes (292) extending upwardly from said valve plate (290) and supporting said gas cushion chamber (214) above said plate (290), each said tube (292) communicating at its lower end with a gas inlet opening in said plate (290), and each such opening having associated therewith a plurality of air inlet openings communicating with said air cushion chamber (34, 204);

and a plurality of one-way valves disposed in said combustion chamber inlet (104) and each including one of a corresponding plurality of valve members responsive to pressure in combustion chamber (22, 22', 218) and movable to close the gas and air inlet openings when combustion pressures exist in said chamber (22, 22', 218) and to open said openings during a vacuum transient for admitting fuel.

14. An apparatus as claimed in Claim 13, characterized in that said exhaust pipe (110, 110') forms part of an exhaust system (26, 220) and defines a primary exhaust pipe (110, 110') having first and second ends and coupled to the combustion chamber (22, 22', 218) at its first end so as to extend generally tangentially from the combustion chamber (22, 22', 218), said primary exhaust pipe (110, 110') being of a length selected so that combustion of gases is substantially complete before the gases leave said pipe (110, 110'), and in that the exhaust

system (26, 220) further includes a manifold (146) having an inlet to which the second end of the primary exhaust pipe (110, 110') is coupled, and a plurality of outlets (152a, b) spaced around the manifold (146), and a corresponding plurality of heat exchange coils (154) coupled to said manifold outlets (152a, b).

15. An apparatus as in any one of claims 11—14 further including the features defined in any one of claims 1—10.

## Revendications

1. Appareil à combustion pulsée comprenant une chambre de combustion (22, 22', 218), au moins un tuyau d'échappement (110, 110') formant un système résonnant avec ladite chambre, un moyen (24, 24') pour admettre des charges successives de combustible dans ladite chambre et un moyen d'allumage utilisable pour amorcer la combustion dans ladite chambre; la chambre de combustion (22, 22', 218) ayant une cavité interne (96, 96') qui s'étend autour d'un plan médian (98, 98'); la chambre de combustion (22, 22', 218) comprenant de plus une entrée (104) à l'une desdites extrémités, par où des charges successives de combustible peuvent entrer dans ladite chambre de combustion (22, 22', 218) dudit moyen d'admission de charges de combustible (24, 24') dans une direction perpendiculaire audit plan médian (98, 98') de la chambre de combustion; et au moins une sortie de gaz d'échappement (106, 106') disposée dans ledit plan médian (98, 98'); un tuyau d'échappement (110, 110') étant relié à ladite sortie de gaz d'échappement (106, 106') et s'étendant de la chambre de combustion (22, 22', 218) généralement tangentiellement par rapport à ladite cavité (96, 96'); caractérisé en ce que la chambre de combustion (22, 22', 218) a une cavité interne (96, 96') qui s'étend autour dudit plan médian (98, 98') et qui a une forme qui est circulaire dans ledit plan (98, 98') et se courbe généralement vers l'intérieur à partir des deux côtés dudit plan sur tout son pourtour vers les première (100) et seconde (102) extrémités de ladite cavité (96, 96'), et le tuyau d'échappement (110, 110') s'étend dans le plan médian à partir de la sortie (106, 106') ainsi les gaz de combustion retournant à ladite chambre de combustion (22, 22', 218) sous l'effet d'un vide transitoire dans la chambre (22, 22', 218) à chaque cycle de l'appareil sont forcés à s'écouler en un double motif d'écoulement toroïdal dans ladite cavité (96, 96') et une charge subséquente de combustible entre dans ledit écoulement généralement au centre à partir de ladite entrée de la chambre de combustion (104).

2. Appareil selon la revendication 1, où la cavité de la chambre de combustion (96) est de forme généralement sphérique et aplatie avec son diamètre maximum disposé dans ledit plan médian (98).

3. Appareil selon la revendication 1 où ladite cavité de la chambre de combustion (96') est définie par une paroi de ladite chambre de combustion qui comprend une partie de surface en protubérance entourant ladite cavité (96') dans ledit plan (98') et agencée pour positivement séparer les gaz de combustion retournant à ladite chambre en deux trajets d'écoulement toroïdal distincts.

4. Appareil selon l'une quelconque des revendications précédentes où le tuyau d'échappement ou les tuyaux (110, 110') est ou sont d'une longueur choisie de façon qu'en utilisation, la combustion des gaz soit au moins sensiblement complète avant que les gaz ne quittent ledit ou lesdits tuyaux (110, 110').

5. Appareil selon la revendication 4 où ledit tuyau d'échappement (110, 110') forme un tuyau primaire d'un système d'échappement (26, 220) comprenant de plus: un collecteur (146) ayant une entrée (148) à laquelle est relié le tuyau d'échappement primaire (110, 110') et un certain nombre de sorties (152a, b) espacées autour du collecteur; et un certain nombre correspondant de serpentins d'échange de chaleur (154), chacun ayant la forme d'un tube creux configuré pour définir une hélice d'un diamètre sensiblement constant qui s'étend autour d'un axe longitudinal et ayant une entrée reliée à l'une desdites sorties de collecteur (152a, b), et une sortie (154a); lesdits serpentins (154) étant agencés autour dudit collecteur (146) avec leurs axes longitudinaux généralement parallèles les uns aux autres.

6. Appareil à combustion pulsée qui est un réchauffeur comprenant: un logement (28, 200), une chambre de combustion (22, 22', 218) dans le logement (28, 200) ayant une entrée (104) et une sortie (106, 106'), des moyens (24, 24') pour admettre des charges successives de combustible dans ladite chambre (22, 22', 218) par ladite entrée (104), un moyen d'allumage servant à amorcer la combustion dans ladite chambre (22, 22', 218); une chambre d'échange de chaleur (36, 206) dans le logement (28, 200) et ayant une entrée (70, 280) et une sortie (72, 282) pour le fluide à chauffer; et un système d'échappement (26, 220) formant un système résonnant avec la chambre (22, 22', 218) et disposé dans la chambre d'échange de chaleur (36, 206); caractérisé en ce qu'un tuyau d'échappement primaire (110, 110') ayant des première et seconde extrémités est relié à la chambre de combustion (22, 22', 218) à sa première extrémité afin de s'étendre généralement tangentiellement de la chambre de combustion (22, 22', 218) et sa longueur est choisie de façon que la combustion des gaz soit au moins sensiblement complète avant que les gaz ne quittent ledit tuyau (110, 110'); un collecteur (146) a une entrée (148) à laquelle est reliée la seconde extrémité du tuyau d'échappement primaire et un certain nombre de sorties (152a, b) espacées autour du collecteur (146); et une

quantité correspondante de serpentins d'échange de chaleur (154), chacun ayant la forme d'un tube creux configuré pour définir une hélice d'un diamètre sensiblement constant qui s'étend autour d'un axe longitudinal et ayant une entrée reliée à l'une des sorties de collecteur (152a, b), une sortie (154a) et ils sont agencés autour dudit collecteur (146) avec leurs axes longitudinaux généralement parallèles les uns aux autres dans l'échangeur de chaleur (36, 206); et une chambre d'échappement (40, 210) dans le logement (28, 200) communique avec les sorties (154a) desdits serpentins d'échange de chaleur et a une sortie (90, 266) pour les gaz d'échappement.

7. Appareil selon la revendication 5 ou 6 où les serpentins d'échange de chaleur (154) sont agencés autour dudit collecteur (146) par paires avec les spires de serpentins respectifs de chaque paire en relation verticalement échelonnée et intercalée les unes avec les autres de façon que l'échangeur de chaleur formé par lesdits serpentins (154) occupe un espace minimum.

8. Appareil selon la revendication 7, où les serpentins (154) de chaque paire sont formés sous forme d'enroulements respectifs à gauche et à droite (154L, R) de forme identique, et où les sorties de collecteur (152a, b) auxquelles sont reliés les serpentins (154) sont verticalement échelonnées pour permettre d'intercaler les spires des serpentins respectifs (154).

9. Appareil selon la revendication 8, où le système d'échappement comprend des première et seconde séries de serpentins (154, 154'), les serpentins de chaque série étant agencés en une configuration annulaire avec les serpentins (154') desdites secondes séries entourant les serpentins (154) desdites premières séries et reliés audit collecteur (146) par des parties extrêmes d'entrée des serpentins en rapport qui sont étendues vers l'intérieur.

10. Appareil selon l'une quelconque des revendications 5 à 9, où chacun des tuyaux d'échappement primaire (110, 110') et desdits serpentins d'échange de chaleur (154) est intérieurement enduit de plomb.

11. Réchauffeur à combustion pulsée comprenant une chambre de combustion (22, 22', 218) avec un moyen d'allumage qui lui est associé, au moins un tuyau d'échappement formant un système résonnant avec la chambre (22, 22', 218) et un logement (200);

caractérisé en ce que le logement (200) comprend trois sections de logement (226, 228, 230) de forme tubulaire qui sont reliées ensemble en un agencement verticalement empilé et comprenant une section supérieure de logement (226) définissant une chambre de coussin d'air (204), une section centrale de logement (228) définissant chambre d'échange de chaleur (206) et une section inférieure de logement (230) définissant une chambre d'échappement (210);

le ou chaque tuyau d'échappement (110,



110') est disposé dans ladite chambre d'échange de chaleur (206) et communique avec l'extérieur dudit logement (200); et

sections supérieure et inférieure (226, 230) ont la forme de moulages en béton fermées à leurs extrémités supérieure et inférieure respectivement, et ladite section centrale (228) fait partie d'un sous-ensemble de chaudière comprenant de plus des têtes supérieure et inférieure de chaudière (274, 276) fermant les extrémités opposées de ladite section centrale du logement (228).

12. Réchauffeur selon la revendication 11, caractérisé en ce que chacune desdites sections de logement (226, 228, 230) est de forme cylindrique creuse et où les sections supérieure et inférieure (226, 230) présentent des évidements annulaires (234, 252) à leurs extrémités inférieure et supérieure respectivement, et où ladite section centrale (228) a un diamètre tel que ses extrémités supérieure et inférieure s'adaptent dans lesdits évidements (234, 252), le logement (200) comprenant de plus un moyen de serrage (242, 254) reliant lesdites sections (226, 228, 230).

13. Appareil à combustion pulsée comprenant:

un logement (28, 200) définissant une chambre de coussin d'air (34, 204);

une chambre de combustion (22, 22', 218) ayant une entrée (104) communiquant avec ladite chambre de coussin d'air (34, 204) et une sortie (106, 106');

un moyen d'allumage utilisable pour amorcer la combustion dans ladite chambre de combustion (22, 22', 218); et

au moins un tuyau d'échappement (110, 110') formant un système résonnant avec ladite chambre de combustion (22, 22', 218);

caractérisé en ce que l'appareil comprend de plus un sous-ensemble de chambre de coussin de gaz en une pièce (288) disposé dans ladite chambre de coussin d'air (34, 204) et comprenant;

une chambre creuse de coussin de gaz (214) reliée à une alimentation en gaz combustible;

une plaque de vanne (290) traversant et fermant ladite entrée de la chambre de combustion (104);

un certain nombre de tubes d'entrée de gaz (292) s'étendant vers le haut de ladite plaque de vanne (290) et supportant ladite chambre de coussin de gaz (214) au-dessus de ladite plaque (290), chaque tube (292) communiquant à son extrémité inférieure avec une ouverture d'entrée de gaz dans ladite plaque (290), et à chaque ouverture étant associé un certain nombre d'ouvertures d'entrée d'air communiquant avec ladite chambre de coussin d'air (34, 204); et

un certain nombre de vannes à une voie disposées dans ladite entrée de chambre de combustion (104), chacune comprenant un parmi un certain nombre d'organes correspondant de vanne répondant à la pression dans la chambre de combustion (22, 22', 218) et

mobile pour fermer les ouvertures d'entrée de gaz et d'air lorsque les pressions de combustion existent dans ladite chambre (22, 22', 218) et pour ouvrir lesdites ouvertures pendant un vide transitoire pour admettre du combustible.

14. Appareil selon la revendication 3, caractérisé en ce que ledit tuyau d'échappement (110, 110') fait partie d'un système d'échappement (26, 220) et définit un tuyau d'échappement primaire (110, 110') ayant des première et seconde extrémités et relié à la chambre de combustion (22, 22', 218) à sa première extrémité afin de s'étendre généralement tangentiellement de la chambre de combustion (22, 22', 218) ledit tuyau d'échappement primaire (110, 110') ayant une longueur choisie de façon que la combustion des gaz soit sensiblement complète avant que les gaz ne quittent ledit tuyau (110, 110') et en ce que le système d'échappement (26, 220) comprend de plus un collecteur (146) ayant une entrée à laquelle est reliée la seconde extrémité du tuyau d'échappement primaire (110, 110') et un certain nombre de sorties (152a, b) espacées autour du collecteur (146) et une quantité correspondante de serpentins d'échange de chaleur (154) reliés auxdites sorties de collecteur (152a, b).

15. Appareil selon l'une quelconque des revendications 11 à 14 comprenant de plus les caractéristiques définies dans les revendications 1 à 10.

#### Patentansprüche

1. Impulsverbrennungsvorrichtung mit einer Brennkammer (22, 22', 218), mindestens einem Auslaßrohr (110, 110'), das mit der Brennkammer ein Resonanzsystem bildet, einer Einrichtung (24, 24') für den Einlaß aufeinanderfolgender Brennstoffladungen in die Brennkammer und einer Zündeinrichtung, die zum Einleiten der Verbrennung in der Brennkammer betätigbar ist, wobei die Brennkammer (22, 22', 218) einen Innenraum (96, 96') aufweist, der sich um eine Mittelebene (98, 98') erstreckt, und wobei die Brennkammer (22, 22', 218) ferner einen Einlaß (104) an einem ihrer Enden aufweist, durch den aufeinanderfolgende Brennstoffladungen von der Brennstoffeinlaßeinrichtung (24, 24') in einer zur Mittelebene (98, 98') der Brennkammer normalen Richtung einströmen können, und wobei mindestens ein Abgasauslaß (106, 106') in der Mittelebene (98, 98') angeordnet ist, wobei ein Auslaßrohr (110, 110') mit dem Abgasauslaß (106, 106') verbunden ist und sich von der Brennkammer (22, 22', 218) im allgemeinen tangential zum Innenraum (96, 96') erstreckt, dadurch gekennzeichnet, daß die Brennkammer (22, 22', 218) einen Innenraum (96, 96') aufweist, der sich um die Mittelebene (98, 98') herum erstreckt und der eine Form hat, die in der Ebene (98, 98') kreisrund ist und von



beiden Seiten der Ebene um ihren gesamten Umfang im allgemeinen nach innen zum ersten und zweiten (100, 102) Ende des Innenraums (96, 96') gekrümmt ist, und daß sich das Auslaßrohr (110, 110') in der Mittelebene vom Auslaß (106, 106') erstreckt, wodurch die unter der Wirkung einer Unterdruckschwingung in der Kammer (22, 22', 218) bei jedem Arbeitszyklus der Vorrichtung in die Brennkammer (22, 22', 218) zurückkehrenden verbrannten Gase zu einer doppelt ringförmigen Strömung im Innenraum (96, 96') veranlaßt werden, und daß eine nachfolgende Brennstoffladung im allgemeinen mittig vom Brennkammereinlaß (104) in diese Abgasströmung einströmt.

2. Vorrichtung nach Anspruch 1, wobei der Brennkammerhohlraum (96) im allgemeinen eine abgeplattete Kugelform hat, deren größter Durchmesser in der Mittelebene (98) liegt.

3. Vorrichtung nach Anspruch 1, wobei der Brennkammerhohlraum (96') von einer Wand der Brennkammer begrenzt ist, die einen vorspringenden Oberflächenbereich hat, der den Hohlraum (96') in der Mittelebene (98') umschließt und der so angeordnet ist, daß er die in die Brennkammer zurückkehrenden Abgase zwangsläufig in zwei getrennte ringförmige Strömungsbahnen unterteilt.

4. Vorrichtung nach einem der vorhergehenden Ansprüche, wobei die Länge des oder der Auslaßrohre (110, 110') so gewählt ist, daß die Verbrennung der Gase im Gebrauch zumindest im wesentlichen abgeschlossen ist, bevor die Gase das oder die Rohre (110, 110') verlassen.

5. Vorrichtung nach Anspruch 4, wobei daß das Auslaßrohr (110, 110') ein Primärrohr eines Auslaßsystems (26, 220) bildet, das ferner umfaßt: einen teiler (136), der einen mit dem primären Auslaßrohr (110, 110') gekuppelten Einlaß (148) und zahlreiche Auslässe (152a, b) aufweist, die im Abstand um den Verteiler herum angeordnet sind, und eine entsprechende Anzahl von Wärmeaustauschschlangen (154), die jeweils aus einem hohlen Rohr bestehen, das so geformt ist, daß es eine Schraubenlinie mit im wesentlichen konstantem Durchmesser bildet, die sich um eine Längsachse herum erstreckt, und das einen mit einem der Verteilerauslässe (152a, b) gekuppelten Einlaß und einen Auslaß (154a) aufweist, wobei die Rohrschlangen (154) derart um den Verteiler (146) herum angeordnet sind, daß ihre Längsachsen im wesentlichen parallel zueinander sind.

6. Impulsverbrennungsvorrichtung mit einer Heizeinrichtung, bestehend aus einem Gehäuse (28, 200), einer in dem Gehäuse (28, 200) angeordneten Brennkammer (22, 22', 218), die einen Einlaß (104) und einen Auslaß (106, 106') aufweist, einer Einrichtung (24, 24') zum Einlassen aufeinanderfolgender Brennstoffladungen in die Kammer (22, 22', 218) durch den Einlaß (104), eine Zündeinrichtung, die zum Einleiten der Verbrennung in der Brennkammer

(22, 22', 218) betätigbar ist; eine in dem Gehäuse (28, 200) angeordnete Wärmeaustauschkammer (36, 206), die einen Einlaß (70, 280) und einen Auslaß (72, 282) für eine zu erwärmende Flüssigkeit aufweist; und einem Auslaßsystem (26, 220), das mit der Kammer (22, 22', 218) ein Resonanzsystem bildet und in der Wärmeaustauschkammer (36, 206) angeordnet ist; gekennzeichnet durch ein primäres Auslaßrohr (110, 110'), das ein erstes und zweites Ende aufweist und mit seinem ersten Ende derart mit der Brennkammer (22, 22', 218) gekuppelt ist, daß es sich im allgemeinen tangential von der Brennkammer (22, 22', 218) weg erstreckt, und dessen Länge derart gewählt ist, daß die Verbrennung der Gase zumindest im wesentlichen abgeschlossen ist, bevor die Gase das Auslaßrohr (110, 110') verlassen; einen Verteiler (146), der einen mit dem zweiten Ende des primären Auslaßrohres (110, 110') gekuppelten Einlaß (148) und zahlreiche Auslässe (152a, b) aufweist, die im gegenseitigen Abstand um den Verteiler (146) herum angeordnet sind; und eine entsprechende Anzahl von Wärmeaustauschschlangen (154), die jeweils aus einem hohlen Rohr bestehen, das die Form einer Schraubenlinie mit im wesentlichen konstanten Durchmesser aufweist, die sich um eine Längsachse erstreckt und einen mit einem der Verteilerauslässe (152a, b) gekuppelten Einlaß und einen Auslaß (154a) aufweist, und die um den Verteiler (146) herum angeordnet sind, wobei ihre Längsachsen in dem Wärmeaustauscher (36, 206) im wesentlichen parallel zueinander sind; und eine in dem Gehäuse (28, 200) angeordnete Auslaßkammer (40, 210), die mit den Auslässen (154a) der Wärmeaustauschschlangen in Verbindung steht und einen Auslaß (90, 266) für die Abgase aufweist.

7. Vorrichtung nach Anspruch 5 oder 6, wobei die Wärmeaustauschschlangen (154) paarweise um den Verteiler (146) herum angeordnet sind und wobei die Windungen der beiden Rohrschlangen eines jeden Paares vertikal versetzt sind und einander überlappen, so daß der von den Rohrschlangen (154) gebildete Wärmetauscher einen minimalen Raumbedarf hat.

8. Vorrichtung nach Anspruch 7, wobei die beiden Rohrschlangen (154) eines jeden Paares rechts- und links-gängige Windungen (154L, 154R) von identischer Form haben, und wobei die Verteilerauslässe (152a, b), mit denen die Rohrschlangen (154) gekuppelt sind, vertikal versetzt sind, um die Überlappung der Windungen der entsprechenden Rohrschlangen (154) zu ermöglichen.

9. Vorrichtung nach Anspruch 8, wobei das Auslaßsystem eine erste und zweite Serie von Rohrschlangen (154, 154') umfaßt, wobei die Rohrschlangen in jeder Serie ringförmig angeordnet sind und wobei die Rohrschlangen (154') der zweiten Serie die Rohrschlangen (154) der ersten Serie umgeben und mit dem



Verteiler (146) durch nach innen verlängerte Einlaßbereiche der betreffenden Rohrschlangen verbunden sind.

10. Vorrichtung nach einem der Ansprüche 5, wobei jedes der primären Auslaßrohre (110, 110') und jede der Wärmeaustauschschlangen (154) auf der Innenseite mit Blei beschichtet ist.

11. Impulsverbrennungsheizeinrichtung, bestehend aus einer Brennkammer (22, 22', 218) mit einer zugeordneten Zündeinrichtung, mindestens einem Auslaßrohr, das mit der Brennkammer (22, 22', 218) ein Resonanzsystem bildet, und einem Gehäuse (200), dadurch gekennzeichnet, daß das Gehäuse (200) drei rohrförmige Gehäuseabschnitte (226, 228, 230) umfaßt, die vertikal gestapelt sind und aus einem eine Luftdampfkammer (204) bildenden oberen Gehäuseabschnitt (226), einem eine Wärmeaustauschkammer (206) bildenden mittleren Gehäuseabschnitt (228) und einem eine Austrittskammer (210) bildenden unteren Gehäuseabschnitt (230) bestehen, daß jedes Austrittsrohr (110, 110') in der Wärmeaustauschkammer (206) angeordnet ist und mit dem äußeren des Gehäuses (200) in Verbindung steht, und daß der obere und der untere Gehäuseabschnitt (226, 230) Gußteile aus Beton sind, die am oberen bzw. unteren Ende geschlossen sind, wobei der mittlere Gehäuseabschnitt (228) einen Bestandteil einer Boilerunterbaugruppe bildet, die ferner eine obere und eine untere Boilerplatte (274, 276) aufweist, welche die gegenüberliegenden Enden des mittleren Gehäuseabschnitts (228) abschließen.

12. Heizeinrichtung nach Anspruch 11, dadurch gekennzeichnet, daß jeder Gehäuseabschnitt (226, 228, 230) die Form eines Hohlzylinders hat, und wobei Gehäuseabschnitt (226, 230) am unteren bzw. am oberen Ende mit einer ringförmigen Ausnehmung (234, 252) versehen sind und wobei der mittlere Abschnitt (228) einen solchen Durchmesser aufweist, daß sein oberes und unteres Ende in die Ausnehmungen (234 bzw. 252) eingreift, wobei das Gehäuse (200) ferner Spanneinrichtungen (242, 254) aufweist, um die Gehäuseabschnitte (226, 228, 230) miteinander zu kuppeln und zwischen den Gehäuseabschnitten (226, 228, 230) eine gasdichte Verbindung beizubehalten.

13. Impulsverbrennungsvorrichtung, bestehend aus einem Gehäuse (28, 200), das eine Luftdampfkammer (34, 204) bildet, einer Brennkammer (22, 22', 218), die einen mit der Luftdampfkammer (34, 204) in Verbindung stehenden Einlaß (104) und einen Auslaß (106, 106') aufweist, einer Zündeinrichtung, die zum Einleiten der Verbrennung in der Brennkammer

(22, 22', 218) betätigbar ist, und mindestens ein Auslaßrohr (110, 110') aufweist, das der Brennkammer (22, 22', 218) ein Resonanzsystem bildet, dadurch gekennzeichnet, daß die Vorrichtung ferner eine einstückige Gasdampfkammer-Unterbaugruppe (288) umfaßt, die in der Luftdampfkammer (34, 204) angeordnet ist, bestehend aus einer hohlen Gasdampfkammer (214), die mit einer Brenngaszufuhrleitung gekuppelt ist, einer Ventilplatte (290), die sich über den Brennkammereinlaß (104) erstreckt und diesen verschließt, einer Vielzahl von Gaseinlaßrohren (292), die von der Ventilplatte (290) nach oben ragen und die Gasdampfkammer (214) über der Platte (290) abstützen, wobei jedes Rohr (292) an seinem unteren Ende mit einer Gaseinlaßöffnung in der Platte (290) verbunden ist, und wobei jeder Gaseinlaßöffnung mehrere Lufteinlaßöffnungen zugeordnet sind, die mit der Luftdampfkammer (34, 204) verbunden sind, und aus einer Vielzahl von Rückschlagventilen, die in dem Brennkammereinlaß (104) angeordnet sind und jeweils eines einer Vielzahl von Ventiltteilen aufweisen, die auf den in der Brennkammer (22, 22', 218) herrschenden Druck ansprechen und beweglich sind, um die Gas- und Lufteinlaßöffnungen zu verschließen, wenn in der Brennkammer (22, 22', 218) ein Verbrennungsdruck herrscht, und um diese Öffnungen während einer Unterdruckschwingung für den Einlaß von Brennstoff zu öffnen.

14. Vorrichtung nach Anspruch 13, dadurch gekennzeichnet, daß das Auslaßrohr (110, 110') ein Bestandteil eines Auslaßsystems (26, 220) ist und ein primäres Auslaßrohr (110, 110') bildet, das ein erstes und zweites Ende aufweist und mit seinem ersten Ende mit der Brennkammer (22, 22', 218) derart verbunden ist, daß es sich im allgemeinen tangential von der Brennkammer (22, 22', 218) weg erstreckt, wobei die Länge des primären Auslaßrohres (110, 110') so gewählt ist, daß die Verbrennung der Gase im wesentlichen abgeschlossen ist, bevor die Gase das Auslaßrohr (110, 110') verlassen, und daß das Auslaßsystem (26, 220) ferner einen Verteiler (146) umfaßt, der einen mit dem zweiten Ende des primären Auslaßrohres (110, 110') gekuppelten Einlaß und zahlreiche Auslässe (152a, b) aufweist, die um den Verteiler (146) herum angeordnet sind, und eine entsprechende Anzahl von Wärmeaustauschschlangen (154) umfaßt, die mit den Verteilerauslässen (152a, b) gekuppelt sind.

15. Vorrichtung nach einem der Ansprüche 11 bis 14 ferner umfassend die Merkmale nach einem der Ansprüche 1 bis 10.

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