

June 2, 1942.

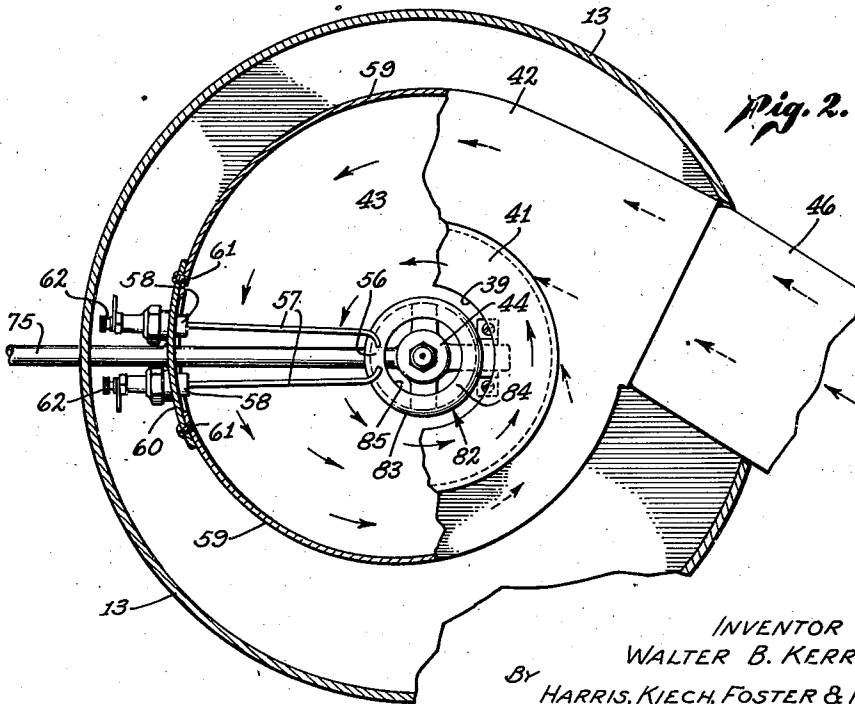
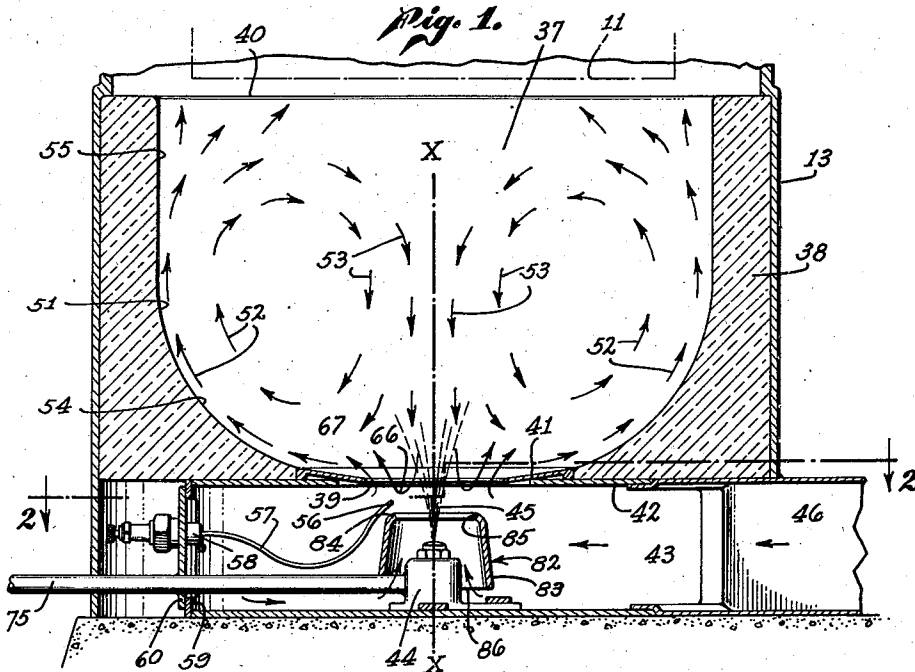
W. B. KERRICK

2,284,906

METHOD AND APPARATUS FOR BURNING FUEL

Filed March 6, 1939

3 Sheets-Sheet 1



INVENTOR
WALTER B. KERRICK
BY HARRIS, KIECH, FOSTER & HARRIS

Lawrence F. Kiech

FOR THE FIRM
ATTORNEYS.

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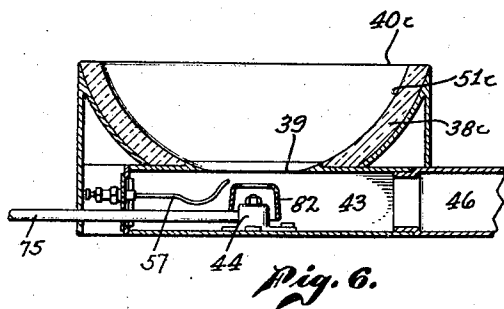
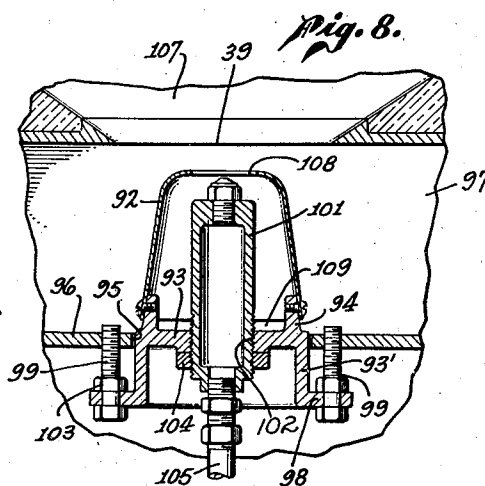
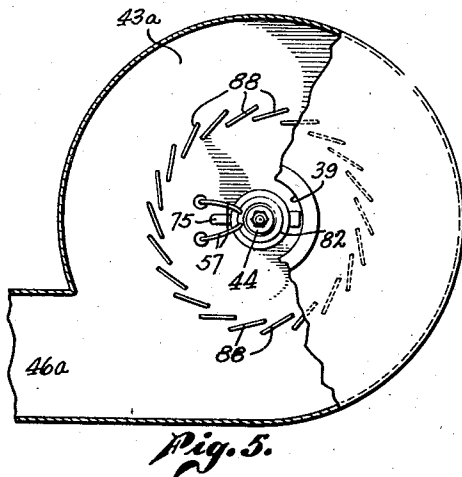
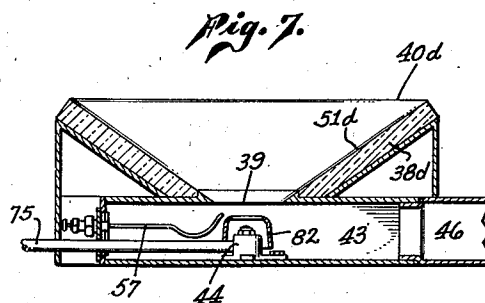
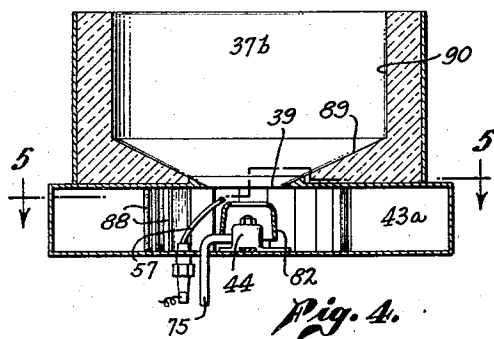
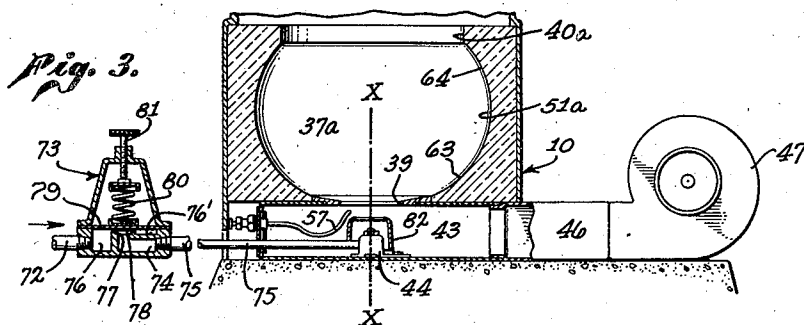
W. B. KERRICK

2,284,906

METHOD AND APPARATUS FOR BURNING FUEL

Filed March 6, 1939

3 Sheets-Sheet 2



INVENTOR

WALTER B. KERRICK

BY
HARRIS, KIECH, FOSTER & HARRIS.

Lawrence F. Kiech

FOR THE FIRM
ATTORNEYS.

June 2, 1942.

W. B. KERRICK

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METHOD AND APPARATUS FOR BURNING FUEL

Filed March 6, 1939

3 Sheets-Sheet 3

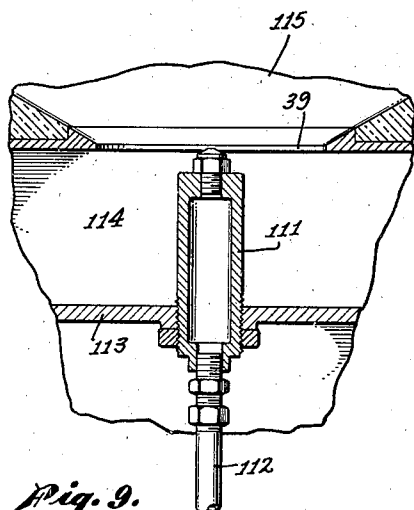


Fig. 9.

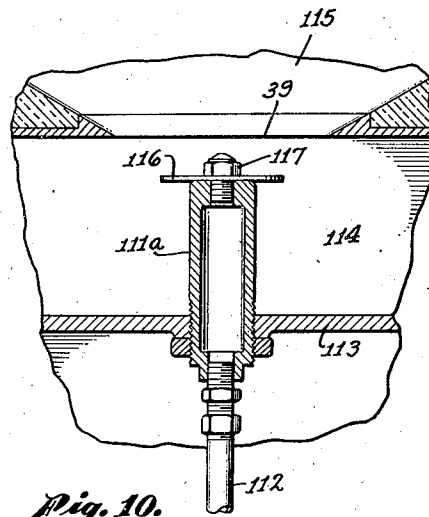


Fig. 10.

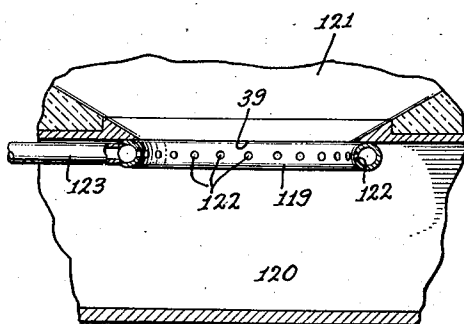


Fig. 11.

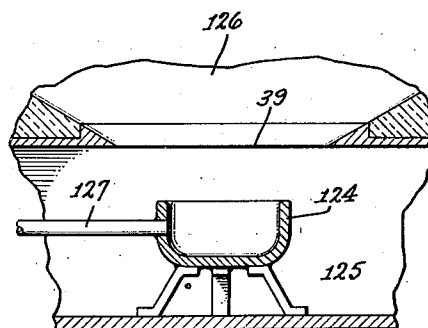


Fig. 12.

INVENTOR
WALTER B. KERRICK
BY HARRIS, KIECH, FOSTER & HARRIS
Ernest F. Kiech
FOR THE FIRM
ATTORNEYS.

UNITED STATES PATENT OFFICE

2,284,906

METHOD AND APPARATUS FOR BURNING FUEL

Walter B. Kerrick, Los Angeles, Calif., assignor
to Clayton Manufacturing Company, Alhambra, Calif., a corporation of California

Application March 6, 1939, Serial No. 259,957

19 Claims. (Cl. 158—4)

This invention relates to a method and apparatus for burning fuel.

This application is a continuation-in-part of my application Serial No. 112,491, filed November 24, 1936.

An important object of the invention is to provide a method and apparatus whereby complete and substantially perfect combustion of fuel (either liquid, gas, or solid) may be obtained, preferably within a relatively small combustion chamber, and a highly effective utilization of the heat so produced may be realized.

Another object of the invention is to provide a compact burner of high efficiency which may be closely associated with a heat-utilizing device, thereby minimizing cost of manufacture and also reducing cost of operation by decreasing loss of heat through radiation or other means.

Another object of the invention is to provide a burner which will operate at high efficiency over a relatively wide range of fuel consumption and heat output.

Another object is to provide a method and apparatus wherein both the fuel and the combustion air are effectively preheated prior to combustion of the fuel; in this connection, it is a particular object to provide for introducing the fuel and combustion air into the combustion space in such manner that they are separately heated and are thereafter brought into intimate contact for combustion.

Another object is to provide a method and apparatus in which heated combustion products are utilized to preheat the supplied fuel and, when liquid fuel or solid fuel containing volatile constituents is used, to volatilize at least a portion thereof prior to combustion, thus promoting the completeness and efficiency of combustion.

A further object is to provide for introduction of fuel into heated gases within a combustion chamber at a position where the gas circulation is of relatively low intensity, whereby the fuel is heated by conduction and radiation before contact with the main body of combustion air. It is a particular object to cause the fuel so introduced to be retained for a relatively long time within a compact combustion chamber so as to cause effective heating and efficient combustion. In this connection, when liquid fuel is used, a further object is to introduce the same, in atomized or finely divided condition, in such manner and in such position as to cause fuel particles of relatively larger size to be retained within the combustion chamber for longer periods of time

than are the smaller particles, thus assuring practically complete and perfect combustion of all the supplied fuel.

Another object is to cause the combustion air to flow in a rapidly moving thin layer adjacent the heated surfaces of the combustion chamber walls, thus preheating the air and preventing the walls from becoming heated to an excessively high temperature.

Another object is to provide for bringing together the preheated fuel and air in a zone of active turbulence to promote rapid and complete combustion.

Another object is to provide for adjustment of certain parts of the burner in relation to other parts in order to control the operation of the burner according to varying conditions.

Other objects will be either pointed out hereinafter or will be apparent from the following description.

The method of burning fuel in accordance with this invention is characterized by the fact that combustion is effected within a rotating, generally annular mass of gas comprising concentric inner and outer peripheral portions whirling about a common axis in a substantially horizontal plane common to the plane of the annulus generally and having opposed components of motion in axial directions respectively toward and away from one side of said annulus, there being a continual movement or flow of gas from the inner to the outer portion adjacent said one side of the annulus, and from the outer to the inner portion at a position axially removed from said side. The foregoing compound motion of the gas may be termed, for want of a more apt expression, a rotating-vortex-ring-like motion in that a substantially annular or ring-like mass of gas is caused to rotate in the combustion space about a vertical axis and this mass of gas has a further motion similar to that of any given particle in the usual toroidal or vortex ring, except that such particle travels in a generally spiral path due to the rotation of the mass about said vertical axis. In other words, the mass of gas may be visualized as a rotating ring of gas in which a given particle of the gas has a further motion in a substantially circular path about the center of any given cross-section of the annular ring so that the outer peripheral portions of the ring have a component of upward movement and the inner peripheral portions have a component of downward movement. Inasmuch as the peripheral portions of the ring move as

described above, while the ring as a whole is rotating, any given particle at the periphery may be considered to travel in a generally spiral path relative to the bounding surfaces of the ring. It will be understood, of course, that the gas making up the annulus is continuously supplemented by additional combustion-supporting air and that the mass of the annulus is continuously depleted by the exit of the products of combustion from the combustion chamber. However, during the operation of the fuel-burning apparatus air introduced into the combustion chamber is caused to produce and maintain the compound rotating-vortex-ring-like motion as described. The above-described compound motion is maintained by introducing combustion supporting air at high whirling velocity into the outer portion of the annulus at said one side thereof, through a circular inlet opening at one end of the combustion space of materially less diameter than the combustion space in which the rotating vortex ring is maintained.

The apparatus includes a wall provided with a circular inlet opening and separating an air inlet chamber at one side thereof from a combustion zone or space at the other side thereof, both said air inlet chamber and said combustion zone or space being of larger diameter than said inlet opening. Means are provided for introducing combustion air through the air inlet chamber and through said inlet opening into the combustion space, with a sufficiently high whirling velocity to maintain in said combustion space a rotating vortex or toroidal ring of the type above-described.

Fuel, either liquid, gas, or solid, is brought into contact with the combustion air and burned, and suitable means are provided for the introduction of the fuel. The fuel may be introduced directly into the combustion air, either prior to or after the air enters the main combustion space. In the preferred embodiment of the invention, however, the fuel is introduced into the inner vortex portion which contains heated products of combustion, and is subsequently brought into contact with the combustion air, as described hereinafter.

The construction and operation of the burner and the advantages thereof will be more fully brought out in connection with the following description of certain illustrative embodiments thereof, in which I will also describe means for igniting the fuel and for controlling the supply of fuel, and other features which are included within the invention.

The accompanying drawings illustrate forms of apparatus in accordance with this invention, and referring thereto:

Fig. 1 is a vertical section of one form of such apparatus;

Fig. 2 is a horizontal section taken substantially on line 2—2 in Fig. 1;

Fig. 3 is a vertical section of an apparatus having a combustion chamber of different shape than that shown in Fig. 1, with a somewhat diagrammatic representation of means for supplying air and fuel and for shutting off the supply of fuel when the supply pressure is reduced;

Fig. 4 is a vertical section of another modified form of apparatus;

Fig. 5 is a horizontal section, taken substantially on line 5—5 of Fig. 4;

Figs. 6 and 7 are vertical sections showing other

modified forms of combustion chamber which may be used;

Fig. 8 is a partial vertical section showing means for adjusting certain parts of the burner; and

Figs. 9, 10, 11, and 12 are partial vertical sections showing further modifications of certain parts of the apparatus.

Referring to Figs. 1 and 2, the burner is shown as including a combustion chamber 37 formed by annular wall means preferably comprising an inner wall or lining 38 of refractory material and an outer metal shell or casing 13, said chamber having a substantially vertical axis, indicated at X—X, and being of circular horizontal cross section, with a restricted centrally disposed inlet opening 39 at its lower end and an outlet opening 40 at its upper end. The inlet opening 39 is bounded by a substantially sharp edge, as shown. The largest internal diameter of chamber 37 is materially greater than the diameter of inlet opening 39, for example, from about three to about five times as great. In this embodiment, the lower portion 54 of the chamber wall surface 51 is shown as inclined outwardly and upwardly away from the opening 39 with an upwardly increasing slope, while the upper portion 55 of the wall surface is shown as extending substantially vertically. Thus, the diameter of the chamber increases first rapidly and then more gradually above said opening, up to a position intermediate the height of the chamber, while the upper portion is of uniform diameter. The outlet opening 40 is shown as having the same diameter as the upper cylindrical portion of the chamber, that is, a diameter equal to the largest internal diameter of the combustion chamber. The chamber may, therefore, be described as having a lower portion 54 of more or less hemispheroidal shape, and an upper cylindrical portion 55.

For best results, inlet opening 39 is substantially circular and concentric with the axis X—X of the combustion chamber. The outlet opening 40 is also shown as being circular and concentric with said axis, but may depart somewhat from circular shape or may be displaced somewhat with relation to the axis.

The inlet opening 39 may be formed in a ring 41 mounted on a wall 42 extending below the refractory wall member 38 and forming the top wall of a volute-shaped air inlet chamber 43 located within the lower portion of the outer casing 13 and below the combustion chamber. This volute air inlet chamber is so arranged that its central portion communicates with the combustion chamber 37 through opening 39, and is provided with a tangential air supply duct 46 through which air may be delivered by any suitable means, such as a fan or blower (as shown in Fig. 3), at high velocity and under the desired pressure, as described more fully hereinafter.

The burner shown in these figures is provided with fuel supply means 44 mounted within the central portion of the air inlet chamber 43 below the opening 39 and preferably on the axis X—X of the combustion chamber. For operation on fluid fuel, the supply means 44 may comprise a nozzle so designed and positioned that, when fluid fuel is supplied thereto under suitable pressure, the fuel will be projected up through the central portion of opening 39 into the combustion chamber, the direction of this upwardly-directed jet of liquid or gaseous fuel coinciding substantially with the axis of the combustion chamber.

Nozzle 44 is provided with a fuel supply pipe 75 extending out through the wall of chamber 43 and through casing 13 and connected to a pump (not shown) or to any other suitable means for supplying fuel under pressure, or to an available source of such fuel under suitable pressure. When the burner is to operate on liquid fuel, the supply nozzle 44 is preferably a pressure atomizing nozzle of a type which will project a spray or jet of atomized or finely divided liquid fuel particles when liquid fuel is supplied thereto at suitable pressure. For use on gaseous fuel, the nozzle may be of any suitable or usual type adapted to deliver a blast or jet of gas through the orifice means thereof. Other forms of fuel supply means may be employed, however, certain examples of which will be referred to hereinafter.

If solid fuel is used, the fuel supply means 44 may comprise a nozzle or conduit through which a blast of air carrying the powdered fuel is blown at suitable velocity in an axial direction through the inlet opening 39 and into the combustion chamber, the amount of air so introduced being preferably only sufficient to carry the fuel in suspension and being only a small portion of the air required for complete combustion of the fuel. The means for thus forcibly introducing the air and the suspended powdered fuel may be of any of the well-known types ordinarily employed for this purpose in powdered fuel burners.

The apparatus may be further provided with a hood or baffle 82 around the nozzle 44, said hood being shown as comprising a tubular wall member 83 preferably of circular cross section and disposed concentrically around and spaced from the nozzle, and preferably extending from a position below, to a position somewhat above, the nozzle orifice. The annular space within said hood is open at both ends to communication with the air inlet chamber outside the hood, as by spacing the lower end of the hood from the bottom wall of chamber 43, as at 86, and providing an opening 85 at the upper end of the hood of sufficient diameter to permit free upward passage of the fuel from the nozzle. The hood is shown as having a slight upward taper and an inwardly-turned lip 84 at its upper end, around the opening 85.

It will be understood that the burner may be employed for heating any desired type of heat-using device, such as a heater for water or other liquid, or a steam generator, retort, oven, or the like, and such a heat-using device may be positioned above, or partly above and partly within, the upper portion of the combustion chamber 37, as indicated, for example, by the dot-dash line at 11 in Fig. 1. It will also be understood that any suitable means, such as a manually or automatically operated valve, may be provided for controlling or regulating the supply of fuel through pipe 75, and that such controlling or regulating means may be adapted for thermostatic control in response to the temperature of the associated heat-using device. Examples of such arrangements are shown and described in my above-mentioned application Serial No. 112,491, but form no part of the invention claimed herein. However, when the burner is to operate on liquid fuel, I prefer to provide means for automatically shutting off the supply of fuel when the pressure in the supply pipe 75 falls below a certain value, as described hereinafter in connection with Fig. 3.

For igniting the fuel, I prefer to provide means for producing an electric spark at a posi-

tion outside the combustion chamber and removed from the direct path of the fuel jet delivered by nozzle 44, but so positioned that, due to the novel operating characteristics of the burner, fuel and air are brought into contact with the spark and are ignited. For this purpose, I have shown a pair of electrodes 57 extending inwardly through insulating bushings 58 mounted on the side wall 59 of chamber 43 and having their inner ends spaced a suitable distance apart to provide a spark gap at 56. Said spark gap is below the opening 39 and outside the path of the generally cone-shaped upwardly-directed jet of fuel issuing from nozzle 44, and is shown positioned between the upper end of hood 82 and said opening 39, and somewhat closer to the axis X-X than the periphery of said opening. The insulating bushings 58 may be carried by a removable arcuate plate 60 adapted to be held in place by screws 61. The electrodes 57 may be provided at their outer ends with binding posts 62 for connection to a high voltage electric circuit to produce a spark at gap 56. Where the conditions of operation of the burning device are such that the burner is completely shut off at frequent intervals, the high voltage current may be continuously or intermittently impressed on the spark gap 56; or, where the conditions of operation of the oil burning device are such that the flame will never be extinguished during a period of use, the electrical ignition may be energized only when the operation of the fuel burning device is started.

Fig. 3 illustrates a burner, generally comparable to that shown in Figs. 1 and 2, provided with means for supplying air to the burner at suitable pressure and velocity, and with means for shutting off the fuel supply completely when the pressure in the fuel supply pipe falls below a certain value. The burner, indicated generally at 10, is provided with a combustion chamber 37a, air inlet chamber 43, fuel nozzle 44, and electrodes 57 for ignition of the fuel. The construction and arrangement of these and other parts of the burner are substantially the same as in Fig. 1, with the exception that the combustion chamber 37a is of a somewhat globular shape and is provided with an outlet opening 40a whose diameter is somewhat less than the largest internal diameter of the chamber. In this case, the lower portion 63 of the chamber wall surface 51a is flared outwardly and upwardly above the inlet opening 39 in a curved manner, comparable to that shown at 54 in Fig. 1, to a point of maximum diameter intermediate the height of the chamber, but the upper portion 64 of such wall surface is curved inwardly from the point of maximum diameter to the outlet opening 40a. Although I have thus shown a modified shape of combustion chamber in Fig. 3, it will be understood that the burner 10 shown in this figure may be provided with a combustion chamber of the shape illustrated in Fig. 1 or in any of the other forms of burner shown herein.

I have shown at 47 a fan or blower, by means of which air may be delivered through duct 46 and into the air inlet chamber 43 with a tangential component of velocity and with sufficient velocity and pressure to maintain the desired compound motion within the combustion chamber, as hereinafter described.

As stated above, the fuel supply pipe 75 leading to the burner nozzle 44 may be connected to any suitable source for supplying fuel under pressure, and under the control of any suitable valve means

for regulating the pressure under which the fuel is supplied. When the burner is intended for operation with liquid fuel and in connection with a variable pressure fuel supply, the nozzle 44 is preferably of the pressure-atomizing type, as stated above, and I prefer to provide means connected to the fuel supply pipe 75 for completely shutting off the flow of fuel when the pressure falls below a certain value. For this purpose, I have shown a pressure-operated shut-off valve device 73 whose outlet 74 is connected to the pipe 75 and whose inlet 76 is connected to a fuel supply pipe 72. Between the inlet 76 and the outlet 74 there is provided a valve orifice 77 adapted to be closed by a valve member 78 supported by a diaphragm 79 whose lower face is presented to the pressure of fuel delivered into the device through the inlet 76, it being noted that the inlet 76 is formed as a chamber which extends completely around the position of the valve member 78 below the diaphragm, and over the outlet passage 74 as indicated at 76'. The outer edge portion of diaphragm 79 is secured to the casing of the valve device 73, and a spring 80 is positioned above the diaphragm in engagement with the upper face thereof, to bias the valve 78 toward closed position with respect to port 77. A screw 81 is provided for adjustment of the spring 80 so that the pressure at which the valve member 78 will be moved to an open position may be varied.

Thus, the shut-off valve device 73 may be adjusted so as to open at any desired fluid pressure, for example, a pressure of about 40 lbs./sq. in., and to close whenever the pressure falls below some value which is sufficient to provide effective atomization at nozzle 44. Under these conditions, no fuel will be delivered to the nozzle 44 until the pressure in supply pipe 72 exceeds the predetermined opening pressure for which the valve is adjusted. When that pressure is attained, the pressure below the diaphragm 79 will open the valve 78 and, as long as the pressure remains above a certain value, the quantity of fuel delivered through the nozzle 44 will increase substantially in proportion to the increase in pressure. If, for any reason, such as by the operation of any associated manually or thermostatically controlled valve or other regulating means, the pressure in the supply pipe 72 falls below a predetermined value, the spring 80 will return the valve 78 to closed position, completely shutting off the supply of fuel to the burner nozzle. It will be seen, therefore, that the pressure of fuel delivered to the small orifice of the nozzle 44 is relatively high at all times when fuel is being delivered from the nozzle so that the fuel atomization is effective at all such times to insure rapid and complete combustion of the fuel in the chamber 37 as a result of the method followed and the means employed in accordance with the present invention.

In the operation of the burner, provided with a combustion chamber of the shape shown in either Fig. 1 or Fig. 3, the air required for combustion is delivered by the fan or blower 47 and enters the air inlet chamber 43 at high velocity and in a substantially tangential direction through duct 46. The air stream entering the chamber 43 has a high energy content consisting of a velocity head and a static pressure head. This air stream is forced to spiral inwardly within chamber 43. Its total energy content remains substantially constant because energy losses due to friction are small. In conformity with the

law of conservation of angular momentum, the velocity head of the air stream increases rapidly, accompanied by a corresponding decrease in static pressure head, as the radial distance of the air stream from the axis X—X decreases.

Under these conditions, the air stream, upon reaching a position below and inwardly of the periphery of the opening 39, is caused to pass through said opening into the combustion chamber 37 (or 37a) instead of continuing its inward spiralling movement within chamber 43. It is observed that the major portion of the air accordingly enters the combustion chamber in the form of an annular stream immediately adjacent the periphery of opening 39. This annular air stream passing through said opening has a high whirling velocity and is of relatively small radial thickness compared to the radius of said opening.

It will be noted that the wall between the air inlet chamber 43 and the combustion chamber 37 is relatively thin adjacent the opening 39, that is to say, the thickness of this wall is materially less than the diameter of the opening, so that the axial length of the passageway between the air inlet chamber and combustion chamber is materially less than the diameter of the passageway. This is the best way known to applicant for producing a high whirling velocity and a relatively low axial velocity with a minimum of frictional losses and therefore minimum power requirements. In this construction, very little whirling velocity is converted into axial velocity so that the whirling velocity is maintained sufficiently high and the axial velocity sufficiently low to produce the rotating vortex ring. No vanes, etc., which give rise to high frictional losses, are required. However, any other mechanical arrangement which will produce and release a whirling stream of air for high whirling and relatively low axial velocity can be employed in accordance with the present invention. When the whirling stream of air is released, the air stream spirals upwardly within the outer portion of the combustion chamber, relatively close to the annular wall surfaces thereof. As the diameter of the combustion chamber increases rapidly above the opening 39, the whirling air stream is caused to spiral outwardly as well as upwardly, producing in the outer portion of the chamber an outer upwardly-moving portion. As the radial distance of the whirling air stream from axis X—X increases, the velocity head decreases and is converted into static pressure head.

Due to the entraining action of the outer portion of the ring, the air in the central portion of the inlet opening 39 and the combustion chamber is also caused to whirl in the same direction about the axis X—X. By reason of the high whirling velocity at which the air enters the combustion chamber and the decrease in whirling velocity of the outer portion as it moves upwardly, there is produced within the combustion chamber a compound vortical motion in which the outer portion moves upwardly along the chamber wall surface 51 (or 51a), as indicated by the arrows at 52, and the inner portion of the vortex ring moves downwardly in the central portion of the chamber toward the opening 39, as indicated by the arrows at 53. Thus, as further indicated by the arrows in Fig. 1; there is superimposed upon the whirling or rotating motion a circulatory motion of air between the outer and inner vortex ring portions, this motion being outwardly in the lower portion of the combustion chamber and at the inlet opening 39 and inwardly

in the upper portion of the combustion chamber. It will, of course, be understood that the arrows in Fig. 1 indicate only the component of motion of the air in the plane of the drawing, which is superimposed upon the whirling motion about the axis of the combustion chamber.

The downward movement of the inner vortex ring portion persists to some extent through and below the central portion of inlet opening 39, as indicated at 66, this portion of the air being then entrained with the ascending outer portion of the vortex ring and returned to the combustion chamber.

Fuel is introduced into the combustion chamber through supply means 44, and is delivered through opening 39, coaxial with the axis X—X, as indicated generally at 45. The cone-shaped fuel jet normally delivered by nozzle 44 does not encompass a sufficiently large angle to penetrate into the outer vortex ring portion issuing through opening 39, nor is this angle normally large enough to include the spark gap 56. However, as the fuel is introduced into the inner vortex ring portion in the combustion chamber, the upwardly-projected fuel will be entrained by the stream spiralling downwardly toward inlet 39, and some of this fuel will be carried across the spark gap 56 as a result of the entraining action of the inner vortex ring portion through said opening, as indicated by the arrow at 66, thus causing the fuel to be ignited by the high voltage electric spark across said gap. I have found that positive ignition always takes place with the electrodes located approximately as shown. When so located, the electrodes do not interfere with the upward flow of fuel from nozzle 44 nor with the flow of air through opening 39, and thus do not disturb the symmetry of the combustion which is desirable to obtain optimum results from the present invention. Furthermore, the location of the electrodes as shown prevents them from becoming over-heated or coated with carbon.

Upon ignition, the combustion chamber becomes more or less filled with the flames of combustion, depending upon the rate of fuel input. The inner surface of the refractory walls 38 becomes heated and radiates heat toward the interior of the combustion space. When the burner is thus operating to produce combustion of fuel, the circulation of the gases (air and/or combustion gases) in the combustion chamber may be described as follows:

In the lower portion of the combustion chamber and adjacent the inlet opening 39, the rate of whirling in the inner vortex ring portion is much lower than the rate of whirling in the outer vortex ring portion so that the gas from the inner portion becomes entrained by the more rapidly flowing gas in the outer portion, in the lower portion of the combustion chamber, in a manner similar to the entraining action of an ejector. The gas, which is thus lost from the inner portion to the outer portion, is replaced by the products of combustion from the outer portion in the upper portion of the combustion chamber where the rate of whirling of the outer portion is materially reduced due to frictional losses and the increased diameter of the combustion chamber. As the inner portion spirals toward inlet opening 39, its rate of whirling increases on account of the frictional drag communicated from the more rapidly whirling outer portion.

Certain particular benefits of the present invention are derived from the following operating

characteristics of the burner. As the fuel is delivered into the combustion chamber, the fuel enters and becomes entrained by the inner portion of the vortex ring which is spiralling toward inlet opening 39 and which consists largely of heated combustion gases. Thus, the fuel is subjected to heating by radiation from the refractory wall surface of the combustion chamber, and also to heating by convection and conduction from the heated combustion gases forming the inner vortex ring portion, for an appreciable time interval, which may be long compared to what might be expected in view of the relatively small dimensions of the combustion chamber and the high velocity of the outer portion of the vortex ring supplying the oxygen required for combustion. When liquid fuel is used, the heating thereof in the inner portion is generally sufficient to vaporize at least a considerable portion thereof before combustion, thus contributing to more perfect and smokeless combustion. Under the combined action of centrifugal force and the entraining action of the gases, the fuel is carried from the inner portion of the vortex ring to the outer portion of the vortex ring in the lower portion of the combustion chamber. The air for combustion is supplied in the outer vortex ring portion which spirals along the surface of the combustion chamber, from inlet opening 39 toward outlet opening 40 (or 40a), as indicated by arrows at 52. During this passage, the air in the outer portion becomes heated, while the walls of the combustion chamber are correspondingly cooled. The whirling velocity of the gas stream in the outer portion is maximum in the plane of opening 39 where the outer portion is of small radial depth, and, as the kinetic energy of the outer portion becomes dissipated through friction at the walls and turbulence resulting from the entrainment of gas from the inner portion, its radial depth increases until the outer portion may fill a substantial part of the upper portion of the chamber adjacent the outlet opening.

As the only exit for gases from the combustion chamber is located at the upper end thereof, it is evident that all the gases which enter the downwardly-whirling inner portion of the vortex ring must become entrained by the outer portion of the vortex ring in order to leave the combustion chamber. In this manner, all the fuel delivered into the inner portion in the combustion chamber, and which becomes entrained by the recirculation in the inner portion, must reach a zone of turbulence in a region indicated generally at 67 where the gases forming the inner portion become entrained by the outer portion. In this zone of turbulence, the fuel, which has already been heated by radiation and convection as indicated above, is brought into intimate contact with the supply of oxygen carried by the outer portion which has also been heated by contact with and radiation from the wall of the chamber. Thus, this zone of turbulence promotes intense, rapid, and complete combustion of the fuel supplied to the combustion chamber. Perfect combustion is assured as none of the fuel can leave the combustion chamber before becoming entrained in the outer portion to which the oxygen required for combustion is supplied. The combustion takes place not only in the outer portion but continues as the gaseous mixture is deflected inwardly and then downwardly in the inner portion.

Due to centrifugal action, unvaporized liquid fuel particles will penetrate appreciably into the

outer portion of the vortex ring and will, therefore, have access to a richer proportion of oxygen. Immediately adjacent the wall 51 (or 51a), the turbulence due to friction between the rapidly spiralling gas stream and the stationary walls is very high, while the frictional drag of the walls causes the adjacent gas film to move at a reduced velocity which will keep the larger fuel droplets for relatively longer time intervals in an active combustion zone.

Some of the heated combustion gases are continuously discharged from the combustion chamber through outlet opening 40 (or 40a), and the heat-using device, positioned for example as indicated generally at 11, is heated by transfer of heat from these hot exit gases, as well as by radiation of heat from the heated walls of the combustion chamber and from the flames therein.

The above-described embodiments of the invention also provide means for causing a continuous flow of relatively cold air from the air stream entering the inlet chamber 43 beneath the lower end of tubular hood 82 and upwardly through the interior of said hood and around nozzle 44, with the result that the temperature of the nozzle is kept at such low value that the oil flowing therein will not carbonize. Likewise, this flow of air prevents settling of carbon particles on the exterior of the nozzle. The flow of gas along the bottom wall of inlet chamber 43 and through the tubular hood 82 encounters a greater frictional resistance to rotation than the main gas flow through the inlet chamber. As a result, the static pressure within the hood 82 is greater than the static pressure opposite opening 85 of the hood so that a continuous stream of relatively cold air is caused to flow across the exterior surface of the nozzle 44 and through the opening 85. This stream of cooling air will also prevent the re-circulation of the inner portion of the vortex ring from extending around the nozzle, which otherwise might cause entrained oil droplets to burn adjacent to the nozzle surfaces and, at the same time, will carry away the heat radiated from the combustion chamber which reaches the nozzle.

The provision of a hood or baffle, such as 82, for causing a portion of the entering air to flow upwardly around and in close proximity to the fuel supply nozzle, is of particular advantage in case the burner is to operate under varying rates of supply of fuel or air, or both. When operating without such a hood or baffle, there is a tendency under some conditions, such as when the rate of fuel supply is reduced to a relatively low value, for the flame to burn at too low a level or to be partially drawn downwardly by the inner portion of the vortex ring so that some of the combustion may take place around or in close proximity to the nozzle, resulting in overheating thereof or deposition of carbon thereon and in a partial loss of efficiency of the burner. For any given set of operating conditions, this may generally be overcome by changing the position of the nozzle or by modifying the design of the burner. I have found, however, that the upward flow of air around the nozzle, caused by the provision of a hood or baffle as above-described, prevents or counteracts this tendency of the flame to burn around the nozzle and enables the burner to operate satisfactorily through a considerable range of burning rates, with a high efficiency of combustion and without difficulty due to overheating of the nozzle or deposition of carbon thereon.

In order that the burner herein-described will operate to bring out the described advantageous combustion of fuel, it is necessary that the combustion air be introduced into the inlet chamber 43 and, thence, through the restricted central inlet opening 39 with a sufficiently high whirling velocity to maintain the above-described rotating-vortex-ring-like gas movement in the combustion chamber. When a whirling gas stream traverses a circular inlet opening into an enlarged combustion chamber, the resulting motion created in the chamber will be either (1) a vortex ring wherein the axial component of an inner portion of the vortex ring is opposed to the axial component of an outer portion of the vortex ring, or (2) a vortex wherein the inner portion thereof has an axial component in the same direction as the outer portion. In a vortex ring of the first type, it is possible to introduce the fuel through the inlet opening directly into the opposed inner portion of the vortex ring and obtain combustion thereof in accordance with the principles of the present invention. On the other hand, if the whirling velocity of the air entering the chamber was not sufficient to maintain such vortical ring motion but was such as to result in a vortical motion of the second type above-mentioned, then the fuel introduced into the inner portion of the vortex ring would be carried upwardly therewith and complete combustion could only be secured by providing a relatively large combustion space, instead of in a small compact combustion space such as is preferably employed in the present invention.

Instead of creating the necessary high whirling velocity of the combustion air by introducing the air tangentially into the volute-shaped air inlet chamber 43, as above-described, other means may be employed for this purpose. For example, in Figs. 4 and 5, I have shown a burner provided with a circular air inlet chamber 43a having a tangential air supply duct 46a. Within this chamber, a plurality of suitably spaced and inclined vanes 88 are arranged in circular fashion, concentrically with respect to, and somewhat outwardly of, the periphery of opening 39 leading into the combustion chamber. Air is supplied to chamber 43a, as by connecting the supply duct 46a to a fan or blower as illustrated at 47 in Fig. 3. The annular space outside vanes 88 serves as an air pressure manifold, and vanes 88 function as nozzles to direct the air inwardly toward opening 39 with a high velocity whirling motion.

The combustion chamber employed in this case may be of the shape illustrated at 37 in Fig. 1 or at 37a in Fig. 3 (or may be of either of the shapes described hereinafter and illustrated in Figs. 6 and 7), but I have shown in Fig. 4 a combustion chamber 37b of somewhat different shape in which the lower portion 89 is of inverted frusto-conical shape and the upper portion 90 is of cylindrical shape. Thus, the diameter increases uniformly from inlet opening 39 upwardly to the juncture of portions 89 and 90, and has a constant maximum value from this point up to the outlet opening at the top of the chamber. The slope of the wall portion 89 is subject to considerable variation, and it is also within the scope of the invention to form this wall portion substantially flat, that is, in a plane perpendicular to the axis of the chamber.

The other parts of the burner, including fuel supply nozzle 44, hood 82, and igniting electrodes 57, are substantially the same as described above

in connection with Figs. 1 to 3, although the fuel supply pipe 75 and the electrodes 57 are shown as extending upwardly through the bottom wall of the air inlet chamber instead of through the side wall thereof. The operation of this form of burner is substantially the same as described above.

Figs. 6 and 7 illustrate two other modified forms of combustion chamber which may be used in which the diameter of the chamber increases, in an upward direction, throughout the entire height of the chamber from the inlet opening 39 to the outlet opening 40c or 40d. In Fig. 6, the refractory wall means 38c is provided with an inner surface 51c, flared outwardly and upwardly in a concave curved fashion from the periphery of inlet opening 39 to the periphery of outlet opening 40c so that the slope of the chamber wall surface increases progressively from the inlet opening to the outlet opening. In Fig. 7, the inner surface 51d of the refractory wall means 38d is flared or inclined upwardly and outwardly, at a constant slope, from inlet opening 39 to outlet opening 40d.

As will be seen from the above-described examples, the shape and dimensions of the combustion chamber are subject to considerable variation. In the forms shown in Figs. 6 and 7, in which the side walls are of relatively small height compared to the diameter, it will be understood that the rotating-vortical-ring-like gas motion and the flames of combustion may extend somewhat above or beyond the upper end of the walls so that the combustion space in which the vortex ring is maintained is only partially enclosed or confined laterally. In case it is not necessary or desired to confine the combustion to a relatively small enclosed chamber, the side walls may be omitted entirely. For example, in Fig. 7, the wall 38d may be substantially flat so that the surface 51d thereof extends outwardly from opening 39 in a substantially horizontal plane, providing a relatively thin wall separating the combustion space above it from the air inlet chamber below it. As in the previously-described forms of apparatus, both the air inlet chamber and the combustion space are of larger diameter than the inlet opening, and the introduction of air at sufficiently high whirling velocity through the air inlet chamber and through the restricted inlet opening will serve to maintain a rotating-vortical-ring-like motion of the type above-described in the combustion space above the wall, and combustion of fuel may be carried out in the same manner.

If desired, I may provide adjusting means for changing the position of the fuel supply nozzle or of the hood surrounding the nozzle, or both the nozzle and hood, relative to the inlet opening of the combustion chamber. For example, as illustrated in Fig. 8, the hood 92, which is generally comparable to the hood 82 shown in Fig. 1, may be mounted on an adjustable supporting base member 93 by means of angularly-spaced lugs 94 projecting upwardly from the base member 93 and secured to the lower edge portion of hood 92. The lower edge of said hood is shown as spaced upwardly from the supporting member 93 so as to admit air into the hood in a manner comparable to that above-described, and member 93 is adjustably disposed within an opening 95 in the bottom wall 96 of the air inlet chamber 97, which may be of either of the types illustrated in Figs. 1 and 4. Base member 93 is provided with a depending cylindrical extension or sleeve 93' and is

adapted to substantially close the opening 95 when said base member is in any position within the desired range of vertical adjustment thereof.

Supporting member 93 is provided with lugs 98 carried by adjusting bolts 99 threadedly engaging the bottom wall 96. The fuel supply nozzle 101 is threadedly mounted at 102 on the supporting member 93 for vertical adjustment relative thereto. Lock nuts 103 and 104 are provided for maintaining the hood and nozzle respectively in any desired position of vertical adjustment.

A fuel supply conduit 105 is connected to nozzle 101 for supplying either liquid or gaseous fuel thereto under suitable pressure. Said nozzle may be of any suitable type adapted to project the supplied fuel upwardly through the inlet opening 39 into the combustion chamber indicated at 107, which may be of any of the types herein-described. The upper end of hood 92 is provided with a central opening 108 of sufficient diameter to permit free upward delivery of fuel from the nozzle and to also permit flow of air therethrough, and the upper end of the hood is spaced from, and preferably somewhat below, the periphery of inlet opening 39 of the combustion chamber.

In operation, the combustion air supplied to inlet chamber 97 is caused to pass principally through the space between the hood and the periphery of the inlet opening, with a high velocity whirling motion through the outer portion of said inlet opening, into the combustion chamber. A portion of the air, however, is forced to pass through the space 109 below the hood, upwardly within the hood, and around nozzle 101 for the purposes mentioned above, and through opening 108.

I have found that the position of the hood and the nozzle relative to the inlet opening of the combustion chamber has an important effect upon the operation of the burner. By lowering the hood and nozzle relative to said inlet opening, the flame within the combustion chamber is caused to spread out very close to the wall of the combustion chamber and to rise through only a relatively small proportion of the height of the combustion chamber before turning inwardly and then downwardly into the inner portion of a vortex ring, while, by raising the hood and nozzle, the flame may be caused to spread to a less extent so that the principal combustion occurs at positions somewhat inwardly from the walls of the combustion chamber and continues upwardly to a higher level in the combustion chamber before turning inwardly and downwardly. By means of the above-described adjustments, therefore, the operation of the burner may be controlled so as to provide the most desirable combustion for the particular type of fuel used, or for adapting the burner to use with any particular type or shape of heat-utilizing device.

In Fig. 9, I have illustrated a construction in which no hood or baffle is provided around the fuel supply nozzle, as in the above-described embodiments. The nozzle 111 provided with fuel supply pipe 112 is shown as mounted on the bottom wall 113 of an air inlet chamber 114 which may be of either of the types illustrated in Figs. 1 and 4. The nozzle is disposed substantially coaxially below inlet opening 39 leading into combustion chamber 115 which may be of any of the types herein-described. The position of the nozzle with respect to the inlet opening 39 may be substantially the same as in any of the other illustrated forms of the in-

vention, although I have in this case shown the upper end of the nozzle and the fuel discharge orifice thereof as located adjacent the horizontal plane of the inlet opening. The nozzle 111 may be provided, as shown, with means for vertically adjusting it, comparable to the means shown in Fig. 8.

The construction shown in Fig. 10 is similar to that in Fig. 9, but the fuel supply nozzle 111a is in this case shown as provided with a deflector or baffle member 116 secured to and projecting outwardly from the upper end of the nozzle, said deflector or baffle member being preferably formed as a thin horizontally disposed disc secured beneath the threadedly-mounted orifice member 117.

Either of the modified arrangements shown in Figs. 9 and 10 may be employed in connection with any of the above-described burner constructions, and the operation of the burner will be substantially as previously described, except for a somewhat modified flow of air from the air inlet chamber into the combustion chamber. In Fig. 9, the major portion of the combustion air will pass through the inlet opening 39 adjacent the periphery thereof with a high velocity whirling motion although, by proper adjustment, a portion of the air may be caused to pass inwardly around the nozzle and then upwardly through the central portion of opening 39. In Fig. 10, the deflector or baffle member 116 serves to confine the upward flow of air substantially entirely to the outer peripheral portion of the inlet opening 39.

While I have illustrated herein certain preferred means for supplying fuel to the burner, it will be understood that various other means may be employed for this purpose. Thus, in Fig. 11, I have shown a ring-shaped tubular fuel supply member 119 disposed immediately below and around the air inlet opening 39 leading from air inlet chamber 120 into combustion chamber 121, which chambers may be of any of the types herein-described. The tubular fuel supply member 119 is provided at its inner face with a plurality of spaced inwardly-directed openings 122 and is connected to a pipe 123 for supplying fuel thereto. This type of fuel supply means is particularly adapted for use with gaseous fuel, and the gaseous fuel so supplied is delivered in the form of inwardly-directed jets through the openings 122 where it is intimately mixed with the rapidly whirling stream of air passing from the air inlet chamber 120 through the inlet opening 39 into the combustion chamber. The fuel is thus brought into contact with the combustion air as it enters the combustion chamber, and combustion is produced and maintained within the combustion chamber in substantially the same manner as above-described.

In Fig. 12, I have illustrated another form of fuel supply means, which is particularly adapted for use with liquid fuel, comprising a circular pan-shaped receptacle 124 disposed centrally below the inlet opening 39 leading from air inlet chamber 125 to combustion chamber 126, which chambers may be of any of the types hereindescribed. Liquid fuel may be supplied to receptacle 124 through fuel supply pipe 127, and the fuel in said receptacle is heated and vaporized, chiefly by radiation, from the flame within the combustion chamber. The vaporized fuel is mixed with the combustion air passing through the opening 39 into the combustion

chamber and is burned therein in substantially the same manner as above-described.

Any suitable means may be provided for igniting the fuel, in connection with fuel supply means such as shown in Fig. 11 or Fig. 12. In Fig. 11, such ignition may be caused, for example, by spark gap means comparable to the spark gap means above-described in connection with Figs. 1 and 2, or by means of a suitable lighting torch. In Fig. 12, the fuel may be ignited by means of a lighting torch and, in the case of relatively heavy liquid fuels which will not readily support combustion at the surface thereof when in a liquid state, the ignition may be facilitated by pouring a small quantity of burning igniting fluid on the surface of the fuel in the receptacle 124 in a manner comparable to that commonly employed in igniting liquid fuel orchard heaters.

I have illustrated a number of different embodiments of the invention, and it will be understood that numerous other modifications may be made therein, within the scope of the invention. The burner has been illustrated and described as having a vertical axis, with the fuel and air introduced at the lower end of the combustion chamber, and with the outlet opening at the upper end of the chamber. This arrangement is desirable for most heating purposes, but it will be understood that the axis of the combustion chamber may be horizontal or at any other desired angle from the vertical, and that, in any of these positions, the restricted inlet opening and the means for supplying fuel and air to the combustion chamber may be located at either end of the chamber, the outlet opening for heated combustion gases being located at the other end.

I claim as my invention:

1. In a method of burning fuel, the steps which comprise: causing gas to rotate in a generally annular mass, said mass comprising concentric inner and outer peripheral portions whirling about a common axis and having opposed components of motion in axial directions respectively toward and away from one end of said annular mass, by introducing air at sufficiently high whirling velocity into a combustion space to produce said rotating motion and cause gas to flow from the inner to the outer portion adjacent said one end and from the outer to the inner portion at a position axially removed from said one end; projecting fuel toward the inner portion from said one end and in a direction substantially coaxial with said common axis and opposed to the axial component of motion of said inner portion, whereby said fuel is entrained and carried along by the whirling gas in the inner portion and is caused to move outwardly into contact with the air in the outer portion; and igniting said fuel to produce combustion of said fuel.

2. In a fuel burning apparatus, the combination which comprises: wall means defining a combustion chamber of substantially circular cross section having a restricted and substantially unobstructed circular inlet opening at one end of materially smaller diameter than the internal diameter of said chamber adjacent said opening and an outlet opening at the other end of larger diameter than the inlet opening, said inlet opening being axially aligned with said combustion chamber and with said outlet opening; means for delivering a whirling annular stream of air into said chamber, through the

outer portion of said inlet opening and concentric therewith, with a sufficiently high velocity of whirling motion about the axis of the chamber to maintain a rotating-vortex-ring-like motion of gas within the chamber and about said axis including an outer portion having a component of motion away from said one end and an inner portion having a component of motion toward said one end; and means for introducing fuel into said chamber.

3. In a fuel burning apparatus, the combination which comprises: wall means defining a combustion chamber of substantially circular cross section having a restricted centrally disposed inlet opening at one end of materially smaller diameter than the internal diameter of said chamber adjacent said opening and an outlet opening at the other end of larger diameter than the inlet opening; an air inlet chamber adjacent said one end of the combustion chamber and communicating therewith through said inlet opening, said air inlet chamber being substantially larger in cross-sectional dimension than the diameter of said inlet opening; means associated with said air inlet chamber for forming a whirling annular stream of air in said air inlet chamber and forcing the same through the outer portion of said inlet opening substantially concentric therewith into the combustion chamber, with a sufficiently high velocity of whirling motion about the axis of the chamber to maintain a body of gas having a rotating-vortex-ring-like motion within the chamber and about said axis including an outer portion having a component of motion away from said one end and an inner portion having a component of motion toward said one end; and means within said air inlet chamber for introducing fuel through said inlet opening into the combustion chamber.

4. In a fuel burning apparatus, the combination which comprises: wall means defining a combustion chamber of substantially circular cross section having a restricted centrally disposed inlet opening at one end of materially smaller diameter than the internal diameter of said chamber adjacent said opening and an outlet opening at the other end of larger diameter than the inlet opening; means for delivering a whirling annular stream of air into said chamber, through the outer portion of said inlet opening, with a sufficiently high velocity of whirling motion about the axis of the chamber to maintain a body of gas having a rotating-vortex-ring-like motion within the chamber and about said axis including an outer portion having a component of motion away from said one end and an inner portion having a component of motion toward said one end; and means for introducing fuel into said chamber through the central portion of said inlet opening and inside the outer portion of said opening through which the whirling vortex-producing air is moving.

5. In a fuel burning apparatus, the combination which comprises: wall means defining a combustion chamber of substantially circular cross section having a restricted centrally disposed inlet opening at one end of materially smaller diameter than the internal diameter of said chamber adjacent said opening and an outlet opening at the other end of larger diameter than the inlet opening; means for delivering a whirling annular stream of air into said chamber, through the outer portion of said inlet opening, with a sufficiently high velocity of whirling

motion about the axis of the chamber to maintain a rotating-vortex-ring-like motion of gas within the chamber and about said axis including an outer portion having a component of motion away from said inlet opening and an inner portion having a component of motion toward said inlet opening; a fuel supply nozzle outside said chamber and so positioned as to deliver fuel into said chamber through the central portion of said inlet opening in a direction substantially along the axis of the chamber; and a hood disposed outside said chamber and surrounding and spaced from said nozzle, said hood being open at both ends to permit flow of air therethrough around said nozzle, and the end of said hood toward the combustion chamber being spaced from the periphery of the inlet opening of the chamber to permit passage therebetween of air supplied by said air-delivering means.

6. In a fuel burning apparatus, the combination which comprises: wall means defining a combustion chamber of substantially circular cross section having a restricted centrally disposed inlet opening at one end of materially smaller diameter than the internal diameter of said chamber adjacent said opening and an outlet opening at the other end of larger diameter than the inlet opening; an air inlet chamber adjacent said one end of the combustion chamber and communicating therewith through said inlet opening; means associated with said air inlet chamber for forming a whirling stream of air in said air inlet chamber and forcing the same through the outer portion of said inlet opening into the combustion chamber, with a sufficiently high velocity of whirling motion about the axis of the chamber to maintain a vortical motion of gas within the chamber and rotary motion of gas about said axis; a fuel supply nozzle located in said air inlet chamber and so positioned as to deliver fuel upwardly into the combustion chamber through a central portion of said inlet opening; and a hood surrounding and spaced from said nozzle, said hood being open at both ends whereby part of the air delivered through the air inlet chamber will pass through said hood and around said nozzle.

7. In a fuel burning apparatus, walls defining a combustion chamber having an outlet opening in one end, means for introducing a stream of air whirling about the axis of said chamber and of materially smaller diameter than said chamber into said chamber adjacent the other end thereof with sufficiently high whirling velocity and low axial velocity to cause said whirling stream of air to abruptly expand radially and produce a low pressure area in said chamber adjacent said air introducing means sufficient to cause said air and gases in said chamber to move in an outer stream portion toward said outlet opening and a substantial portion thereof to move radially inwardly adjacent said outlet opening and return toward said air introducing means in an inner stream portion and again into said outer stream portion, whereby a compound motion is imparted to the air in said chamber, and fuel-supply means outside said chamber at said other end thereof for introducing a stream of fuel into said chamber adjacent said air introducing means and in a direction opposed to the return motion of said inner portion to impinge against the return stream.

8. In a method of burning fuel, the steps which comprise: forming an annular stream of air having high whirling velocity and relatively

low axial velocity; releasing said stream of air into a relatively large space with sufficiently high whirling velocity and sufficiently low axial velocity to produce a rotating vortex ring comprising inner and outer portions whirling about a common axis and having axial components of motion in opposite directions; introducing fuel into contact with the air in said vortex ring from a direction opposed to the axial component of motion of said inner portion; igniting said fuel; and substantially completely burning the same within said vortex ring.

9. In a fuel-burning apparatus, the combination of: walls defining an air inlet chamber and a combustion zone and including a wall separating said air inlet chamber from said combustion zone and having a circular opening of much smaller size than said air inlet chamber, said circular opening providing communication between said air inlet chamber and said combustion zone; means for introducing combustion-supporting air into said air inlet chamber, said air inlet chamber having a curved wall cooperating with said air introducing means for whirling the air therein, said wall being curved so that the whirling air is forced inward to said opening and passes through only the outer zone of said opening into said combustion zone with sufficiently high velocity of whirling motion to establish and maintain in said combustion zone a rotating vortex ring in which the outer portion of said ring has a component of motion away from said wall and the inner portion of said ring has a component of motion toward the center of said opening; and fuel-supply means for introducing fuel into contact with a portion of said rotating vortex ring.

10. In a method of burning fuel, the steps comprising: creating and maintaining a body of combustion-supporting air moving with a rotating-vortex-ring-like motion and with inner and outer portions of the vortex ring whirling in the same direction about a common axis and with the outer whirling portion having an upward component of motion and said inner whirling portion having a downward component of motion; introducing fuel so that at least a portion of said fuel is entrained by the downward whirling portion and is carried into said outer portion of said moving combustion supporting air; and igniting said fuel to produce combustion thereof.

11. In a method of burning fuel, the steps comprising: creating and maintaining a body of combustion-supporting air moving with a rotating-vortex-ring-like motion and with inner and outer portions of the vortex ring whirling in the same direction about a common axis and with the outer whirling portion having an upward component of motion and said inner whirling portion having a downward component of motion; introducing fuel into said moving combustion supporting air in a direction opposed to the downward movement of said inner portion; and igniting said fuel to produce combustion thereof.

12. In a method of burning fuel, the steps comprising: causing combustion-supporting air to rotate in a generally annular mass about a substantially vertical axis with portions of said mass moving upwardly at the outer part of the annulus and with portions of said mass moving downwardly at the inner part of the annulus while said mass is rotating; introducing fuel into said mass of combustion-supporting air; and igniting said fuel to produce combustion thereof.

13. In a method of burning fuel, the steps

comprising: introducing air into a combustion space so as to impart thereto a rotating-vortex-ring-like motion with the inner and outer portions of the vortex ring rotating in the same direction about a common axis and wherein said outer portion has a substantially spiral motion including a component moving in a direction away from one end of said combustion space and said inner portion has a substantially spiral motion including a component of motion toward said end of said combustion space; introducing fuel into said moving air; and igniting said fuel to produce combustion thereof.

14. In a method of burning fuel, the step of introducing combustion-supporting air into one end of a combustion space so as to impart a compound rotating-vortex-ring-like motion to said air upon entry into said combustion space.

15. In a method of burning fuel, the steps comprising: moving combustion-supporting air in a volute path at high velocity; and introducing said moving air into a combustion space so as to impart a rotating-vortex-ring-like motion to said air in said combustion space.

16. In a fuel-burning apparatus, means providing a combustion chamber, said combustion chamber having a circular air-inlet opening at one end thereof, said combustion chamber also having wall portions which slope downwardly and inwardly toward said inlet opening; means for delivering a stream of air through said inlet opening into said combustion chamber so as to cause said air to move with a rotating-vortex-ring-like motion in said combustion chamber; means for introducing fuel into said combustion chamber; and means for igniting said fuel.

17. In a fuel-burning apparatus, means providing a combustion chamber, said combustion chamber having a circular air-inlet opening at one end thereof and an opening for the products of combustion at the opposite end thereof, said combustion chamber also having wall portions which slope downwardly and inwardly toward said inlet opening and terminate in a substantially sharp edge forming the boundary of said inlet opening; means for delivering a stream of air through said inlet opening into said combustion chamber so as to cause said air to move with a rotating-vortex-ring-like motion in said combustion chamber; means for introducing fuel into said combustion chamber through said air inlet opening; and means for igniting said fuel.

18. Fuel-burning apparatus comprising: a casing having a combustion chamber formed therein, said combustion chamber having a circular inlet opening at one end thereof for combustion-supporting air and an outlet opening at the opposite end thereof for the products of combustion, said combustion chamber also having beveled wall portions which slope downwardly and inwardly toward said inlet opening; means for delivering a rotating stream of combustion-supporting air to said inlet opening and at a velocity sufficient to cause the air stream to expand outwardly in the combustion chamber to produce and maintain a substantially annular body of gas rotating about the axis of said inlet opening, said annular body having inner and outer portions whirling in the same direction about said axis, said outer portion having a component of motion away from said inlet opening and said inner portion having a component of motion toward said inlet opening; means positioned substantially coaxially with said inlet opening for introducing fuel into said combustion

tion chamber through said inlet opening; and means for igniting said fuel.

19. Fuel-burning apparatus comprising: means having a combustion chamber formed therein, said combustion chamber having a circular air-inlet opening at the lower end thereof and an opening for the products of combustion at the upper end thereof, said combustion chamber having an inclined bottom wall portion which slopes downwardly and inwardly toward said inlet opening; means for delivering a stream of

5 combustion-supporting air through a volute path to said inlet opening and at a velocity sufficient to cause the air stream to expand outwardly immediately upon moving through said inlet opening to produce and maintain a body of gas having a rotating-vortex-ring-like motion in said combustion chamber; means for introducing fuel into said moving gas through said inlet opening; and means for igniting said fuel.

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WALTER B. KERRICK.

CERTIFICATE OF CORRECTION.

Patent No. 2,284,906.

June 2, 1942.

WALTER B. KERRICK.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, second column, line 28, strike out the word "generally" and insert the same before "axial" in line 29; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 4th day of August, A. D. 1942.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.