Dec. 18, 1951 M. KADENACY 2,579,321

APPARATUS FOR PRODUCING GAS UNDER PRESSURE

Filed April 9, 1948 4 Sheets-Sheet 1

Fig. 1.

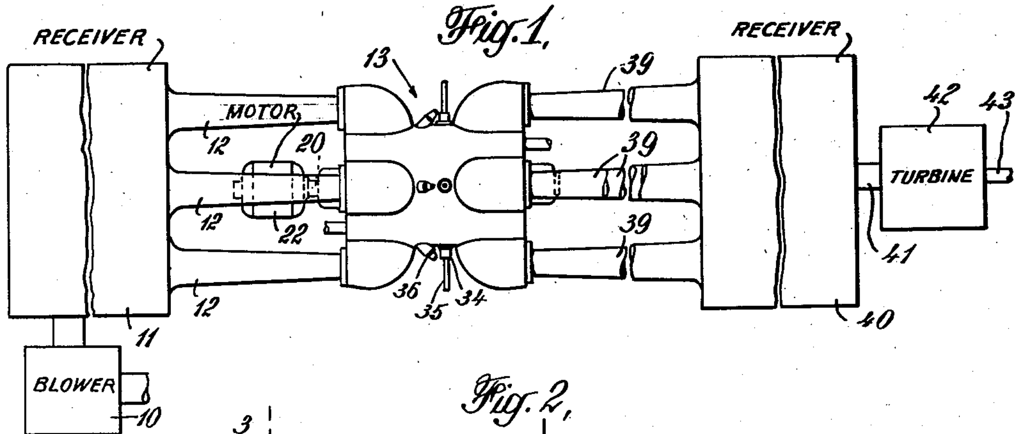
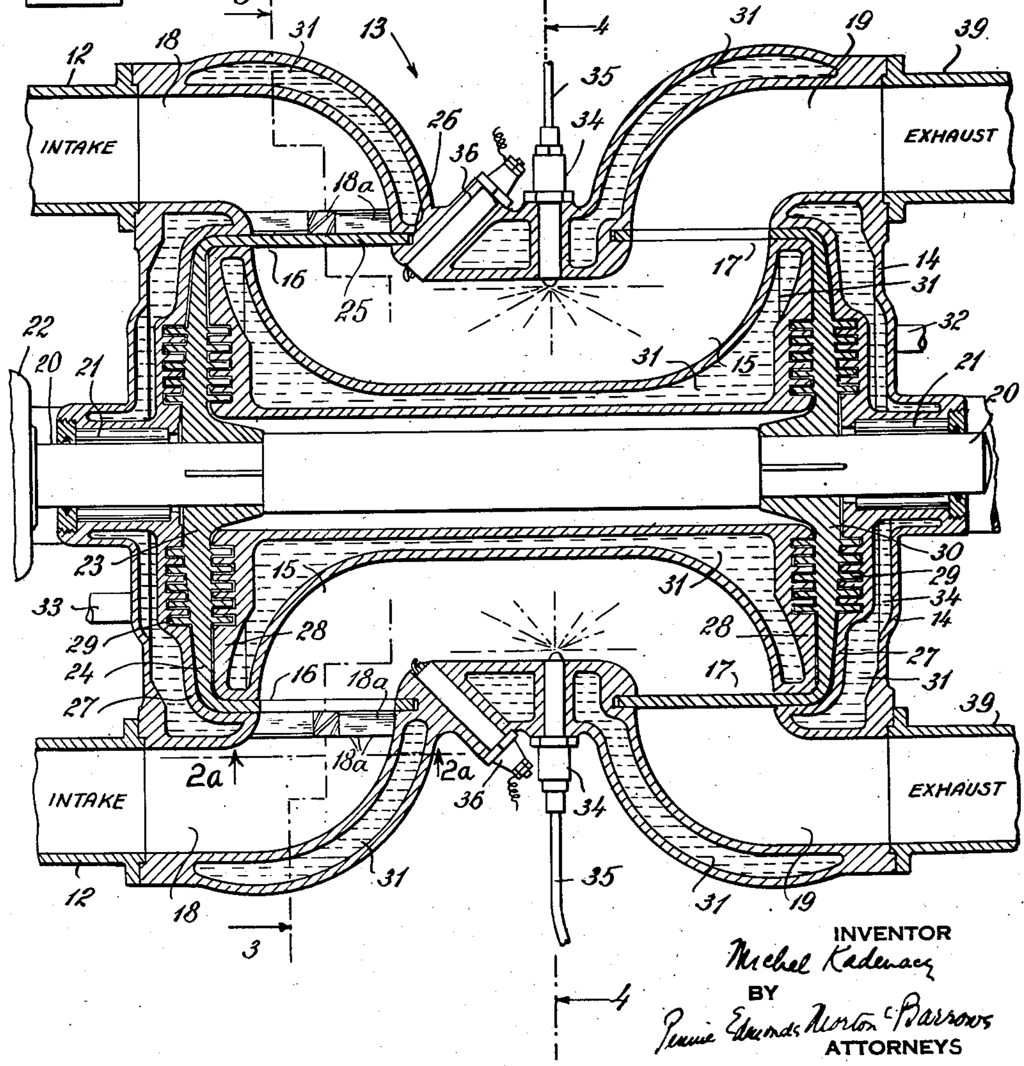


Fig. 2.



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APPARATUS FOR PRODUCING GAS UNDER PRESSURE

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Fig. 3,

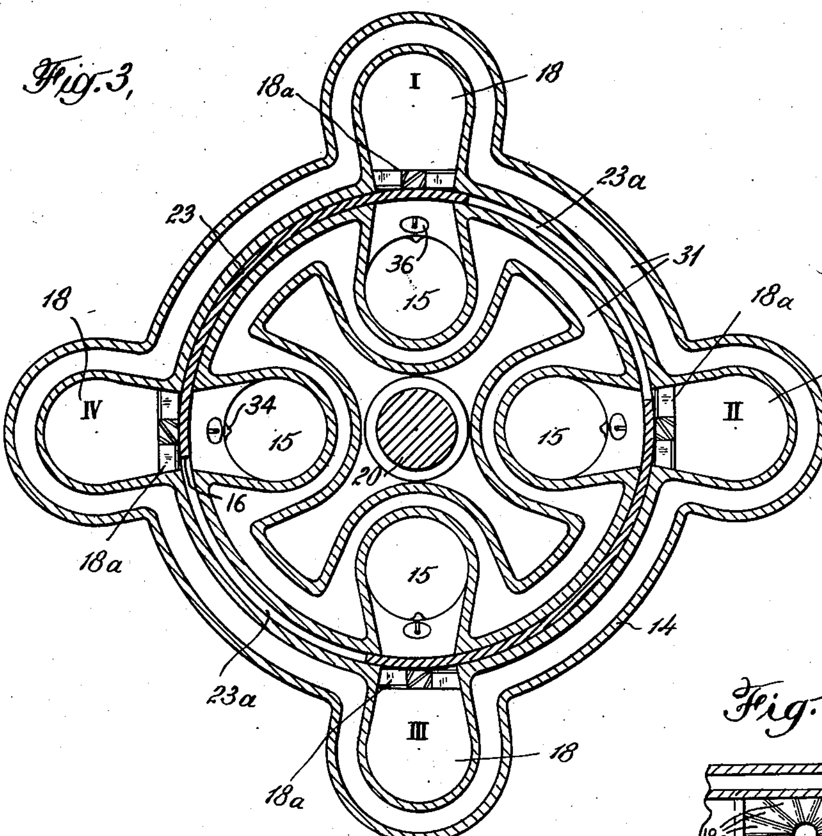


Fig. 2a.

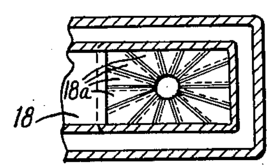
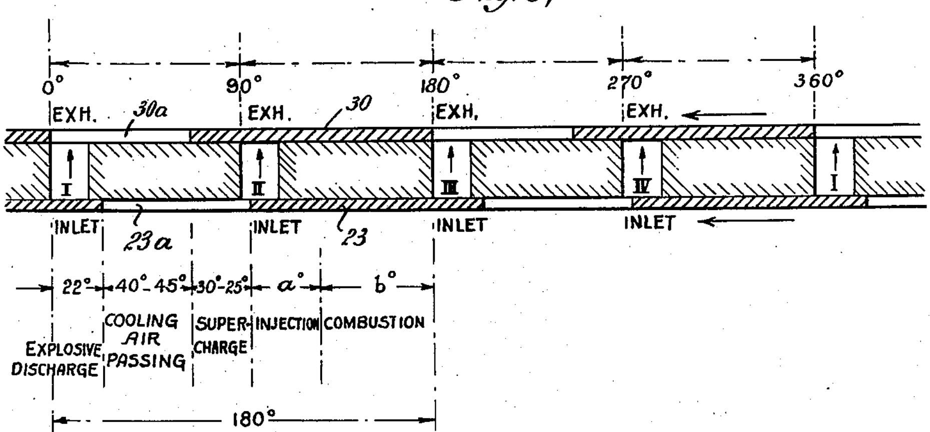


Fig. 5,



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APPARATUS FOR PRODUCING GAS UNDER PRESSURE

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Fig. 4,

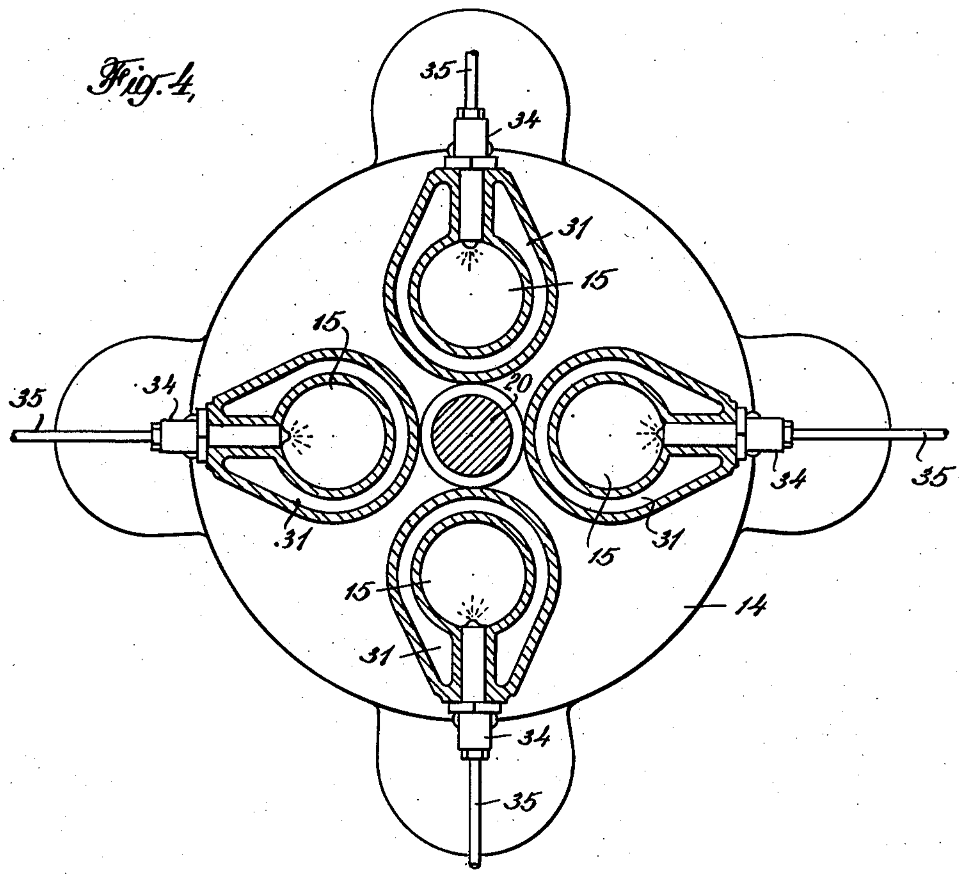
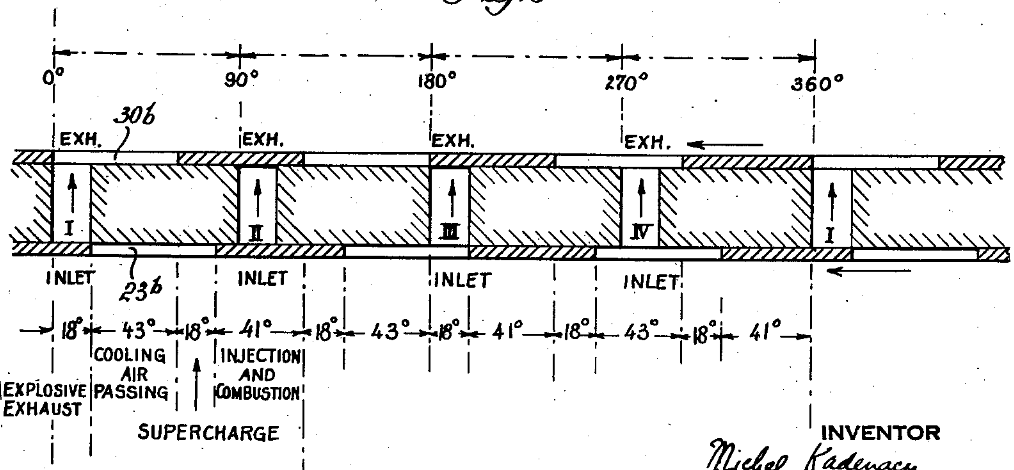


Fig. 6



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APPARATUS FOR PRODUCING GAS UNDER PRESSURE

Filed April 9, 1948 4 Sheets-Sheet 4

Fig. 7.

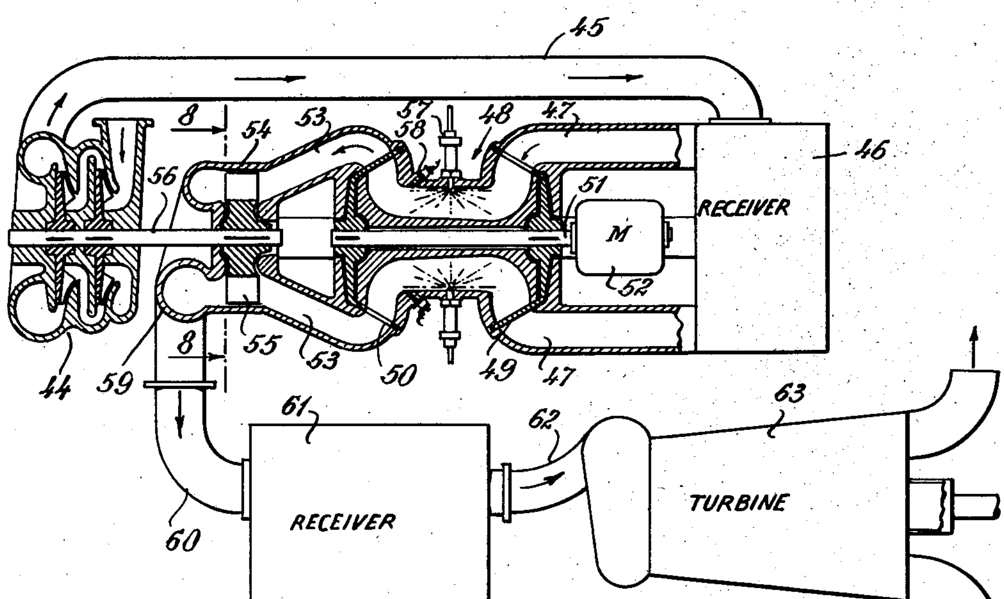


Fig. 8.

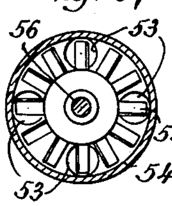


Fig. 9.

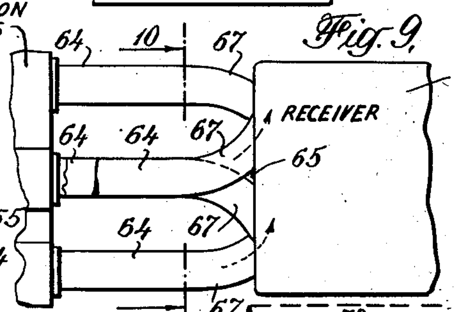


Fig. 10.

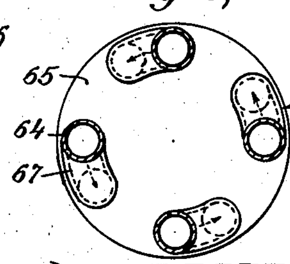
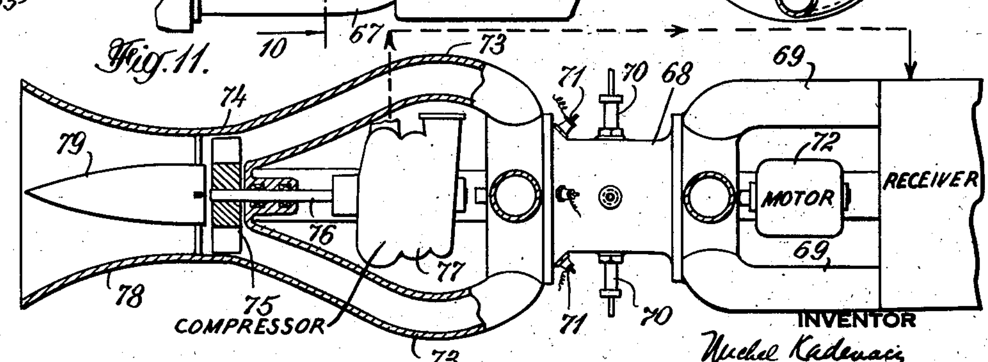


Fig. 11.



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Patented Dec. 18, 1951

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UNITED STATES PATENT OFFICE

2,579,321

APPARATUS FOR PRODUCING GAS UNDER PRESSURE

Michel Kadenacy, Summit, N. J.; Nina K. Guercken executrix of said Michel Kadenacy, deceased

Application April 9, 1948, Serial No. 19,973

13 Claims. (Cl. 60—35.6)

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This invention relates to apparatus of the kind which includes a gas turbine of the constant volume explosive combustion type and is concerned more particularly with a novel apparatus for producing a supply of gases under pressure or moving at high velocity, which may be used for jet propulsion, for the operation of a prime mover, such as a turbine, or for other purposes. The new gas producing apparatus is of simple construction with few moving parts and it can be built and operated at low cost. The apparatus requires little attention in service and may be run for long periods without interruption and at high efficiency.

The apparatus of the invention includes a plurality of elongated combustion chambers arranged in a circular series with their longitudinal axes parallel and each chamber has an inlet orifice and an outlet orifice in its side wall facing outwardly at opposite ends of the chamber. A pair of rotors are mounted at opposite ends of the series of chambers for rotation in unison on the central axis of the series and each rotor has a portion overlying the orifices at the adjacent ends of the chambers and one or more openings in that portion, which register with the orifices in successive chambers along the series, as the rotor rotates. The inlet and exhaust orifices of each chamber are of such size in relation to the transverse cross-sectional area of the chamber as to be suitable for introduction of fresh charges into the chamber and the discharge of burned gases therefrom in accordance with the natural phenomena of implosive inlet and explosive exhaust, respectively. The chambers are supplied with air under pressure and with fuel and the combustible charges are ignited by auto-ignition or by suitable ignition means. The burned gases are discharged from the chambers through exhaust pipes and, in a jet propulsion apparatus, the gases are utilized to operate a turbine driving a compressor supplying air under pressure to the combustion chambers, and are then passed through a common nozzle to the atmosphere. In a power plant, in which the gases are to be employed under pressure, the gases may be used to drive a compressor, if desired, and are stored under pressure in a receiver, which is connected to the inlet of the prime mover.

In the operation of the new apparatus, combustible charges of fuel and air are ignited successively in the chambers along the series, and, when a charge in a chamber is in process of combustion or combustion of such a charge is substantially complete, the exhaust orifice of the

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chamber is opened to such an extent and in so short an interval of time, that the burned gases leave the chamber in accordance with the phenomenon of explosion at ballistic speed as part of an exhaust gas mass. When the movement of the exhaust gas mass is in full progress through the exhaust orifice and away from the chamber, the inlet orifice of the chamber is opened to such an extent and in so short an interval that a fresh gaseous charge enters the chamber in accordance with the phenomenon of implosive inlet. Preferably, both orifices of the chamber are maintained open to permit a substantial quantity of inlet air to pass through the chamber and into the exhaust pipe connected thereto. When a predetermined quantity of air has thus passed through the chamber, the exhaust orifice is quickly closed and the inlet orifice is quickly closed shortly thereafter. As a result of closing the orifices as described, the chamber is supercharged by the ramming effect of the mass of the inlet air against the closed exhaust orifice and the quick closing of the inlet orifice traps the air within the chamber, so that the final pressure within the chamber is greater than the pressure of the inlet air at the source. Fuel is then injected into the chamber to form a combustible mixture, the mixture is ignited, and the cycle is complete. The cycle of operations above described in connection with one chamber is carried on in each chamber along the series with the cycles starting one after another in successive chambers.

For a better understanding of the invention, reference may be had to the accompanying drawings, in which

Fig. 1 is a plan view of a power plant embodying the invention;

Fig. 2 is a longitudinal vertical section through the gas producing apparatus of the plant of Fig. 1;

Fig. 2*a* is a sectional view on the line 2*a*—2*a* of Fig. 2;

Figs. 3 and 4 are sectional views on the lines 3—3 and 4—4 of Fig. 2, respectively;

Figs. 5 and 6 are diagrammatic views showing the operation of the rotors;

Fig. 7 is a view partly in section and partly in side elevation of another form of power plant embodying the invention;

Fig. 8 is a sectional view on the line 8—8 of Fig. 7;

Fig. 9 is a fragmentary elevational view illustrating another means for preventing the return of gases to the combustion chambers;

Fig. 10 is a sectional view on the line 10—10 of Fig. 9; and

Fig. 11 is a view, partly in elevation and partly in longitudinal section, of a jet propulsion apparatus embodying the invention.

The power plant illustrated in Fig. 1 comprises a blower or compressor 10, which supplies compressed air to a receiver 11 connected by pipes 12 to a plurality of combustion chambers of the gas producing apparatus, which is generally designated 13.

The gas producing apparatus illustrated comprises a casing 14 containing walls defining four elongated combustion chambers 15 arranged in a circular series with their longitudinal axes parallel. Each chamber is provided with an inlet orifice 16 and an exhaust orifice 17 at opposite ends thereof, the orifices being formed in the side wall of the chamber and facing outwardly.

The cross-section of each chamber may be generally rectangular or smoothly curved in outline, with a circular cross-section preferred. The cross-section of the chamber should not change abruptly along its length, but the cross-section may decrease toward the exhaust orifice at a rate such that, in the case of a chamber of circular cross-section, the chamber has a conicity of about 1% to 2%. Each orifice may be circular but is preferably generally rectangular and its dimensions are preferably such that its cross-sectional area is approximately equal to or greater than the transverse cross-sectional area of its chamber and its dimension transverse to the chamber is smaller than its dimension lengthwise of the chamber. The casing is formed with inlet passages 18, which are connected to respective air supply pipes 12 and lead to individual inlet orifices 16, and means, such as vanes 18*a*, for causing air to enter the chamber with a swirling movement, may be mounted in each inlet passage adjacent its inlet orifice. The casing is provided with an exhaust passage 19 leading from each exhaust orifice 17.

A shaft 20 extends through the casing with its axis coincident with the central axis of the series of chambers and is supported for rotation in bearings 21 at opposite ends of the casing and is driven by a suitable electric or gas-driven motor 22. At the ends of the chambers having the inlet orifices 16, the shaft carries a rotor 23, which includes a radial portion 24 attached to the shaft and a portion 25 concentric with the shaft and of cylindrical or conical form (see Figs. 2 and 7). The portion of the rotor concentric with the shaft overlies the inlet orifices and extends into a circular recess 26 formed in a wall of the casing. Any suitable means are provided for sealing the rotor to prevent escape of gases along the rotor to the shaft and, for this purpose, the casing may be formed with walls 27, 28 lying close to the inner and outer surfaces of the rotor and the radial portion of the rotor may be provided with concentric ribs 29 entering corresponding grooves in walls 27, 28 to form a labyrinth seal. The portion of the inlet rotor 23, which is concentric with the shaft, is provided with oppositely disposed openings 23*a*, each of which is of approximately the same dimension lengthwise of the chambers as the inlet orifices 16, but is substantially longer circumferentially than the corresponding dimension of the individual orifices.

The shaft 20 carries a second rotor 30 at the ends of the chambers provided with the exhaust orifices and the exhaust rotor 30 is of the same general shape and construction as the inlet rotor 23, except that the openings 30*a* in the exhaust rotor are offset angularly ahead of the corresponding openings in the inlet rotor.

The walls of the chambers and of the inlet and exhaust passages and the end walls of the casing may be cooled by air or by a cooling fluid and, in the construction illustrated, the walls are jacketed to form spaces 31, through which a cooling medium may be circulated. The fluid, which may be water, may be supplied through inlet 32 and withdrawn through outlet 33. A fuel nozzle 34 is mounted in an opening through the walls of each chamber and is connected by a line 35 to a fuel pump of any suitable type. The nozzle atomizes fuel into the chamber, whenever a charge of fuel is supplied thereto by the pump. Each chamber is also provided with ignition means, illustrated as a spark plug 36.

The combustion chambers 15 of the gas producing apparatus are preferably of like cross-sectional area and the exhaust orifices of the chambers are of like size. Also, the cross-sectional area of each exhaust orifice bears such relation to the transverse cross-sectional area of its chamber that it is possible to cause discharge of the burned gases from the chamber as a mass at ballistic speed in accordance with the phenomenon of explosive exhaust. As explained in a number of my prior patents, such as Patent 2,123,569, it is necessary, in order to obtain explosive exhaust of the burned gases from such a combustion chamber, that the exhaust orifice be opened to a critical extent in a critical time interval. The extent, to which the orfice must thus be opened, is at least ¼ and preferably more than ½ of the transverse cross-sectional area of the chamber and the orifice should be opened in an interval of about 1/300 second or less. When such an exhaust orifice is so opened, the total mass of the burning gases begins to react upon the chamber walls and is accelerated in a direction out of the chamber through the exhaust orifice. When the gases have been sufficiently accelerated and have acquired sufficient speed, they cease reacting upon the chamber walls and begin to move out of the chamber in a mass at ballistic speed by virtue of their momentum, leaving a potential void behind in the chamber.

The inlet orifices of the combustion chambers are of like size and the cross-sectional area of each inlet orifice bears such relation to the transverse cross-sectional area of its chamber that it is possible to cause air from the receiver 11 to be introduced into each combustion chamber in a dense mass at ballistic speed in accordance with the phenomenon of implosive inlet. The conditions required to obtain implosive inlet are explained in my Patent 2,281,585 and they involve opening the inlet orifice to a critical extent in a critical time interval. The critical opening of an inlet orifice for implosive inlet is at least ¼ and preferably more than ½ of the transverse cross-sectional area of the chamber and such an orifice should thus be opened in an interval of about 1/300 second or less. The air inlet pipes 12 of the apparatus are of such form, as explained in Patent 2,281,585, as to facilitate supercharging of each chamber, that is, introducing air into the chamber by implosive inlet in such manner, that the pressure of the charge in the chamber is higher than that of the pressure in receiver 11.

Each exhaust passage 19 leading from the combustion chamber is connected by an exhaust pipe 39 to an exhaust gas receiver 40, which is, in turn, connected by a pipe 41 to the inlet of a turbine 42. The shaft 43 of the turbine may be utilized to drive any desired machine.

In the operation of the apparatus illustrated, the cycle of operations in a given combustion chamber may be assumed to start with ignition of a charge of combustible mixture in that chamber. Such ignition may be initiated by the temperature of the air in the chamber at the time the fuel is injected or by ignition means, such as a spark plug. When the charge in the chamber is in process of combustion or combustion is substantially complete, the rotation of exhaust rotor 30 brings one of its openings 30a into registry with the exhaust orifice 17 of the chamber and the orifice is opened within the critical conditions for explosive exhaust. Upon the opening of the orifice, the total mass of the burning gases within the chamber begins to react upon the chamber walls and is accelerated in a direction toward the exhaust orifice. During this period of acceleration of the gases, an acceleration front travels through the inert gases in the exhaust passage 19 leading from the chamber and the exhaust pipe 39 connected to that passage. Ultimately, the gases in the chamber acquire such speed that they cease reacting upon the chamber walls and start to move out of the chamber by virtue of their momentum as part of an exhaust gas mass, which includes the burned gases and the inert gases in the exhaust passage and pipe connected to the chamber, which have been accelerated thereby during the period of acceleration of the burned gases. The leading end of such an exhaust gas mass lies at the point, which has been reached by the acceleration front traveling through the inert gases at the time that the gases cease reacting upon the chamber walls and the period of acceleration thereof terminates.

Each exhaust gas mass produced during explosive exhaust from a combustion chamber travels through the exhaust passage leading from that chamber and the exhaust pipe connected to the passage and to the gas receiver. For best conditions of operation, the cross-sectionl area of the exhaust orifice of a chamber should be substantially the same as the transverse cross-sectional area of the adjacent end of the chamber and the rotor should be so constructed and operated that the orifice will be fully opened at the moment when the burned gases begin to leave the chamber as a mass. The cross-sectional area of the exhaust passage should be substantially the same as that of the exhaust orifice and the cross-sectional area of the exhaust pipe at its end adjacent the exhaust passage should be substantially the same as that of the passage. The cross-sectional area of the pipe may increase slightly, either gradually or in steps, toward its end connected to the receiver. When the exhaust passage and the exhaust pipe are formed, as described, they provide a "free passage" for exhaust gas masses therethrough, in that the outward travel of the exhaust gas masses from the combustion chamber through such a passage is against a minimum resistance of inert gases per unit length of travel of the exhaust gas masses. Also, those masses, while confined in such a free passage against lateral expansion, can travel therethrough with a minimum frictional resistance.

As each exhaust gas mass travels outwardly through an exhaust pipe 39, it displaces inert gases ahead of it and its dynamic energy is converted into potential energy of gas pressure during such action. When all the dynamic energy of an exahust gas mass has been converted into potential energy, a static rebounding pressure front is formed in the inert gases being displaced by the exhaust gas mass and this pressure front immediately explodes, with part of the exploding gases returning toward the exhaust orifice of the combustion chamber. It is important that the gases returning from the static rebounding pressure front be prevented from returning through the exhaust pipe and reentering the chamber through the exhaust orifice and, by properly constructing the exhaust pipe, as above explained, the outward movement of the exhaust gases may be prolonged and the distance between the chamber and the place of formation of the static rebounding pressure front increased. The time interval between the mass exit of the gases from the chamber and the return of the gases from the static rebounding pressure front is then, correspondingly, increased. In some instances, it may be desirable to provide means between the chambers and the exhaust gas receiver for preventing the return of the gases, and one form of such means is illustrated in the power plant shown in Fig. 7.

The power plant illustrated in Fig. 7 includes an air compressor 44, the outlet of which is connected by a pipe 45 to a compressed air receiver 46, from which a plurality of pipes 47 lead to the respective inlet orifices of combustion chambers of a gas producing device, generally designated 48. Each chamber has an exhaust orifice adjacent one end, which is slightly smaller than the inlet orifice of the chamber, and the chambers are of gradually decreasing cross-section toward their exhaust orifices. The inlet and exhaust orifices are controlled by respective rotors 49, 50 mounted on a shaft 51 driven by a motor 52. The rotors have radial portions attached to the shaft 51 and conical portions, which overlie the orifices and have openings registering with the orifices during the rotation of the rotors. An exhaust pipe 53 leads from the exhaust orifice of each chamber to a separate inlet of a casing 54 containing an impulse turbine wheel 55 mounted on the shaft 56 carrying the rotors of compressor 44. The gas producing apparatus comprises four combustion chambers, each of which is provided with a fuel injection nozzle 57 and a spark plug 58. The chambers are arranged in a circular series with their longitudinal axes parallel and the inlets of casing 54 are arranged in a circular series on equal spacings. The casing 54 has an annular outlet 59 connected by a pipe 60 to an exhaust gas receiver 61, from which a pipe 62 leads to the inlet of a multi-stage turbine 63.

The construction of the impulse turbine wheel 55 is such that each exhaust gas mass leaving a chamber of the gas producing apparatus 48 acts on the blades of the wheel and rotates the wheel at high speed. The total cross-sectional area of the spaces between the blades of wheel 55 in line with each inlet of casing 54 is substantially the same as the cross-sectional area of the pipe 53 leading to that inlet, so that there is a free passage for each gas mass through the wheel. The outlet 59 from casing 54 and pipe 60 are so formed as to constitute a prolongation of the free passage.

The impulse turbine wheel is disposed at approximately the leading end of each exhaust gas mass about to travel away from a combustion chamber at the time that the burned gases stop reacting upon the chamber walls and the mass begins to move by virtue of its momentum. The wheel is thus approximately at the point reached by the acceleration front traveling through the inert gases in a pipe 53 at the time that the period of acceleration of the burned gases in a combustion chamber, from which that pipe leads, comes to an end. By placing the turbine wheel at the critical point specified, each exhaust gas mass acts in its entirety on the wheel and the action starts coincidentally with beginning of movement of the mass away from the chamber. Accordingly, each exhaust gas mass acts on the wheel with maximum dynamic energy and the wheel is rotated at high speed. As each exhaust gas mass travels through the wheel, the casing outlet 59, and pipe 60 and a static rebounding pressure front is formed in either pipe 60 or the exhaust gas receiver 61, the gases returning from the static rebounding pressure front upon the explosion thereof are unable to pass through the wheel and re-enter the chambers.

In the modified construction shown in Figs. 9 and 10, the exhaust pipes 64 lead from combustion chambers (not shown) to inlets in an end wall 65 of an exhaust gas receiver 66. The inlets are disposed in a circular series in the end wall and are offset angularly from the main lengths of the exhaust pipes 64 leading thereto. Each exhaust pipe has a curved end portion 67 connected to its inlet and the curved portions extend in the same direction from their respective pipes to the inlets, so that, each exhaust gas mass enters the receiver in a tangential direction and thus rotates within the receiver. Successive exhaust gas masses entering the receiver maintain the rotating gas mass and the gases, which return from the static rebounding pressure front, upon the explosion of the latter, are unable to pass through the rotating gas mass and enter an exhaust pipe. The receiver is preferably so disposed that the inlets in its end wall 65 lie at approximately the leading end of each exhaust gas mass at the time the burned gases forming part of that mass cease reacting upon the walls of a chamber and the mass begins to move out of and away from the chamber because of its momentum. As a result, each exhaust gas mass begins its rotational movement within the receiver at the time that the mass has maximum momentum, and the rotating body of gas within the receiver, accordingly, has maximum rotational speed.

The jet propulsion apparatus illustrated in Fig. 11 includes a gas producing apparatus 68 having a plurality of combustion chambers, to which air is supplied under pressure through inlet pipes 69. The fuel is injected into the chambers through nozzles 70 and the combustible charges are ignited by spark plugs 71. The inlet and exhaust rotors controlling the orifices of the chambers are rotated by a motor 72. The exhaust pipes 73 leading from the individual chambers deliver the exhaust gases to respective inlets in a casing 74 containing an impulse turbine wheel 75, the shaft 76 of which is connected to the rotor of a compressor 77 delivering air under pressure to a receiver (not shown), from which the inlet pipes 69 lead. The gases issuing from casing 74 are discharged through a common nozzle 78, which contains a cone deflector 79.

The gas producing apparatus employed in the construction shown in Fig. 11 is built and operated in accordance with the principles above set forth and the impulse turbine wheel 75 is preferably disposed at such a distance from the combustion chambers that it lies at the location of the leading end of each exhaust gas mass about

to travel away from a chamber at the time that the burned gases forming part of that mass stop reacting upon the chamber walls. The wheel is thus maintained in high speed rotation and prevents the return of gases which have passed through it. The gases issuing from the wheel are discharged through the common nozzle 78 to the atmosphere.

The operation of one form of the gas producing apparatus of the convention is illustrated in the diagram, Fig. 5. The apparatus is one which includes four combustion chambers and rotors having two openings. In such an apparatus, there are two cycles of operation in each chamber for each revolution of the rotor, so that each cycle is carried out in a period of time corresponding to 180° of rotor movement. The diagram shows that the exhaust opening 30*a* of exhaust rotor 30 has just opened the exhaust orifice of combustion chamber I and explosive discharge of the contents of the chamber is occurring. In such explosive discharge, the burned gases issue from the combustion chamber as a mass, leaving a potential void behind them adjacent the inlet port. In the apparatus, to which the diagram, Fig. 5, applies, the volume of the individual combustion chambers and the speed of rotation of the rotors are such that the exhaust orifice is opened, the acceleration of the burned gases within the chamber is completed, and the mass movement of gases starts within a period corresponding to 22° of rotor travel.

At the time that the mass movement of the exhaust gases from the chamber starts, or shortly thereafter, the opening 23*a* of the inlet rotor 23 moves into registry with the inlet orifice of chamber I at such speed that air under pressure from receiver 11 enters the chamber in accordance with the phenomenon of implosive inlet. The exhaust opening 30*a* is of such length as to overlap the inlet opening 23*a*, so that for a period corresponding, for example, to 40° to 45° of rotor movement, both the inlet and the exhaust orifice of chamber I are open and air is passing through the chamber and into the exhaust passage and exhaust pipe leading therefrom. When a predetermined amount of cooling air has passed determined amount of cooling air has passed through the chamber, the exhaust orifice is quickly closed by rotor 30, while the inlet orifice continues open. The sudden closing of the exhaust orifice produces a ramming effect of the inlet air within the chamber, so that the pressure of the air therein exceeds the pressure of the air at its source. The inlet orifice is then closed before the supercharged air within the chamber can escape through the inlet orifice. This supercharging of the chamber is in accordance with the method disclosed in my Patent 2,281,585. The operations of explosive exhaust, the passage of air through the chamber, and the supercharging of the chamber occur in a period of time corresponding to about 92° of rotor travel and, in the remaining period of the cycle corresponding to about 88° of rotor travel, the fuel is injected and ignited and the combustion occurs.

As shown in Fig. 5, the cycles of operation in chambers I and III of the apparatus are in phase and the cycles in chamber II and IV are also in phase but half a cycle behind the cycles in chambers I and III. This arrangement is desirable for use in the power plant shown in Fig. 7, in that exhaust gas masses issuing simultaneously from chambers I and III strike the blades of the impulse turbine wheel 55 at diametrically opposite points, so that the action is balanced. Similarly, the exhaust gas masses issuing from chambers II and IV strike diametrically disposed blades of the wheel.

Apparatus of the type described, in which there are two cycles of operation in each chamber during one rotation of the rotors, is preferred for operation with low inlet air pressure and low rotor speed, since there may be a relatively long overlap of the inlet and exhaust orifice rotor openings and, therefore, more time for the passage of air through each combustion chamber. The air thus passed through a chamber cools the chamber and also reduces the temperature of the exhaust gas within the exhaust gas receiver. Such a reduction of the temperature of the compressed gases in that receiver is necessary, since the exhaust gases at the temperature, at which they leave the combustion chambers, are too hot for passage through the turbines **42** or **63** without doing damage thereto. The introduction of air through each chamber into the receiver reduces the temperature of the gases stored under pressure within the receiver, but the potential energy of the stored gases remains substantially the same in each unit of time, because of the added weight of air introduced into the receiver within that unit of time.

The total quantity of air passing through a chamber, when both the inlet and exhaust orifices are open, depends on the length of the rotor openings, the pressure of the inlet receiver air, and the speed of rotation of the rotors. By forming the chambers with the orifices in their side walls, it is possible to use rotors of the construction described for controlling those orifices, and numerous advantages are thereby afforded, as follows. The dimension of an orifice in a direction lengthwise of its chamber may be substantially longer than the diameter of the chamber, so that, although the orifice has a cross-sectional area equal to the transverse cross-sectional area of the chamber, the dimension of the orifice in a direction transverse to the chamber or circumferentially of the rotors is less than the diameter of the chamber. As a result, less angular movement of a rotor is required to open the orifice and the orifice may be opened within the critical conditions for explosive exhaust or implosive inlet without the necessity of driving the rotor at an excessive peripheral speed. The minimum speed, at which the rotors may be driven, is that necessary to open the orifices within about 1/300 of a second or less, and the maximum speed, at which the rotors may be driven, is that at which it is possible to pass a sufficient amount of air through each chamber after each explosive exhaust therefrom to effect the reduction in temperature of the exhaust gases necessary to protect the turbine. It will be apparent that the maximum rotor speed depends on the pressure of the inlet air, since with a higher inlet pressure, a larger amount of air may be passed through a chamber in a given interval.

The formation of the chambers with the orifices in their side walls and facing outwardly has a further advantage in that the orifices can be opened by openings in the cylindrical or conical portions of the rotors. With such a rotor construction, ample room is available between the rotor openings and the rotor shaft for the provision of sealing means to prevent escape of gases from the chambers toward the shaft. Also, the opening and closing of the orifices by the rotation of the rotors is at a maximum rate for a given centrifugal force applied to the rotors. With the rotor openings formed in the cylindrical or conical portions of the rotors, space is available for large size openings.

The diagram, Fig. 6, illustrates the sequence of operations in another form of the new apparatus. In the modified apparatus, there are four combustion chambers and each rotor has three openings, so that each cycle of operations within a chamber occurs within a period corresponding to 120° of rotor travel. The diagram, Fig. 6, shows an exhaust opening **30b** in registry with the exhaust orifice of combustion chamber I and explosive exhaust of the burned gases from the chamber occurring. In the apparatus, to which the diagram, Fig. 6, applies, the volume of the individual combustion chambers and the speed of rotation of the rotors are such that each explosive exhaust occurs during a period corresponding to 18° of rotor travel and, at the end of that period, the burned gases have stopped reacting on the chamber walls adjacent the inlet orifice and are leaving the chamber as a mass with a potential void behind them. At the end of the period, an opening **23b** of the inlet rotor moves into registry with the inlet orifice of chamber I, so rapidly that implosive inlet of fresh air into the chamber occurs. At this time, the exhaust opening **30b** is still in registry with the exhaust orifice and, for a period corresponding, for example, to 43° of rotor travel, both orifices are open, so that fresh air may pass through the chamber and into the exhaust pipe. At the end of the 43° period, the exhaust orifice begins to close while the inlet orifice remains open and, after a period corresponding to 18° of rotor travel, the exhaust orifice is fully closed and the inlet orifice begins to close, so that air is trapped in the chamber at a pressure in excess of the supply pressure. During the next period corresponding to 41° of rotor travel, fuel is injected into the chamber to form a combustible mixture, which is ignited and burned, and the exhaust orifice is opened by the registration of an opening **30b** in the exhaust rotor with the orifice.

While the cycle of operations above described is taking place in combustion chamber I, corresponding cycles are occurring in chambers II, III and IV, but those cycles are out of phase with the cycle in chamber I. Thus, at the time that explosive exhaust from chamber I is occurring, as illustrated, injection and combustion are occurring in chamber II, supercharge is occurring in chamber III, and both orifices of chamber IV are open, so that air is passing through the chamber. In the apparatus illustrated in Fig. 6, three cycles of operation occur in each chamber per rotation of the rotor, so that twelve volumes of burned gases are produced from the apparatus per rotation of the rotors. An apparatus operating in accordance with Fig. 6 is suitable for operation with inlet air at a higher pressure than the apparatus, the operation of which is represented by Fig. 5, because, with a given rotor speed, the time available for a cycle of operation of the Fig. 6 apparatus is less than that available for a cycle in the Fig. 5 apparatus. Accordingly, in order to pass the necessary quantity of air through the chambers in the Fig. 6 apparatus, the pressure of the air supplied is increased. The pressure and the temperature within each chamber during the injection period are correspondingly increased and this increases the speed of combustion of the fuel.

In the apparatus illustrated, air is supplied under pressure to the combustion chambers to produce a high output, but the chambers may be supplied with atmospheric air, if desired. Implosive inlet does not depend on the use of air under pressure but is obtained whenever gas from a source at one pressure is discharged therefrom into a space at a lower pressure through an orifice of critical dimensions opened within a critical time limit, as explained in my Patent 2,281,585. When the chambers are operated with explosive exhaust, the mass movement of the burned gases from each chamber leaves behind a potential void, which is thus a space in which the gas pressure is lower than atmospheric. By employing an inlet orifice of the critical size and opening such an orifice within the critical time interval, it is, accordingly, possible to obtain implosive inlet into the chamber with the air supply at atmospheric pressure. When the air supplied is under a pressure and implosive inlet is utilized, the phenomenon is the same but the level of pressure throughout the entire system is raised by an amount corresponding to the increased pressure of the source and the output is correspondingly increased. By introducing air into the chamber in accordance with implosive inlet, it is readily possible in practice, as explained in Patent 2,281,585, to supercharge each chamber to an absolute pressure of 1.5 or more times the absolute pressure of the source.

In the apparatus illustrated, a combustible mixture is produced in each chamber by injection of the fuel into the charge of air within the chamber but, if desired, it is possible to supply of a fuel-air mixture, such as carbureted air or a mixture of air and pulverized solid fuel. The production of the combustible charges in the chambers by fuel injection is preferred, however, since it permits the passage of fresh air through each chamber after the combustion of each charge therein. If the fuel is introduced with the air rather than by injection, a quantity of fuel-air mixture should be passed through each chamber, after combustion of each charge, to cool the chamber and lower the temperature of the exhaust gases, and the fuel in the mixture thus passed through the chamber is wasted.

When the burned gases produced by the combustion of a charge in a chamber of the apparatus are discharged by explosive exhaust, the chamber is self-cleaning, since the burned gases leave the chamber as a mass. The air admitted by implosive inlet is not utilized, as in ordinary two-stroke cycle internal combustion engines, to scavenge the chamber and discharge residual burned gases therefrom, since no such scavenging is necessary. A portion of the air admitted during implosive inlet is used, as described, to cool the chamber and lower the temperature of the exhaust gases, while the remainder provides the air content of the next charge in the chamber.

In the new apparatus, the speed of rotation of the rotors controls the amount of gas delivered per unit of time and thus controls the power output. Since the speed of rotation of the rotors may be varied within the limits above explained, the apparatus is highly flexible in operation. As the speed of rotation of the rotors is increased, the inlet air pressure may be increased to increase the speed of combustion and to insure that the desired quantity of air will pass through each chamber after combustion of each charge therein. It is undesirable to rotate the rotors at too high a speed because of the centrifugal force, to which they are subjected, but a gas producing apparatus containing four chambers can be built to produce a high output and the output of such an apparatus can be readily increased by increasing the number or size of the combustion chambers, while maintaining the peripheral speed of the rotors within acceptable limits.

The gas producing apparatus, made up of one or more elongated chambers, each having an inlet orifice and an outlet orifice at opposite ends in its side wall, and a pair of rotors for controlling the orifices, may be operated in accordance with the disclosure of my Patent 2,281,585 as a means for producing gas at a pressure higher than that of the gas supplied thereto, even though there is no combustion within the chambers. For this purpose, the gas under super-atmospheric pressure is admitted to each chamber in accordance with the conditions for implosive inlet and the gas is trapped in the chamber at a pressure of 1.5 or more times the pressure of the supply. The supercharged contents of the chamber are then discharged in accordance with the conditions for explosive exhaust and with the succeeding charge introduced by implosive inlet, as soon as the gases within the chamber stop reacting upon the chamber walls and begin to issue from the chamber as a mass, leaving a potential void behind.

The gas producing apparatus, in the constructions illustrated, includes four chambers, but it may be constructed with one chamber or more, as desired. The number of openings in the rotors may also be varied, so long as the apparatus operates as described.

I claim:

1. An apparatus for producing gases under pressure, which comprises the combination of an elongated chamber of substantially uniform cross-section from end to end and having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the exhaust orifice having such an area in relation to the cross-sectional area of the chamber as to be suitable for explosive exhaust operation, a pair of rotors mounted at opposite ends of the chamber for rotation on a common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifice, each rotor having at least one opening in said section registrable with the adjacent orifice and of an axial dimension substantially equal to the axial dimension of said adjacent orifice and a circumferential dimension substantially greater than that of said orifice, the openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust end of the chamber leading, means for rotating the rotors in unison and at such a speed that the exhaust orifice is opened within the critical conditions for explosive exhaust, and means for introducing fuel into the chamber.

2. An apparatus for producing gases under pressure, which comprises the combination of an elongated chamber of substantially uniform cross-section from end to end and having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the orifices being of such area in relation to the cross-sectional area of the chamber as to be suitable for implosive inlet and explosive exhaust operation, respectively, a pair of rotors mounted at opposite ends of the chamber for rotation on a common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifice, each rotor having at least one opening in said section registrable with the adjacent

orifice and of an axial dimension substantially equal to the axial dimension of said adjacent orifice and a circumferential dimension substantially greater than that of said orifice, the openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust end of the chamber leading, means for rotating the rotors in unison and at such a speed that the inlet and exhaust orifices are opened within the critical conditions for implosive inlet and explosive exhaust, respectively, and means for introducing fuel into the chamber.

3. An apparatus for producing gases under pressure, which comprises the combination of an elongated chamber of substantially uniform cross-section from end to end and having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the orifices being of such area in relation to the cross-sectional area of the chamber as to be suitable for implosive inlet and explosive exhaust operation, respectively, a pair of rotors mounted at opposite ends of the chamber for rotation on a common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifice, each rotor having at least one opening in said section registrable with the adjacent orifice and of an axial dimension substantially equal to the axial dimension of said adjacent orifice and a circumferential dimension substantially greater than that of said orifice, the openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust end of the chamber leading, means for rotating the rotors in unison and at such a speed that the inlet and exhaust orifices are opened within the critical conditions for implosive inlet and explosive exhaust, respectively, and means for supplying air under pressure to the chamber through the inlet orifice.

4. An apparatus for producing gases under pressure, which comprises the combination of an elongated chamber of substantially uniform cross-section from end to end and having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the orifices being of such area in relation to the cross-sectional area of the chamber as to be suitable for implosive inlet and explosive exhaust operation, respectively, a pair of rotors mounted at opposite ends of the chamber for rotation on a common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifice, each rotor having at least one opening in said section registrable with the adjacent orifice and of an axial dimension substantially equal to the axial dimension of said adjacent orifice and a circumferential dimension substantially greater than that of said orifice, the openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust end of the chamber leading, means for rotating the rotors in unison and at such a speed that the inlet and exhaust orifices are opened within the critical conditions for implosive inlet and explosive exhaust, respectively, means for introducing fuel into the chamber, an exhaust conduit leading from the exhaust orifice and so formed as to provide a free passage for exhaust gas masses traveling therethrough, and means for supplying air under pressure to the chamber through the inlet orifice, the circumferential dimensions of the rotor openings and the speed of the rotors being such that, following explosive exhaust of each exhaust gas mass from the chamber, a portion of air entering the chamber by implosive inlet passes through the chamber and into the conduit and is prevented from returning into the chamber by the closing of the exhaust orifice.

5. An apparatus for producing gases under pressure, which comprises the combination of an elongated chamber of substantially uniform cross-section from end to end and having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the exhaust orifice having such an area in relation to the cross-sectional area of the chamber as to be suitable for explosive exhaust operation, a pair of rotors mounted at opposite ends of the chamber for rotation on a common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifice, each rotor having at least one opening in said section registrable with the adjacent orifice and of an axial dimension substantially equal to the axial dimension of said adjacent orifice and a circumferential dimension substantially greater than that of said orifice, the openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust end of the chamber leading, means for rotating the rotors in unison and at such a speed that the exhaust orifice is opened within the critical conditions for explosive exhaust, means for supplying air under pressure to the chamber through the inlet orifice, and means for introducing fuel into the chamber.

6. An apparatus for producing gases under pressure, which comprises the combination of an elongated chamber of substantially uniform cross-section from end to end and having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the exhaust orifice having such an area in relation to the cross-sectional area of the chamber as to be suitable for explosive exhaust operation, a pair of rotors mounted at opposite ends of the chamber for rotation on a common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifice, each rotor having at least one opening in said section registrable with the adjacent orifice and of an axial dimension substantially equal to the axial dimension of said adjacent orifice and a circumferential dimension substantially greater than that of said orifice, the openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust end of the chamber leading, means for rotating the rotors in unison and at such a speed that the exhaust orifice is opened within the critical conditions for explosive exhaust, means for supplying air under pressure to the chamber through the inlet orifice, means for introducing fuel into the chamber, and an exhaust conduit leading from the exhaust orifice and so formed as to provide a free passage for exhaust gas masses traveling therethrough, the circumferential dimensions of the rotor openings and the speed of the rotors being such that, following explosive exhaust of each exhaust gas mass from the chamber, a portion of air entering the chamber passes through the chamber and into the conduit and is prevented from returning into the chamber by the closing of the exhaust orifice.

7. An apparatus for producing gases under pressure, which comprises the combination of a plurality of like elongated combustion chambers of substantially uniform cross-section from end to end and disposed with their axes parallel, the

chambers lying symmetrically with respect to a common axis and each having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the inlet orifices being alike and lying at one end of the group of chambers and the exhaust orifices being alike and lying at the other end of the group of chambers, each exhaust orifice having such an area in relation to the cross-sectional area of its chamber as to be suitable for explosive exhaust operation, a pair of rotors mounted at opposite ends of the group of chambers for rotation on said common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifices and each rotor having at least one opening in said peripheral section registrable with the adjacent orifices and of an axial dimension substantially equal to that of said adjacent orifices and a circumferential dimension substantially greater than that of said adjacent orifices, the circumferential length of said opening in each rotor being shorter than the distance between like orifices in adjacent chambers, corresponding openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust ends of the chambers leading, means for rotating the rotors in unison and at such a speed that the exhaust orifices of the chambers are opened within the critical conditions for explosive exhaust, and means for introducing fuel into the chambers.

8. An apparatus for producing gases under pressure, which comprises the combination of a plurality of like elongated combustion chambers of substantially uniform cross-section from end to end and disposed with their axes parallel, the chambers lying symmetrically with respect to a common axis and each having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the inlet orifices being alike and lying at one end of the group of chambers and the exhaust orifices being alike and lying at the other end of the group of chambers, each exhaust orifice having such an area in relation to the cross-sectional area of its chamber as to be suitable for explosive exhaust operation, a pair of rotors mounted at opposite ends of the group of chambers for rotation on said common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifices and each rotor having at least one opening in said peripheral section registrable with the adjacent orifices and of an axial dimension substantially equal to that of said adjacent orifices and a circumferential dimension substantially greater than that of said adjacent orifices, the circumferential length of said opening in each rotor being shorter than the distance between like orifices in adjacent chambers, corresponding openings in the rotors being angularly offset but overlapping with the opening in the rotor at the exhaust ends of the chambers leading, means for rotating the rotors in unison and at such a speed that the exhaust orifices of the chambers are opened within the critical conditions for explosive exhaust, means for supplying air under pressure to the several chambers through their inlet orifices, and means for introducing fuel into the several chambers.

9. An apparatus for producing gases under pressure, which comprises the combination of a plurality of like elongated combustion chambers of substantially uniform cross-section from end to end and disposed with their axes parallel, the chambers lying symmetrically with respect to a common axis and each having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the inlet orifices being alike and lying at one end of the group of chambers and the exhaust orifices being alike and lying at the other end of the group of chambers, each exhaust orifice having such an area in relation to the cross-sectional area of its chamber as to be suitable for explosive exhaust operation, a pair of rotors mounted at opposite ends of the group of chambers for rotation on said common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifices and each rotor having at least one opening in said peripheral section registrable with the adjacent orifiices and of an axial dimension substantially equal to that of said adjacent orifices and a circumferential dimension substantially greater than that of said adjacent orifices, the circumferential length of said opening in each rotor being shorter than the distance between like orifices in adjacent chambers, corresponding openings in the rotors being angularly offset but overlapping, with the opening in the rotor at the exhaust ends of the chambers leading, means for rotating the rotors in unison and at such a speed that the exhaust orifices of the successive chambers are opened within the critical conditions for explosive exhaust, means for supplying air under pressure to the several chambers through their inlet orifices, means for introducing fuel into the several chambers, and a separate exhaust gas conduit leading from the exhaust orifice of each chamber and so formed as to provide a free passage for exhaust gas masses traveling therethrough, the circumferential dimensions of the rotor openings and the rotor speed being such that, following explosive exhaust of each exhaust gas mass from a chamber, a portion of air entering the chamber through its inlet orifice passes through the chamber into the exhaust conduit and is prevented from returning into the chamber by closing of the exhaust orifice of said chamber.

10. An apparatus for producing gases under pressure, which comprises the combination of a plurality of like elongated combustion chambers of substantially uniform cross-section from end to end and disposed with their axes parallel, the chambers lying symmetrically with respect to a common axis and each having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the inlet orifices being alike and lying at one end of the group of chambers and the exhaust orifices being alike and lying at the other end of the group of chambers, each inlet orifice and each exhaust orifice having such an area in relation to the cross-sectional area of its chamber as to be suitable for implosive inlet and explosive exhaust operation, respectively, a pair of rotors mounted at opposite ends of the group of chambers for rotation on said common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifices and each rotor having at least one opening in said peripheral section registrable with the adjacent orifices and of an axial dimension substantially equal to that of the adjacent orifices and a circumferential dimension substantially greater than that of said orifices, the circumferential length of the opening in each rotor being shorter than the distance between like orifices in adjacent chambers, corresponding openings in the rotors being offset but overlapping with the opening in the rotor at the exhaust ends

of the chambers leading, means for rotating the rotors in unison and at such a speed that the inlet and exhaust orifices of the chambers are opened within the critical conditions for implosive inlet and explosive exhaust, respectively, and means for supplying the chambers with air under pressure through their inlet orifices.

11. An apparatus for producing gases under pressure, which comprises the combination of a plurality of like elongated combustion chambers of substantially uniform cross-section from end to end and disposed with their axes parallel, the chambers lying symmetrically with respect to a common axis and each having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the inlet orifices being alike and lying at one end of the group of chambers and the exhaust orifices being alike and lying at the other end of the group of chambers, each inlet orifice and each exhaust orifice having such an area in relation to the cross-sectional area of its chamber as to be suitable for implosive inlet and explosive exhaust operation, respectively, a pair of rotors mounted at opposite ends of the group of chambers for rotation on said common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifices and each rotor having at least one opening in said peripheral section registrable with the adjacent orifices and of an axial dimension substantially equal to that of the adjacent orifices and a circumferential dimension substantially greater than that of said orifices, the circumferential length of the opening in each rotor being shorter than the distance between like orifices in adjacent chambers, corresponding openings in the rotors being offset but overlapping with the opening in the rotor at the exhaust ends of the chambers leading, means for rotating the rotors in unison and at such a speed that the inlet and exhaust orifices of the chambers are opened within the critical conditions for implosive inlet and explosive exhaust, respectively, and means for introducing fuel into the chambers in succession.

12. An apparatus for producing gases under pressure, which comprises the combination of a plurality of like elongated combustion chambers of substantially uniform cross-section from end to end and disposed with their axes parallel, the chambers lying symmetrically with respect to a common axis and each having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the inlet orifices being alike and lying at one end of the group of chambers and the exhaust orifices being alike and lying at the other end of the group of chambers, each inlet orifice and each exhaust orifice having such an area in relation to the cross-sectional area of its chamber as to be suitable for implosive inlet and explosive exhaust operation, respectively, a pair of rotors mounted at opposite ends of the group of chambers for rotation on said common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifices and each rotor having at least one opening in said peripheral section registrable with the adjacent orifices and of an axial dimension substantially equal to that of the adjacent orifices and a circumferential dimension substantially greater than that of said orifices, the circumferential length of the opening in each rotor being shorter than the distance between like orifices in adjacent chambers, corresponding openings in the rotors being offset but overlapping with the opening in the rotor at the exhaust ends of the chambers leading, means for rotating the rotors in unison and at such a speed that the inlet and exhaust orifices of the successive chambers are opened within the critical conditions for implosive inlet and explosive exhaust, respectively, means for supplying the chambers with air under pressure through their inlet orifices, means for introducing fuel into the chambers, and a separate exhaust conduit leading from the exhaust orifice of each chamber and formed to provide a free passage for exhaust gas masses traveling therethrough, the circumferential dimensions of the rotor openings and the speed of the rotors being such that, following explosive exhaust of each exhaust gas mass from the chamber, a portion of air entering the chamber passes through the chamber and into the conduit of said chamber and is prevented from returning into the chamber by the closing of the exhaust orifice.

13. An apparatus for producing gases under pressure, which comprises the combination of a plurality of like elongated combustion chambers of substantially uniform cross-section from end to end and disposed with their axes parallel, the chambers lying symmetrically with respect to a common axis and each having a single inlet orifice and a single exhaust orifice in its side wall at opposite ends thereof, the inlet orifices being alike and lying at one end of the group of chambers and the exhaust orifices being alike and lying at the other end of the group of chambers, each exhaust orifice having such an area in relation to the cross-sectional area of its chamber as to be suitable for explosive exhaust operation, a pair of rotors mounted at opposite ends of the group of chambers for rotation on said common axis, each rotor having a peripheral section overlying and normally closing the adjacent orifices and each rotor having a plurality of openings in said peripheral section registrable successively with the adjacent orifices, each opening in a rotor having an axial dimension substantially equal to that of the adjacent orifices and a circumferential dimension substantially greater than that of said orifices, the circumferential length of each opening in a rotor being shorter than the distance between like orifices in adjacent chambers, the openings in each rotor being paired with those in the other with said openings in a pair being angularly offset but overlapping and with the opening in the rotor at the exhaust ends of the chambers leading, means for rotating the rotors in unison and at such a speed that the exhaust orifices are opened within the critical conditions for explosive exhaust, the number of chambers and the number of pairs of openings in the rotors being such that the exhaust orifices of diametrically disposed chambers are simultaneously opened, a separate exhaust conduit leading from each exhaust orifice and formed to provide a free passage for exhaust gas masses traveling therethrough, means for introducing fuel into the chambers, and an impulse turbine having a casing with equiangularly spaced inlets, to which the exhaust conduits lead, and a wheel receiving impulses diametrically from exhaust gases traveling through conduits from diametrically disposed chambers.

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