April 3, 1951

E. MERCIER

EQUIPRESSURE VAPOR GENERATOR AND METHOD OF OPERATING SAME

2,547,135

Filed July 9, 1949

4 Sheets-Sheet 1

Fig. 1

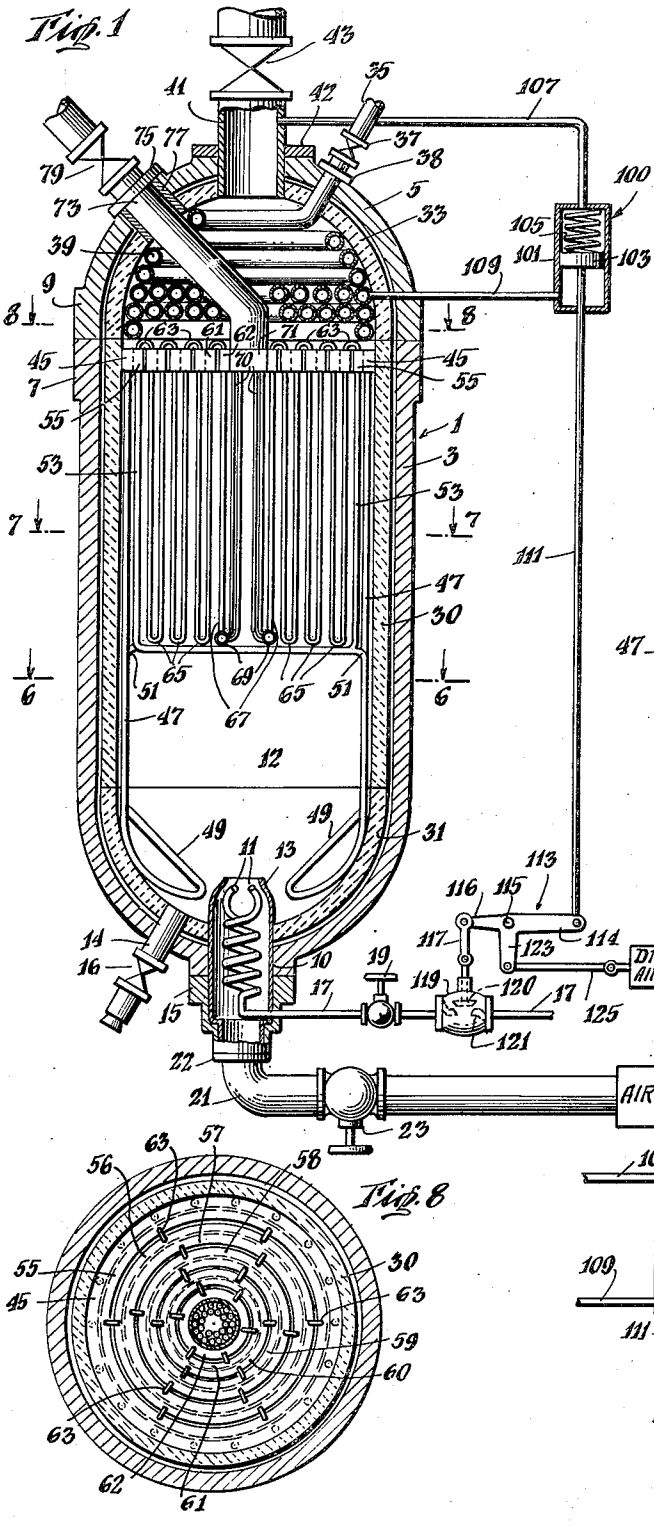


Fig. 6

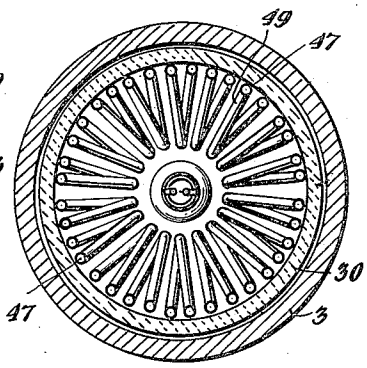


Fig. 7

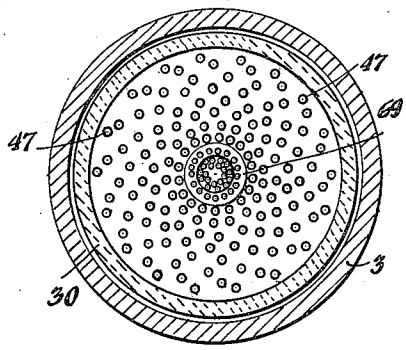
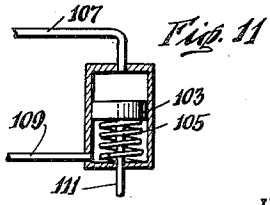


Fig. 8

Fig. 11



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EQUIPRESSURE VAPOR GENERATOR AND METHOD OF OPERATING SAME

Filed July 9, 1949 4 Sheets-Sheet 2

Fig. 2

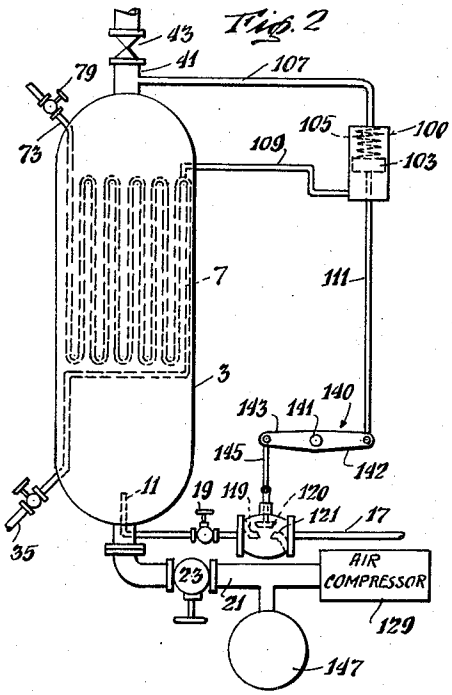


Fig. 3

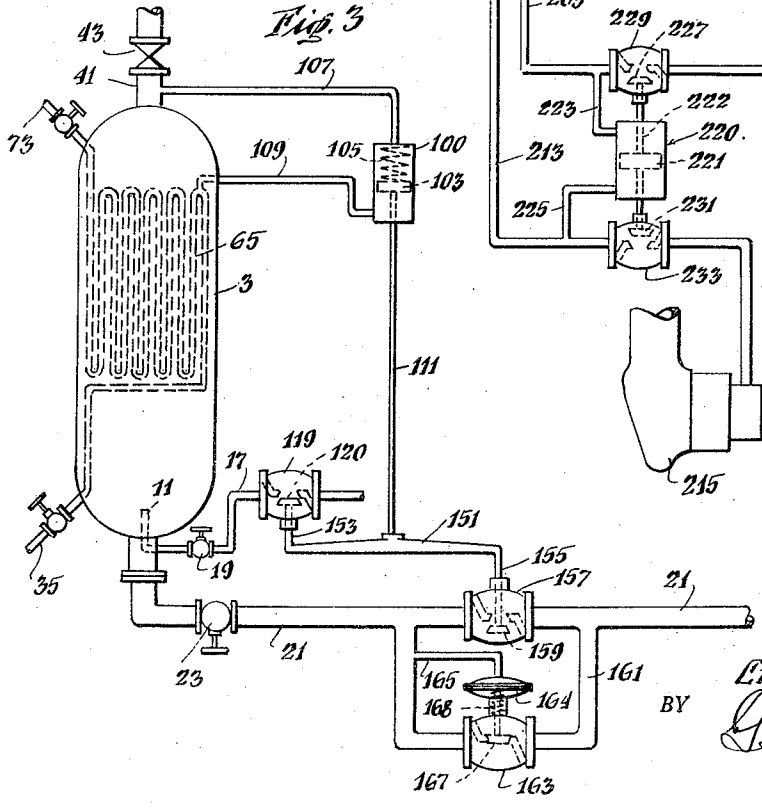
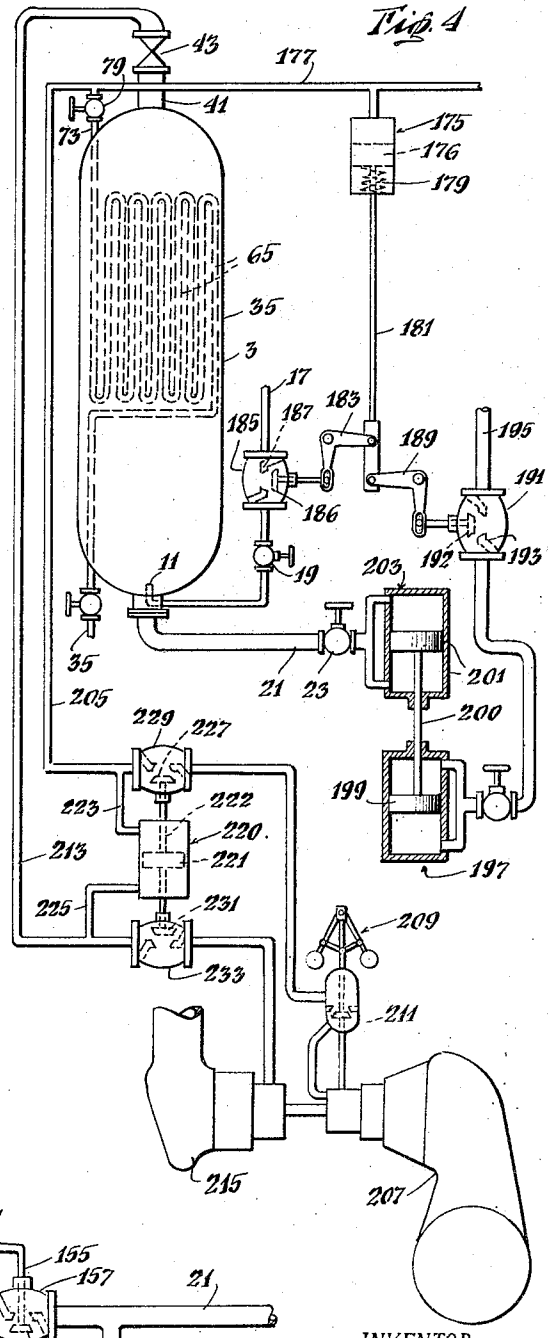


Fig. 4



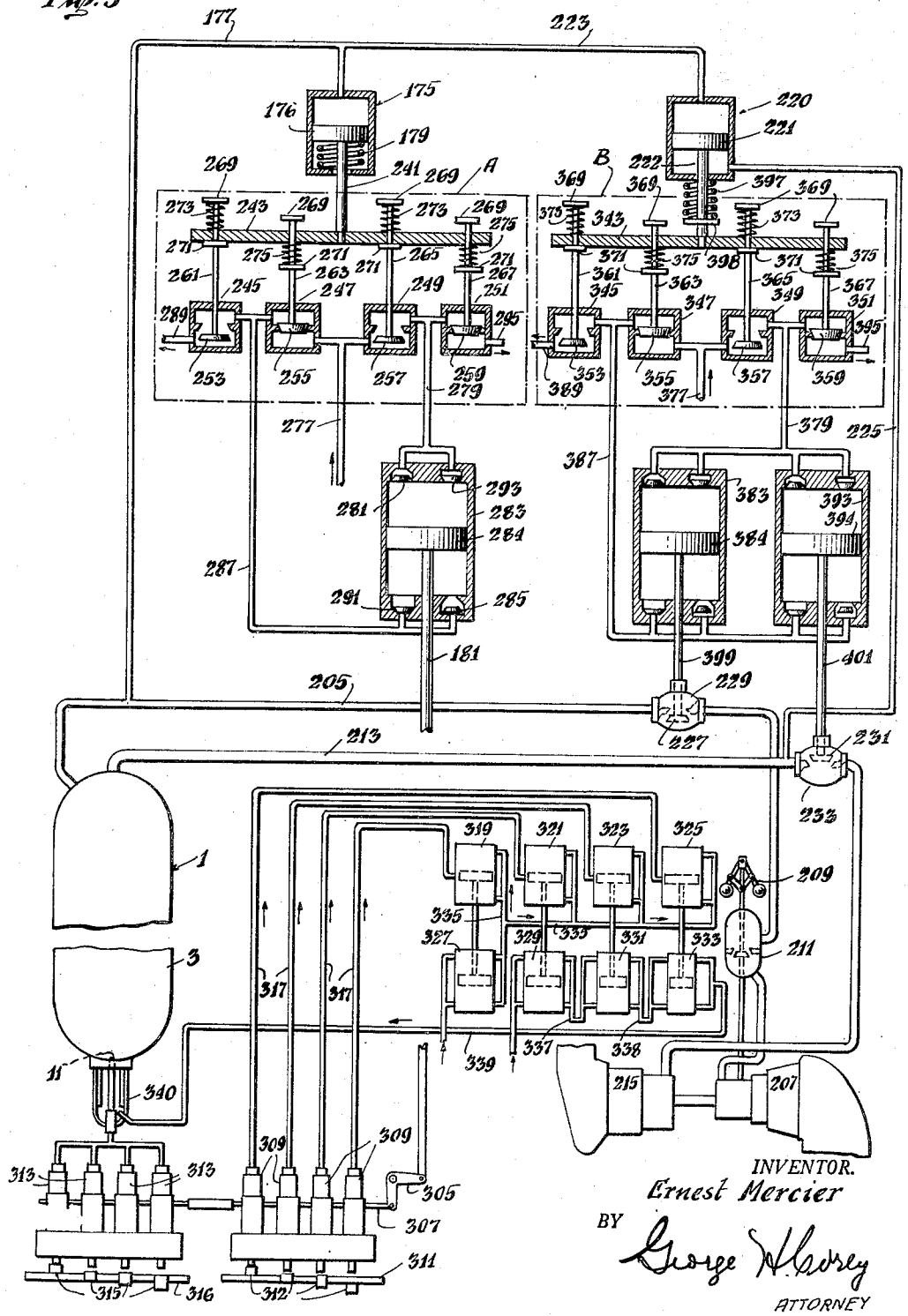
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EQUIPRESSURE VAPOR GENERATOR AND METHOD OF OPERATING SAME

Filed July 9, 1949 4 Sheets-Sheet 3

Fig. 5



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EQUIPRESSURE VAPOR GENERATOR AND METHOD OF OPERATING SAME

2,547,135

Filed July 9, 1949

4 Sheets-Sheet 4

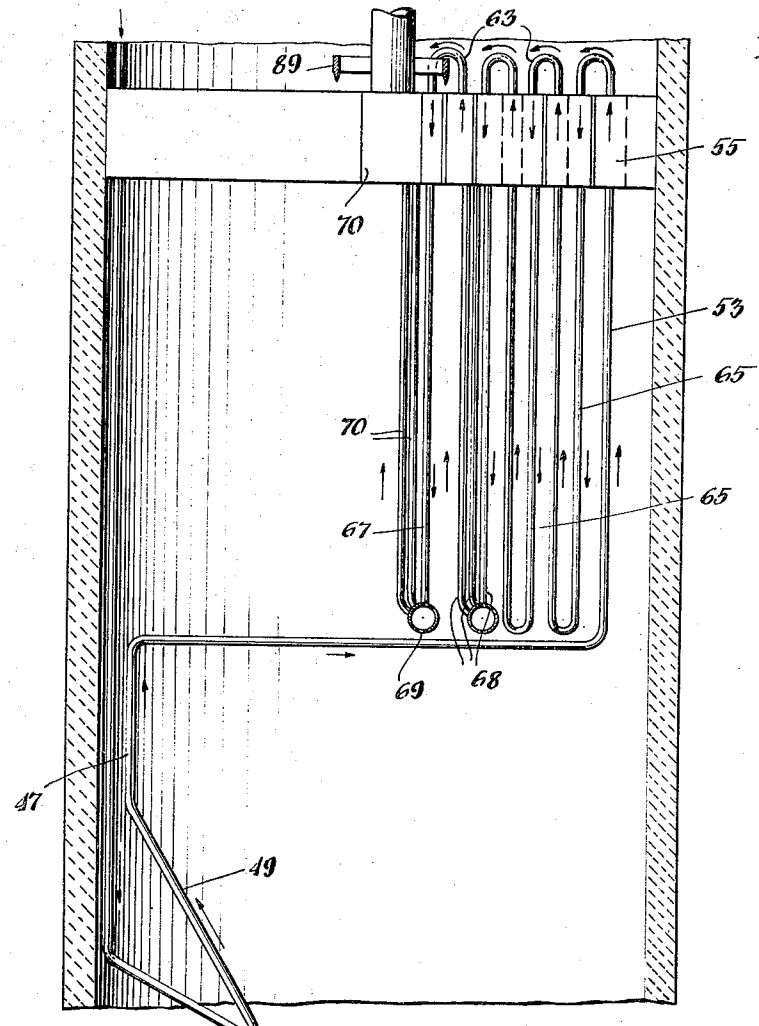


Fig. 9

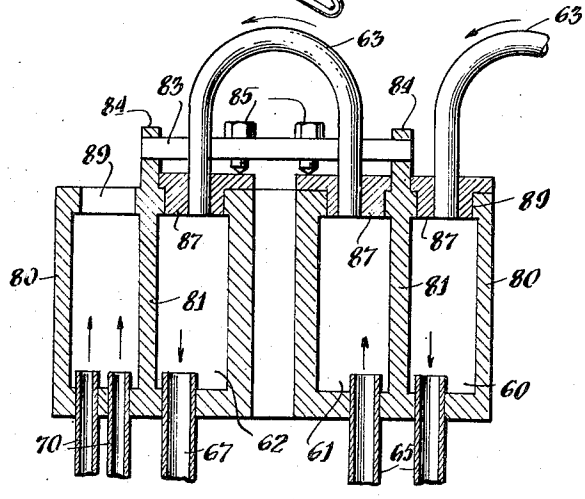


Fig. 10

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EQUIPRESSURE VAPOR GENERATOR AND METHOD OF OPERATING SAME

Ernest Mercier, Paris, France, assignor, by mesne assignments, to Moore, Inc., Atlanta, Ga., a corporation of Georgia

Application July 9, 1949, Serial No. 103,893
In France September 15, 1942

17 Claims. (Cl. 122—333)

1

This invention relates to the generation of vapor from a liquid by heat developed in the combustion of fuel. The invention more especially relates to the generation of a vapor at an elevated pressure for the development of power therefrom concomitantly with the production of combustion gases at an elevated pressure for development of power from these gases. The invention in a particular feature thereof relates to the control of the generation of the vapor and of the production of the combustion gases to secure operation at pressures of the vapor and of the gases which are in a predetermined relation.

It has been proposed heretofore to generate steam at pressures of 80 to 100 atmospheres absolute, but in generating steam at such pressures all of the steam and water confining parts of the boiler of necessity have been of heavy construction to withstand the internal pressure. This is true not only when the boiler is fired under low pressure combustion conditions, but also when high pressure combustion of the order taught in the prior art is mentioned. In operating under low pressure combustion conditions, the pressure in the combustion chamber is ordinarily kept at about atmospheric pressure or only slightly above atmospheric pressure, i. e., in the range of ½ inch of water pressure up to 10 to 12 inches of water pressure. In conventional combustion chambers such pressures slightly above the atmospheric pressure have been utilized to prevent or minimize the leakage of air into the combustion chamber ordinarily constructed of refractory material so as to control and improve the efficiency of combustion or to provide the pressure for producing rapid flow of the gas over the usually extensive heating surface and through tortuous gas passages.

In order to operate under higher pressure combustion conditions it is necessary to employ a pressure confining casing within which the steam generating elements may be disposed in heat-receiving relation to the combustion gases formed therein. It has been proposed to discharge the combustion gases produced in such a vapor generating system to a gas turbine or other gas utilizing prime mover. To avoid the use of thick wall casings the pressure of the gases within such a combustion chamber has been limited heretofore, however, this pressure usually not exceeding 4 to 5 atmospheres absolute. Even where in such conventional steam generators the pressure of the generated steam is not in excess of 30 to 40 atmospheres absolute the difference between the pressure of the steam generated within the steam

2

generating elements or tubes and the pressure of the combustion gases within the combustion chamber is so great that the steam and water confining elements and parts must be made to withstand a high differential pressure. The casing of the combustion chamber also must be made sufficiently strong to withstand the pressure of the combustion gases in the combustion chamber. The practical limitations heretofore placed upon the pressure at which the combustion gases may be produced within a combustion chamber not only have limited severely the range of pressure available for the production of power from the combustion gases in a gas utilizing prime mover but also have prevented the attainment of other improvements in the efficiency of production and utilization of the combustion gases. For example, the efficiency of heat absorption by the generated steam has been limited.

It is an object of the invention to provide apparatus of an improved construction for generating vapor by the heat of combustion of fuel under pressure in a combustion chamber.

It is another object of the invention to provide apparatus and a method of operating such apparatus for generation of vapor by the heat of combustion of fuel in a combustion chamber which will secure advantages in the efficiency of operation as well as in the construction of the apparatus and the cost thereof.

It is a further object of the invention to provide a method of operating a power generating plant by utilizing for development of power both the vapor generated by the heat of the combustion of fuel in a combustion chamber and the combustion gases produced in this combustion chamber which will secure improvement in the efficiency of operation and in the cost of the plant.

It is an important underlying feature of the invention that the pressure at which the combustion of the fuel is effected in the combustion chamber is approximately the same and preferably substantially equal to the pressure of the vapor generated in the vapor generating element receiving the heat from the combustion gases.

According to the invention there is provided in a vapor generator, e. g., a water tube boiler, a pressure resistant casing enclosing a combustion chamber wherein high pressures approximating the steam pressures generated in said boiler may be maintained, means for supplying fuel to said chamber, means for delivering air under pressure into said chamber for combustion of the fuel supplied thereto, vapor generating

tubes within said chamber, the air for combustion being injected into said chamber under pressure, at least 5 kilograms per square centimeter, and the pressure of the gases within said chamber outside of said tubes being maintained substantially equal, as hereinafter described, to the pressure of the vapor produced in said tubes so that stresses of the heated elements of said vapor generator are limited and only the cool casing is required to withstand high pressures.

Since the casing of the combustion chamber is constructed to confine the combustion gases therein at a pressure approximating the vapor pressure, the differential between vapor pressure and the pressure of the combustion gases within the chamber which the vapor generating element is required to withstand is small and the walls of the vapor generating element may constitute merely separating partitions between the combustion gases at the outside of the element and the liquid and vapor within the element. These walls are not subjected to any appreciable mechanical stress and may be made thin and capable of providing a high rate of heat transfer therethrough. Vapor generating elements of this form also readily may be made of any desired shape or cross section suitable for the conditions of the construction and for a high rate of heat transfer from the gases to the liquid and to the generated vapor and to provide for nontortuous gas passages therebetween requiring only a relatively small pressure drop in the gases to insure their flow over the vapor generating elements in heat transferring relation thereto.

Although the casing is required to be constructed so as to withstand internally thereof the full pressure of the combustion gases of a degree approximating or equal to the pressure of the generated vapor, the metal of this casing or shell may be thoroughly protected from the heat of the combustion gases and from contact therewith so that this metal may be maintained at a temperature which maintains the strength of the metal. To aid in securing the protection of the shell against the heat of the combustion gases it may be lined internally thereof with a refractory material as well as with an insulation layer between the refractory and the metal of the shell. The exterior of the casing is exposed to the atmosphere and its temperature is kept low by transfer to the air of such heat as passes thereto through the refractory lining and insulation.

The vapor generating element or certain of a plurality of such elements are arranged adjacent the wall of the casing or adjacent and within the refractory lining thereof to shield this wall and lining from the radiant heat of the combustion gases as well as from direct contact with the hot gases. The heat directed toward the wall of the shell thus is intercepted and utilized for the generation of the vapor and the shell exposed to the atmosphere exteriorly thereof is maintained at a safe temperature. Since, as above stated, these vapor generating elements are not required to withstand a high pressure they may be of any desired cross section and shape to suit the arrangement thereof which will insure the requisite heat intercepting relation with respect to the wall of the shell or the refractory lining thereof.

By thus constructing and arranging the combustion chamber and the vapor generating element or elements therein it becomes possible to utilize materials ordinarily available for the construction of conventional low pressure vapor generators for constructing the vapor generator of the invention to generate vapor at pressures of the degree of 120 atmospheres absolute or higher. Moreover, the combustion gases may be produced by the combustion of fuel within the combustion chamber at temperatures ordinarily developed in the combustion of conventional fuels such as oil, gas, powdered coal or composite or colloidal fuels, and the temperature of the combustion gases after delivering heat to the vapor generating elements for the generation of vapor may become reduced, for example, to a temperature of 500° C. at the gas discharge from the casing. Thus, without exceeding the temperatures which conventionally used materials may withstand, the gases at such elevated pressure and temperature may be used in a gas utilizing prime mover with a high pressure drop and a high temperature drop to the pressure and temperature of the exhaust from the prime mover to the atmosphere. These gases, however, may be used for other purposes in the development of power or for supplying heat.

By effecting the combustion of the fuel to produce combustion gases at high pressure the heat released from the fuel is carried by combustion gases of a very high density. The volume of such high density gases is very small as compared with the volume of gases ordinarily produced in conventional combustion chambers adapted for effecting combustion at the relatively low pressures heretofore used. Since the volume of the combustion gases is small the requisite cross section for flow thereof through the gas passages for contact with heating surfaces of the vapor generating elements or other heat transfer elements is small and may be made sufficient to produce only a small pressure drop requisite for effecting movement of the gas over such heating surfaces. Moreover, as the mass of the gases per unit of volume is high the heat transfer rate is high and the amount of heating surface necessary for a given capacity, that is, a given amount of vapor to be generated and a corresponding amount of combustion gases to be produced, is small. This limited amount of required heating surface further limits the pressure drop necessary to produce flow of the gases over the heating surface while securing the desired reduction of the temperature of these gases corresponding to the amount of vapor generated from the heat thereof.

For these and other reasons which will appear from the further description of the invention the method of operating a vapor generator by effecting combustion of the fuel to produce combustion gases at a pressure approximating the pressure of the generated vapor requires a construction of much reduced size and cost for a given capacity as compared with conventional methods and structures and makes possible not only improved efficiency in the combustion of the fuel but also more efficient utilization of the heat thereof for the generation of the vapor concomitantly with the production of gases at elevated pressure and temperature. It may be shown that the cost of the auxiliary equipment necessary for compressing the combustion supporting gas, usually air and the cost of operation of this equipment are such that a marked overall improvement is obtained in the efficiency and in the economy of operation.

In accordance with another important feature of the invention means are provided for maintaining the pressure of the combustion gases within the combustion chamber and the pressure

of the vapor generated in the vapor generating element in a predetermined relation to each other and preferably substantially equal. Although not so limited this feature will be described in connection with its application to the operation of a steam generator which may be provided with a plurality of tubes arranged within a combustion chamber, the fuel being burned to produce the combustion gases under a pressure approximating the steam pressure by supplying air to the combustion chamber compressed to a pressure approximating the steam pressure.

The pressure of the steam generated by the combustion of the fuel varies as the withdrawal of the steam from the tubes and the supply of the heat varies. The pressure of the combustion gases within the chamber varies in accordance to the rate of withdrawal of the combustion gases therefrom and the delivery of fuel and compressed air thereto. To maintain the desired predetermined relation of the pressures means are provided for controlling the supply of the fuel to the combustion chamber and concomitantly controlling delivery of the air to the chamber against the pressure of the gases within the chamber. Means also may be provided for controlling the discharge of the steam and of the combustion gases from the generator. Similarly to the conventional types of control the supply of fuel to the combustion chamber may be regulated so as to maintain the desired pressure of the generated steam. The delivery of the air also may be regulated to supply an amount of air necessary for combustion of the fuel for generating the steam and concomitantly it may be regulated to maintain the desired relation of the pressure within the combustion chamber with respect to the pressure of the generated steam.

To accomplish the control of the fuel supply and the delivery of the compressed air, in accordance with a unique aspect of the invention, means responsive both to the pressure of the steam and the pressure of the combustion gases within the chamber may be used to adjust or regulate the fuel supply and to adjust or regulate the delivery of the air so as to maintain the requisite combustion and the desired relation of the pressures of the steam and of the gases within the combustion chamber. This means may include a device so constructed and so connected to a space confining the generated steam and to a space communicating with the combustion chamber as to be actuated by variations from a predetermined difference between the pressure of the steam and the pressure of the combustion gases. The predetermined difference, or narrow range within which the vapor pressure and the pressure of the combustion gases are permitted to vary with respect to one another, in practice usually will be kept below about 14 pounds per square inch or 1 kilogram per square centimeter, and such a variation is encompassed within the term "substantially equal pressures" as used herein.

This differential device may be connected to the means for supplying the fuel and to the means for delivering the air so that as the pressure of the steam increases and decreases relative to the pressure of the combustion gases the supply of fuel is decreased and increased to effect decrease and increase of the steam generated and of the pressure of the steam, the delivery of the air concomitantly being increased and decreased to increase and decrease the pressure of the combustion gases within the chamber. In a modification the differential device may be connected only to the means for supplying the fuel to the combustion chamber and conventional means may be utilized for effecting delivery of the air to the combustion chamber at a predetermined pressure to maintain the pressure therein substantially constant. In another modification the differential device may be connected to actuate the fuel supply means as well as the air delivery means so as to decrease and increase as is customary both the supply of the fuel and the delivery of the air to the combustion chamber, such decrease and increase, however, being effected in response to increase and decrease of the pressure of the generated steam relative to the pressure of the combustion gases within the combustion chamber. In this embodiment means responsive to the pressure of the gases within the combustion chamber may be utilized for effecting supplementary delivery of compressed air to the combustion chamber so as to regulate the pressure therein and thereby to cooperate with the device which is responsive to the difference between the steam pressure and the combustion gas pressure so as to maintain the predetermined relation between these pressures.

In another aspect of the invention the device which is responsive to the variations in the difference between the pressure of the generated steam and the pressure of the combustion gases within the combustion chamber may be connected to means for controlling the discharge or withdrawal of the steam from the steam generating elements and to the means for controlling the discharge or withdrawal of the combustion gases from the combustion chamber. When thus connected the device may be effective to regulate the discharge of the steam and of the combustion gases so as to maintain the pressures thereof respectively in the steam generating structure and in the combustion chamber in the predetermined differential relation. This differential device may be constructed and so connected to these discharge means as to actuate these means so as to reduce the amount or rate of discharge of the steam and correspondingly to increase the amount or rate of discharge of the combustion gases from the combustion chamber whenever the pressure of the generated steam reduces below the predetermined relation with respect to the pressure of the combustion gases until the predetermined differential relation of these pressures is restored. Whenever the pressure of the generated steam relative to the combustion gas pressure becomes in excess of the predetermined differential the device may actuate the discharge control means to increase the discharge of the steam and to decrease the discharge of the combustion gases. As will be more clearly understood from the description of the drawings to follow the differential control device thus arranged for control of the discharge of the steam and of the combustion gases from the steam generator of the invention may control the flow of the steam and of the gases respectively to steam and gas utilizing prime movers and may cooperate with the governor of one prime mover, for example that utilizing the generated steam, so as to control the flow of this steam to this prime mover to regulate the speed and deliver the power while also controlling the flow of the combustion gases to a gas utilizing prime mover.

In a further modification the supply of fuel and the delivery of air to the combustion cham-

ber may be regulated in a conventional manner by means responsive to variations in pressure of the generated steam. Such conventional means ordinarily are adapted to increase and decrease both the supply of fuel and of air in response to decrease and increase of the steam pressure. In a particular adaptation of such control this means responsive to variations in the steam pressure may be connected to a fuel feeding device for controlling the operation of this device to increase and decrease the feed of the fuel to the combustion chamber. It also may be connected to means controlling the flow of the air to the combustion chamber or in a particular application it may be connected to a power means which drives a compressor for compressing the combustion air. Such power means may be an internal combustion engine utilizing fuel such as oil and in such case the means responsive to variations in the steam pressure may be connected to a fuel feed pump for controlling the operation of this pump to regulate the feed of the fuel to the internal combustion engine, thereby to regulate the amount of the compressed air delivered to the combustion chamber.

In combination with such means responsive to variations in the pressure of the generated steam and regulating the supply of fuel and delivery of air to the combustion chamber, the differential device above referred to may be utilized for controlling the discharge of the generated steam from the steam generating elements and the discharge of the combustion gases from the combustion chamber as above described so as to maintain the predetermined relation of the pressures of the steam in the steam generating elements and of the combustion gases in the combustion chamber.

The differential device above generally described may be constructed and may be connected to the steam space and to the combustion chamber so as to be responsive to variations from a predetermined difference between the steam pressure and the combustion chamber pressure both for the condition that the pressure of the steam normally is to be maintained somewhat in excess of the pressure of the combustion gases in the combustion chamber and for the condition that the combustion gas pressure is to be maintained somewhat in excess of the steam pressure. If for either condition means are utilized as above described for maintaining the pressure of the gases in the combustion chamber substantially constant it will be understood that the differtntial device may effect control of the fuel supply to regulate the steam pressure or it may control both fuel supply and delivery of air to provide for efficient combustion of the fuel. For either condition as the steam pressure increases relative to the atmosphere it is necessary that the device be connected to the fuel supply so as to reduce the supply of fuel in order to reduce the generation of the steam. As the steam pressure falls the fuel supply must be increased. For the condition that the steam pressure normally is in excess of the combustion gas pressure the difference of pressure between the steam and combust'on gases will be increased when the pressure of the steam increases and vice versa. When the pressure of the steam normally is less than the combustion gas pressure the pressure difference will decrease when the steam pressure rises and vice versa.

It will be understood, therefore, that increase of the vapor or steam pressure herein referred to as relative to the pressure of the combustion gas within the combustion chamber relates to both of the normal conditions above mentioned and that such increase of the steam pressure relative to the combustion gas pressure may correspond to an increase or a decrease of the difference between the pressures. On the other hand, decrease of the steam pressure relative to the combustion gas pressure may correspond to a decrease or an increase of the difference between said pressures. It will be further understood that the relationship just described and the manner of connecting the differential device are to be maintained even though the pressure of the combustion gases, instead of being maintained substantially constant, varies with variation in the amount and pressure of the air delivered to the combustion chamber or of the gases withdrawn therefrom.

Other objects and features of the invention will be understood from the description to follow of the drawings in which:

Fig. 1 is a vertical section of a steam generating apparatus in accordance with the invention showing control by the differential device both of the fuel supply and the delivery of the combustion supporting air to maintain a predetermined relation of steam and gas pressures;

Fig. 2 shows diagrammatically the control of the fuel supply by the differential device, the combustion chamber pressure being maintained substantially constant by control of the pressure of the compressed air delivered thereto;

Fig. 3 shows diagrammatically a modification in which the differential device controls the fuel supply and the delivery of air for combustion, the combustion chamber pressure being maintained substantially constant by a pressure regulator controlling supplementary delivery of compressed air;

Fig. 4 shows diagrammatically the steam generator of the invention arranged for delivery of the steam to a steam turbine and of the combustion gases to a gas turbine for developing power from the steam and these gases;

Fig. 5 shows a modification of the power plant of Fig. 4 in which the pressure responsive controls include relays for controlling an auxiliary or control fluid for operating the fuel supply control means and the air delivery means;

Figs. 6, 7 and 8 are sections taken on lines 6—6, 7—7 and 8—8 respectively of Fig. 1;

Fig. 9 shows diagrammatically a somewhat modified arrangement of the steam generating and superheating tubes of Fig. 1 and the course of the water and steam therethrough;

Fig. 10 is a vertical section of a portion of the headers to which the steam generating tubes of Fig. 1 are connected;

Fig. 11 shows diagrammatically a modification of the steam generator of Fig. 1 in which the normal pressure of the combustion gases exceeds the pressure of the generated vapor.

In Fig. 1 is shown more or less diagrammatically a steam generator or equipressure boiler 1 which is constructed with an outer casing or shell 3 as a steel cylinder having a hemispherical lower end which may be forged in one piece. At the upper end of the casing 3 is fitted a hemispherical removable cap 5 fastened by any suitable means at the flanges 7 and 9 respectively of the casing 3 and the cap 5. At the lower end of the casing a flanged opening 10 is provided for the admission of air and for the insertion of

the burners 11 disposed within a burner shell 13 carrying a flanged connector 15. This air for combustion may be controlled by hand valve 23 and by control of the air compressor about to be described.

Within the casing 3 is supported a refractory lining 30. The lower hemispherical end of the casing 13 is provided with a hemispherical refractory lining 31. The cap 5 also is lined with a refractory lining 33. These refractory linings are supported in spaced relation to the casing 3 and the cap 5, this space preferably being filled with insulating material, for example asbestos flock. The refractory lining may be supported by a light metal framework constructed so that the lining may be placed in position or removed from the casing upon removal of the cap 5 and the other parts of the steam generator further to be described. The refractory lining and the insulating layer serve not only to limit the heat which is transmitted to the casing but also to confine the heat within the combustion chamber to improve the combustion.

Because of the high pressure at which the combustion is effected in the steam generator of the invention the volume of the combustion space necessary for the combustion of the fuel for a given capacity is small. The diameter as well as the overall size and weight of the casing 3, therefore, is small. The thickness of the casing 3 need not be excessive safely to withstand the pressure of the combustion gas within the combustion chamber of the degree of or equal to the steam pressure which may be as high as 120 atmospheres or more. Without need for a large amount of material sufficient thickness of the refractory lining and of the insulating layer, moreover, may be provided to keep the temperature of the casing from rising to the point where the strength of the metal of the casing would be reduced. The construction and dimensions of the gas confining casing or shell, therefore, correspond generally to the dimensions of pressure vessels for corresponding pressures rather than to the dimensions necessary for combustion of fuel in conventional combustion chambers. The thickness of the shell need not be such as to allow for the action of the heat or the impingement of the hot gases thereon since it is protected by the refractory and insulating materials supported between the material of the shell and the hot combustion gases as well as by the steam generating elements about to be described. For a capacity, for example, of 440,000 pounds of steam per hour at a pressure of 80 atmospheres absolute, the pressure of the combustion gases being substantially equal to the steam pressure, and burning, for example, powdered coal as fuel, the diameter of the casing of the steam generator may be about 5.5 feet and the length of the casing including the hemispherical ends may be about 18.5 feet.

Within the space defined by the refractory lining supported within casing 3 and the cap 5 of Fig. 1 are disposed the steam generating elements in the form of tubes to which the feed water is delivered from a feed pipe 35 controlled by valve 37. The pipe 35 is fastened to the cap 5 by means of flange 38 extending about an opening in the cap 5 and passes to the interior of the shell through this opening and through the refractory lining 33. The pipe 35 is connected to the economizer 39 so that the feed water flows in series through the successive convolutions or wraps of the coil 39. Some of these wraps are disposed along the hemispherical refractory lining 33 of the cap 5 to protect this lining and the cap from the direct action of the combustion gases passing from the combustion chamber upwardly through the nested wraps of the economizer and through the discharge pipe 41 fastened by the flange 42 to the cap 5, this discharge being controlled by the gas outlet valve 43. The lower end of the coil 39 is connected to a ring shaped header 45 extending about the space within the lining 30 adjacent the joint between the flanges 7 and 9 of the casing 3 and the cap 5. The header 45 may be connected to the lowermost wrap of the economizer coil 39 at one or more places to insure proper delivery of the feed water heated in the economizer coil to the header 45 for distribution to the steam generating tubes.

The steam generating tubes comprise the legs 47 which extend vertically downward from the header 45 along the inner face of the refractory lining 30 and form loops 49 at the lower end thereof adjacent the burner 11 as shown in Figs. 1 and 6 to intercept the heat and to protect the refractory lining and the vertical wall of casing 3 as well as the lower hemispherical end of the casing. From the loops 49 the tubes again proceed upwardly along the face of the refractory lining 30 and bend at 51 to pass across the combustion space to the opposite side thereof, thence to proceed upwardly as legs 53 to the ring shaped header 55 disposed within and concentric with the header 45. As shown in Figs. 1 and 8 concentrically disposed with respect to the headers 45 and 55 are headers 56, 57, 58, 59, 60, 61 and 62. By the U-shaped connector 63 shown to enlarged scale in Fig. 10, at the upper side of the headers the header 55 is connected to the header 56, the header 57 is connected to the header 58, the header 59 is connected to the header 60 and the header 61 is connected to the header 62. These connections are made at a plurality of points about the central axis of the casing 3. At the lower side of these headers steam generating tubes 65 of U or hairpin shape with the bends thereof disposed downwardly are connected to the headers so as to connect together respectively headers 56 and 57, 58 and 59, 60 and 61. These steam generating tubes 65 are disposed about the axis of the casing in the manner shown in the horizontal cross section in Fig. 7. As shown in Fig. 7 the vertical legs of the tubes 65 are disposed in staggered relation at opposite sides of the radial lines which extend from the axis of the casing generally toward the legs 47 of the tubes which are disposed adjacent the refractory lining. Having regard to the connections as just described of the U-shaped connectors 63 and to the connections of the upper ends of the U-shaped steam generating tubes 65 to the headers it will be noted that the water which is delivered to the header 45 is directed downwardly through the legs 47 and again upwardly and across the combustion chamber and continues upwardly in the legs 53 to the header 55, thence in succession through the tubes 65 and the consecutively numbered headers 56 to 62. The innermost leg of the steam generating tube 65 is connected to the header 61 which is connected by the U-connector to the innermost ring header 62.

To the lower side of the header 62 in the manner shown for the left hand header of the detail section in Fig. 10 the first vertically disposed leg 67 of the superheater is connected, the lower end of this leg being connected to a ring shaped

header 69, Fig. 1. Also connected to the header 69 are two riser legs 70 of the superheater which at their upper ends are connected to a central superheated steam collector 71 to which the outlet pipe 73 is connected, this pipe passing through an opening in the refractory lining 33 and a registering opening in the cap 5 to which the pipe 73 is attached by means of flange 75, suitable packing 77 being provided about the pipe 73 to provide for expansion and contraction. A valve 79 is provided in the outlet pipe 73 for control of the outflow of superheated steam from the steam generator.

As shown in Fig. 10 the headers 56 and 57, 58 and 59, 60 and 61 may be formed as compartments in respective integral headers 80 divided into these compartments by partition 81, the tubes 65, 67 and 70 being connected at the respective sides of the partitions 81 having regard to the connection of the U connectors 63 which provide for flow of the water or steam from one header to the next, that is, between the respective compartments in the adjacent headers to secure a series flow through steam generating and superheating tubes. The U connectors 63 are held in place by yoke bars 83 which pass through openings in upwardly extending lugs 84 formed in the embodiment of Fig. 10 as extensions of the partitions 81. Tapped in the bars 83 and extending therethrough are screws 85 for engaging plates 87 which are formed as closures for openings 89 in the upper face of the headers 80. Each compartment is provided with an opening to provide access to the tubes for rolling them into the lower walls of the headers 80 and for cleaning of the tubes. It will be understood that the screws 85 may be screwed downwardly to press the plates 87 downwardly into closing engagement with the headers 80, the reaction being taken by the lugs 84 through the bars 83 to secure a tight closure of the openings 89. This construction provides for disconnecting the headers so that they may be removed together with the tubes which are attached thereto.

It will be understood from the above description and consideration more particularly of Figs. 1, 6, 8 and 10 that by disconnecting at the respective flanges the external steam and gas outlet pipes 41 and 73 and the feed supply pipe 35 the cap 5 may be removed in one piece. The economizer 35 and the headers 45 and 55 to 62 inclusive are supported so that the economizer first may be removed and then the other boiler elements, such as the headers and the steam generating tubes connected thereto, or the whole assembly of these elements within the refractory lining may be removed as a unit.

In order that the drop in temperature of the hot gases as they pass through the nest of tubes within the gas space above the combustion chamber proper as shown in Fig. 1 shall be substantially the same at the center of the chamber as at the periphery, although the temperature of the steam in the superheater is different from that of the water flowing from the economizer through the outermost tubes 47 and different from the temperature of the steam and water mixture confined within the intermediate steam generating tubes 65, the cross section of the gas passages between these several tubes decreases in the direction from the periphery of the chamber toward the center thereof as may be seen in Fig. 7. As shown in Fig. 9 a damper 89 movable in the direction along the axis of the combustion chamber may be provided to cooperate with the central box 70 to control the flow of the gases over the superheater section constituted by the tubes 70 for regulating the temperature of the superheated steam.

In order to secure control of the operation of the steam generator of Fig. 1 and to maintain the desired difference between the steam pressure and the pressure of the combustion gases within the casing 3 as above generally described, a differential pressure device 100 is provided having a cylinder 101 within which is movable a piston 103 between the upper side of which and the upper head of the cylinder 101 is positioned a compression spring 105. The space above piston 103 communicates through pipe 107 with the gas space within the casing 3 by being connected to the outlet pipe 41 below the valve 43. The connection of the pipe 107 may be made at this place in view of the low pressure drop between the pressure of the combustion gases within the combustion chamber 12 and the pressure of the gases at the discharge pipe 41, this low pressure drop being possible because of the limited amount of heating surface and its arrangement and construction in view of the high density of the combustion gases as above described. The pipe 107, however, may be connected at some other place upon the casing 3 in order to make the piston 103 responsive to the combustion chamber pressure or to the pressure of the gases at some other point in the flow thereof from the burners 11 to the gas outlet 41.

The space beneath the piston 103 in the cylinder 101 is connected by pipe 109 in the embodiment shown in Fig. 1 to a wrap or convolution of the economizer coil 39. As the water is delivered in series through the economizer to the steam generating tubes 65 and the economizer tubes may be made to provide a substantial area for flow of the water therethrough, the pressure within the economizer may be substantially the same as or not greatly different from the pressure of the generated steam. The pipe 109, however, may be connected elsewhere to the steam space within the steam generating structure or to some space within a header or other part which is in communication with the space in which the steam is generated or is superheated so as to substantially bring upon the underside of the piston 103 the pressure of the generated steam.

It will be understood in the particular embodiment shown in Fig. 1 that the pressure of the steam may be somewhat higher than the pressure of the combustion gases confined within the casing 3, the difference between these pressures corresponding substantially to the compression of the spring 105. It will be understood also in this embodiment that as the steam pressure rises relative to the pressure of the gases within the combustion chamber the difference between these pressures, that is, the excess of the steam pressure over the gas pressure, increases and the spring 105 is compressed with concomitant movement of the piston 103 upwardly in Fig. 1. If the steam pressure, on the other hand, falls the difference between the pressures, that is the excess of the steam pressure over the gas pressure, is reduced and the piston 103 moves downwardly until the pressure of the steam acting on the piston 103 balances the pressure of the gas and the compression of the spring acting at the upper side of the piston 103.

If, on the other hand, the normal condition of operation desired to be secured is that the gas pressure within the combustion chamber or the

gas space within the casing 3 shall exceed somewhat the pressure of the generated steam the spring 105 may be placed at the under side of the piston 103, as shown in Fig. 11, the spring thus balancing the excess of the gas pressure over the steam pressure brought upon the under side of the piston 103. In such case, when the pressure of the steam rises relative to the gas pressure the difference between the pressures, that is, the excess of the gas pressure over the steam pressure will decrease. Nevertheless, the piston 103 will move upwardly being assisted by the spring 105 until the balance is restored. If, on the other hand, the pressure of the steam falls relative to the gas pressure the difference between these pressures will increase but the piston will move downwardly in Fig. 11, the gas pressure compressing the spring somewhat until the balance of the pressures acting on the piston 103 is reached.

It will be apparent, therefore, that in both cases where the steam pressure rises relative to the gas pressure the piston is moved upwardly and where the steam pressure falls relative to the gas pressure the piston moves downwardly. If by means about to be described the gas pressure within the combustion space is maintained constant or substantially so the differential device as shown in Figs. 1 and 11 is responsive to variations of the steam pressure relative to this constant gas pressure. On the other hand, if both the gas and the steam pressure are subject to variation the device, nevertheless, is responsive to variations of the pressure difference from a predetermined difference between these pressures, these variations being utilized in the manner now to be described to control the pressures of the generated steam and of the combustion gases within the casing 3 so as to maintain substantially constant the difference between these pressures. The advantages above referred to with respect to the structure and the economy of operation of the steam generator of the invention thereby may be insured.

In the embodiment of Fig. 1 the piston 103 is connected by the vertical rod 111 to a three arm lever 113, this rod being connected at the outer end of the right hand arm 114 of the lever 113 with respect to a stud or shaft 115 upon which the lever 113 pivots. The left hand arm 116 of the lever 113 is connected by means of a link 117 to the stem of a valve 119 connected in the fuel line 17, the valve disc 120 of this valve as shown in dotted outline being arranged to move upwardly with respect to the valve seat 121 to open this valve. Extending downwardly from the pivotal stud 115 the lever 113 is provided with an arm 123 connected by connecting link 125 to the driver 127 of the air compressor 129, this air compressor being connected to the pipe 21 for delivery of the compressed air therefrom to the combustion chamber 12. The connections of the rod 125 to the driver 127 and between the driver and the air compressor 129 are shown diagrammatically. The driver may be a motor or a prime mover of suitable type and the air compressor may be of conventional type for supplying air under a pressure of the same degree as the steam pressure to be generated, this compressor being provided with conventional regulating means for maintaining a suitable outlet pressure and constructed for delivery of the compressed air in the proper volume to supply the combustion chamber for combustion of the fuel therein having regard to the outflow of the combustion gases withdrawn from the combustion chamber through the outlet pipe 41 as controlled by valve 43 or by the controls at the point of use.

It now will be understood that in the embodiment of Fig. 1 an increase of the steam pressure relative to the pressure of the gases in the combustion chamber effecting an upward movement of the piston 103 produces counterclockwise rotation of the lever 113 on its stud 115 to close the valve disc 120 upon the seat 121, thus to reduce or to stop flow of the fuel through the pipe 17 to the burners 11. Correspondingly such upward movement of the piston 103 produces movement toward the right of the connecting link 125. The link 125 is so connected to the driver of the compressor as to increase the speed of this driver and of the compressor or otherwise to control the operation of the compressor so as to increase the delivery of the compressed air or the pressure thereof through the pipe 21 to the combustion space 12 for combustion of the fuel delivered to the burners 11. The reduction in the amount of fuel delivered to the burners 11 reduces the amount of heat released in the combustion space 12 thereby to reduce the pressure of the generated steam. The increase in the delivery of the compressed air to the combustion space or the pressure thereof increases the pressure of the gases within this combustion space. The controls of the fuel supply and of the delivery of the air in this manner cooperate to restore the relation of the steam pressure to the combustion gas pressure.

If, in the embodiment of Fig. 1, where the steam pressure is desired to be somewhat in excess of the gas pressure, because of variation in the outflow or in the generation of the gases of combustion or for other reason, the pressure of the gases within the casing 3 should decrease relative to the steam pressure, thereby increasing the difference between these pressures, the piston 103 in this case also will move upwardly and the valve disc 120 will move toward its seat 121 to reduce the supply of fuel and the operation of the compressor will be controlled so as to increase the delivery of the compressed air to the combustion space or its pressure. It will be clear also, on the other hand, that if the pressure of the steam is reduced relative to the gas pressure, either by reduction of the steam pressure or by increase of the gas pressure, opposite movement of the piston 103 will be produced with corresponding opening of the fuel valve 120 and decrease in the delivery of the compressed air or its pressure until the predetermined pressure difference within the casing 3 is restored. It will be understood that the device as schematically shown in Fig. 1 operates to restore the relation of the steam and gas pressures within the casing 3 for any variation in the steam pressure or of the gas pressure which produces an increase of the steam pressure relative to the gas pressure or a decrease of the steam pressure relative to the gas pressure.

It will be apparent also, where the gas pressure to be maintained within the combustion chamber is in excess of the steam pressure to be generated in the steam generator, that the differential device arranged as shown in Fig. 11 when its piston 103 is connected to the valve 119 and to the driver of the air compressor by the rod 111, lever 113 and the link connections 117 and 125 as shown in Fig. 1 will be effective to decrease and increase the supply of the fuel to the burners and concomitantly to increase and decrease the delivery of the compressed air to the combustion space,

thereby to control the pressures of the generated steam and of the combustion gases within the casing to maintain the desired predetermined pressure difference according as the pressure of the steam rises or falls relative to the combustion gas pressure.

If the combustion gas pressure within the casing 3 is maintained constant by suitable means, the differential device responsive to variations of the difference between steam pressure and combustion gas pressure may be utilized to control the fuel supply. Such an arrangement is shown in Fig. 2 in which the corresponding parts bear the same reference numerals as those of Fig. 1, the steam generating tubes 65 in this embodiment being diagrammatically represented in serpentine form, the feed water being delivered thereto through pipe 35. The steam is discharged through the pipe 73. As shown in Fig. 2 the differential device 100 is connected in the same manner as in Fig. 1 to the gas space within casing 3 through pipe 107 and to the steam space through pipe 109. The rod 111 connected to the piston 103 is connected to a double arm lever 140 in this embodiment. This lever is pivoted upon a stud 141, the rod 111 being connected to its right hand arm 142. The left hand arm 143 of lever 140 is connected by the link 145 to the stem of valve 119 the valve disc 120 of which in its lowermost position rests on the seat 121 within the valve body 119 connected in the fuel supply line 17 the same as in Fig. 1. In Fig. 2 the burner 11 is diagrammatically shown and the compressed air is delivered to the combustion space within casing 3 through the pipe 21 from the compressor 129 similarly to Fig. 1. In Fig. 2 the driver of the air compressor is not shown and no connection is provided between the rod 111 and the driver of the compressor or to any flow controlling means associated with the compressor. In this embodiment a receiver 147 is provided connected to the discharge pipe 21 of the compressor to receive and store the compressed air in the conventional manner. The compressor also may be provided with conventional control means, such as an unloading device responsive to the pressure in the receiver 147 and connected also to means for driving the compressor, for example the throttle valve of an engine connected to the compressor for driving the compressor, so as always to maintain within the receiver a predetermined pressure. The pipe 21 may be of sufficient size, having regard to the length thereof and to other flow conditions, so that the pressure maintained in the receiver is substantially the same as or in the predetermined relation to the pressure within the combustion chamber. It will be understood, therefore, that the compressor cooperating with this receiver 147 may be utilized in the conventional manner to maintain a predetermined substantially constant pressure of the combustion gases within the combustion space and within the casing 3. When such contant or substantially constant pressure of the combustion gases is maintainel within the casing 3 the differential device as shown in Fig. 2 operates to control the supply of the fuel to the combustion space and, therefore, the generation of the steam in response to variations in the pressure of the steam relative to this substantially constant pressure of the combustion gases. In the embodiment of Fig. 2, a predetermined difference, that is, an excess of the steam pressure over the gas pressure may be maintained by such control of the fuel supply to the burners 11. The construction of the differential device of Fig. 11, however, may be utilized in the embodiment of Fig. 2 when it is desired to maintain the combustion gas pressure somewhat in excess of the steam pressure, the rod 111 of Fig. 11 being connected to the lever 140 in the manner shown in Fig. 2.

In Fig. 3 the steam generating tubes 65 are also of serpentine form, the feed water being delivered thereto through the pipe 35 and the steam being discharged therefrom through pipe 73. In this embodiment the differential device 100 is connected to the gas space through pipe 107 and to the steam space through pipe 109 as in Figs. 1 and 2, the pressure of the steam in this embodiment also being normally somewhat in excess of the pressure of gas in the combustion chamber. The rod 111 is connected at its lower end to a stiff arm 151 to the opposite ends of which respectively are connected the stems 153 and 155 of the fuel supply valve 119 and of the valve 157 for controlling the delivery of the compressed air through the pipe 21 to the combustion chamber. As shown in Fig. 3 the valves are of such construction and arranged in relation to the stiff arm 151 that upward and downward movement of the rod 111 respectively effect closing and opening movements of both the valve disc 120 of the valve 119 and of the valve disc 159 of the valve 157 in response to increase and decrease in the steam pressure relative to the gas pressure. It thus will be apparent that an increase of the steam pressure relative to the gas pressure is effective to decrease the supply of fuel to the burner 11 through the pipe 17 and simultaneously to decrease the delivery of the compressed air to the combustion chamber through the pipe 21 so as to supply the air requisite for the combustion of the decreased amount of fuel. Correspondingly when the steam pressure decreases relative to the gas pressure the control device of Fig. 3 is effective to increase the supply of fuel to the burner 11 and correspondingly to increase the flow of compressed air through pipe 21 to the combustion chamber.

In order to maintain a predetermined relation between the pressure of the gas within the combustion chamber and the steam pressure desired for operation of the steam generator of the invention means are provided in the embodiment of Fig. 3 for regulating the delivery of the air in response to variations in the pressure within the combustion chamber. In a bypass pipe 161 about the valve 157 is connected a valve 163 of the pressure regulating type provided with a diaphragm within the cell 164 responsive through pipe 165 to the pressure in the pipe 21. The pipe 21 may be of such size that the pressure to which the diaphragm of the valve 163 is subjected is substantially that of the combustion chamber or the pipe 165 may be connected directly to the combustion chamber. The diaphragm actuates the valve stem of the valve 163 to effect flow restricting movement of the valve disc 167 upon an increase in the pressure in the combustion chamber and will close the valve when the combustion chamber pressure equals or is in excess of a desired predetermined pressure above atmospheric pressure. Upon reduction of this combustion chamber pressure below the desired pressure opening movement of the valve disc 167 is effected by bias means such as a spring 168 as in conventional pressure regulating devices to increase the flow.

The condition may arise that the delivery of the compressed air from a compressor through

the pipe 21 connected thereto under the control of the valve 157 is in an amount which, although sufficient for the efficient combustion of the fuel delivered to the burner 11 under the control of the valve 119, and to maintain or increase the steam pressure, may be insufficient to maintain the pressure of the gases in the combustion chamber requisite for the predetermined difference of pressure between the pressure of steam and gases to which the device 100, Fig. 3, is responsive. In such event sufficient air is delivered through bypass 161 and the control valve 163 to restore and maintain the desired predetermined pressure in the combustion chamber. Thus, if the condition occurs that the pressure of the steam falls relative to the pressure of the combustion gases within the combustion chamber and both the valve discs 120 and 159 are moved from or further from their seats in response to the differential device 100 to increase the supply of fuel and the flow of the compressed air and to increase the steam generation and the pressure of the generated steam, the pressure within the combustion chamber may be maintained up to the desired pressure or may tend to be restored to the desired pressure by delivery of additional air through the bypass valve 163 if the flow through valve 159 is insufficient. If, on the contrary, the pressure of the steam rises relative to the combustion chamber pressure the valve discs 120 and 159 will move toward their seats to reduce both the supply of fuel and the delivery of the compressed air to the combustion chamber. Any such reduction of the compressed air delivery which causes the pressure within the combustion chamber to fall below the desired predetermined pressure will cause the valve disc 167 to move from its seat to supply additional air through the bypass to restore the pressure within the combustion chamber to the desired pressure. Correspondingly if, due to increased withdrawal of the combustion gases from the casing 3 through the discharge pipe 41 or for other reason, the pressure within the combustion chamber tends to fall relative to the steam pressure the differential device 100 acts to produce closing movement of the valve discs 120 and 159 to reduce the supply of fuel and of combustion air so as to reduce the pressure of the steam to maintain a predetermined differential. The valve 163, however, will prevent undue reduction of the combustion chamber pressure by opening to deliver additional compressed air to the combustion chamber to restore this pressure to the desired predetermined pressure. Thus the valve 163 serves in cooperation with the valves 119 and 157 to maintain not only a predetermined pressure above atmosphere within the combustion chamber but the predetermined difference between the pressure of the steam and of the combustion gases within the casing 3.

In Fig. 4 is shown an embodiment of the invention which utilizes for control of the fuel and air supply a conventional device responsive to the steam pressure. In this embodiment the steam generating tubes 65 also are shown diagrammatically as of serpentine form, the feed water being delivered thereto through the pine 35 and the steam being discharged through pipe 73 controlled by the valve 79. Gases are discharged from the casing 3 through pipe 41 controlled by the valve 43.

The device for controlling the combustion within the combustion chamber comprises a cylinder 175 having a piston 176 movable therein. The space above the piston 176 is connected by the pipe 177 to the steam outlet pipe 73 so that the pressure of the generated steam is brought upon the upper face of the piston 176. At the under side of the piston 176 is a spring 179 compressed upon the increase of the steam pressure and effective to move the piston 176 upward upon reduction of the steam pressure. Increase and decrease of the steam pressure produces respectively downward and upward movement of the rod 181. To this rod is connected the horizontally extending arm of a bell crank lever 183 the downwardly extending arm of which is connected to the stem of the valve 185 to move the valve disc 186 of this valve toward its seat 187 upon downward movement of rod 181, thereby to decrease the flow of the fuel through the pipe 17 to the burner 11. Downward movement of the rod 181 also effects movement of the bell crank 189 the horizontally extending arm of which is connected to the rod 181 so that the downwardly extending arm of this bell crank lever connected to the stem of the valve 191 moves the valve disc 192 toward the valve seat 193, thereby to reduce the supply of fuel through the pipe 195 to an internal combustion engine or a gas engine 197. The piston 199 of this engine in the embodiment of Fig. 4 is connected by the piston rod 200 to the piston 201 of an air compressor 203. The air delivery pipe 21 connects this compressor to the combustion space within the casing 3 of the steam generator as in the embodiments previously described. It will be apparent that as the steam pressure increases both the supply of the fuel to the combustion chamber and the supply of the fuel to the engine driving the compressor will be decreased, thereby decreasing the delivery of the compressed air to the combustion chamber simultaneously with the decrease of the supply of fuel to the combustion chamber and decrease in the heat release. Conversely upon decrease of the steam pressure the piston 176 is moved upwardly and the supply of the fuel to the combustion chamber and to the prime mover 197 are increased to increase the release of heat in the combustion chamber.

As shown in Fig. 4 the steam generated in the steam generating tubes 65 is delivered by pipe 73 through valve 79 and through a pipe 205 to a steam turbine 207 for developing power therefrom. This turbine is controlled by a governor 209 actuating the governor valve 211 to control the speed of the turbine in response to variations in the speed and of load in the conventional manner. The gases discharged from the gas space within the casing 3 of the steam generator are delivered through the valve 43 and the pipe 213 to a gas turbine 215 for developing power therefrom. The rotor of this turbine is mounted on the same shaft as the rotor of the steam turbine 207. In the embodiment of Fig. 4 no governor and governor valve is provided in the gas turbine 215 for control of the combustion gases delivered thereto under pressure from the space within the casing 3. The two fluids, however, namely steam and combustion gases, under pressure of like degree or at equal pressures are delivered to the respective turbines for development of power upon the same shaft in cooperation with each other by expansion of the steam and the gases in the respective turbines. The speed of the shaft for a given load thereon will depend upon the combined effort induced thereon by the two fluids.

In order to control the operation of the gas

turbine 215 in proper relation to the operation of the steam turbine 207 in the embodiment of Fig. 4 a differential device 220 is provided which comprises a vertically disposed cylinder within which is movable a piston 221. To the space above the piston 221 connection is established through the pipe 223 to the steam delivery pipe 205 so that the pressure of the generated steam substantially is brought upon the upper face of the piston 221. Similarly through pipe 225 connection is established between the space beneath the piston 221 and the gas delivery pipe 213 so that the pressure at the under face of the piston is substantially that of the gases discharged from the space within the casing 3 of the steam generator. The size of the pipes and connections and the length thereof in Fig. 4 are not significant, the drawing being diagrammatic. In a practical embodiment the differential device 220 may be suitably located and the connections may be made so as to avoid under pressure drop. Increase and decrease of the generated steam pressure relative to the gas pressure developed in the combustion chamber, therefore, is effective to move the piston 221 downwardly and upwardly.

The piston rod 222 of the device 220 extends outwardly of the cylinder at the upper and lower ends thereof. The upper end of the rod 222 is connected to the valve disc 227 of a valve 229 connected in the steam delivery pipe 205, the lower end of rod 222 being connected to the valve disc 227 of a valve 229 connected in the steam delivery pipe 205. The lower end of rod 222 is connected to valve disc 231 of a valve 233 connected in the pipe 213 delivering the combustion gases to the gas turbine 215. The valves 229 and 233 and their valve discs and seats are so arranged in relation to the rod 222 that upward movement of the piston 221 effects closing movement of the steam control valve disc 227 and opening movement of the gas control valve disc 231. Downward movement of the piston 221 effects opening movement of the steam control valve disc 227 and closing movement of the gas control valve disc 231.

It will be understood, therefore, that as the steam pressure rises in the steam generating tubes and in the delivery pipe 205 opening movement of the valve disc 227 will be effected and correspondingly closing movement of the gas control valve disc 231. This operation will provide for increased flow of the steam through the pipe 205 to the turbine 207 and will decrease the flow of the combustion gases through the pipe 213 to the gas turbine 215. Such operation will tend to increase the speed of the steam turbine and the power output thereof and to decrease the speed of the gas turbine and the power output thereof. The speed of both turbines, however, is the same as they drive the same shaft. The governor 209 controlling the supply of steam to the steam turbine tends to regulate the speed in response to variations in the load. If under a given load the speed is too low, for the conditions of pressure which have just been stated the increased delivery of the steam through the valve 229 will tend to increase the speed to supply the power demand upon the turbines. Since the power delivered by the gas turbine is reduced, the governor 209 will operate to permit the additional steam supplied through the valve 229 to flow through the governor valve 211 to the steam turbine 207 to maintain the speed and the power delivery of the combined turbine unit. The action of the differential device 220 upon the valve discs 227 and 231, however, will have been effective for restoring the proper differential between the pressure of the steam generated within the steam generating tubes and the pressure of the combustion gases within the casing 3 by increasing the outflow of the generated steam when the steam pressure increases and concomitantly reducing the outflow of the gases from the combustion chamber.

If, on the contrary, the pressure of the steam generated in the steam generating tubes 65 falls relative to the gas pressure within the casing 3, the pressure at the under side of the piston 221 exceeds the pressure at the upper side of this piston and upward movement of the piston rod 222 is effected with closing movement of the valve disc 227 and opening movement of the valve disc 231. By such operation the delivery of the steam from the steam generator to the steam turbine 207 is reduced and the delivery of the gases to the gas turbine 215 is increased. Such throttling of the steam will increase the pressure within the steam generating tubes 65 and such increased flow of the gases decrease the pressure within the combustion chamber so as to maintain the desired relation between the pressure of the steam and of the gases. Such reduction of the steam delivered to the turbine 207 will tend to reduce the speed of the steam turbine and the power delivered thereby. The increase of the flow of the gases to the gas turbine, however, will increase the speed thereof and of the combined unit to maintain the speed thereof and the delivery of power.

In the embodiment of Fig. 4 the steam pressure responsive means 175 and the differential device 220 and the connections thereto are shown in simple diagrammatic form for ease of explanation of the principle of operation. In order to avoid hunting and to secure smoothness of control and the desired degree of regulation it is desirable or necessary to provide additional devices and relays. In Fig. 5 is shown a system of controls for this purpose for effecting control of the supply of fuel to the combustion chamber and the delivery thereto of air at the requisite pressure. In Fig. 5 certain of the parts like those of Fig. 4 have reference numerals corresponding to those of Fig. 4.

In Fig. 5 the device 175 which is responsive to the pressure of the steam is connected through pipe 177 to the pipe 205 which delivers steam from the steam generator 1 to the steam turbine 207 so that the pressure of the generated steam is brought upon the upper face of the piston 176 of the device 175 in opposition to spring 179 in the same manner as shown in Fig. 4. As in Fig. 4 the steam pressure responsive device 175 is operatively connected to the means for supplying the fuel to the burner 11 and to the means for supplying fuel to the internal combustion engines which drive the compressor for delivering the compressed air to the combustion chamber. The piston 176, however, instead of being connected directly to the rod 181 as in Fig. 4 is connected through a relay about to be described, the rod 181 being connected to two sets of fuel pumps for controlling these pumps respectively to control the fuel supplied to the combustion chamber and the fuel supplied to the internal combustion engines.

The piston 176 is connected by piston rod 241 to a transverse bar 243 carried at the lower end of the piston rod 241 so that upward and downward movement of the piston 176 effects upward

and downward movement of the bar 243. Beneath the bar 243 are arranged four valve boxes 245, 247, 249 and 251. The valve boxes 245 and 249 are provided with seats so formed therein that valve discs 253 and 257 respectively therein both move upwardly to closed position of the valves. In the boxes 247 and 251 the seats are formed so that the valve discs 255 and 259 move downwardly to closed position. The stems 261, 263, 265 and 267 respectively of the valve discs 253, 255, 257 and 259 pass upwardly through suitable stuffing boxes (not shown) in the top walls of the boxes 245, 247, 249, 251 and through corresponding holes in the bar 243 in sliding relation to this bar. These valve stems carry flanges 269 at their upper ends and beneath the bar 243 flanges 271. Between the flanges 269 of the valve stems 261, 265 and the bar 243 compression springs 273 are provided which bias these valve stems upwardly with respect to the bar 243 to bring the flanges 271 thereof against the under face of this bar. Between the flanges 271 of the valve stems 263 and 267 and the under face of the bar 243 springs 275 are provided which bias the stems 263 and 267 downwardly relative to the bar to bring the flanges 269 into engagement with the upper face of the bar 243.

In the position shown in Fig. 5, the piston 176 being somewhat below the mid-position in the cylinder 175 bar 243 compresses the springs 275 to close the valves 255 and 259, the bar 243 having moved somewhat away from the flanges 269 of the valve stems 263 and 267. The springs 273 of the valve stems 261 and 265, however, have expanded to move the flanges 271 of these valve stems upwardly into contact with the bar 243, the bar 243 acting as a unit with the flanges 271 and the valve stems 261 and 265 and springs 273 and flanges 269 to hold the valves 253 and 257 downwardly from their seats. Further downward movement of the piston 175 will effect further compression of the springs 275, further downward movement of the stems 263 and 267 not being possible. Such further downward movement of the stems 261, 265 and of the valves 253, 257, however, is possible from the position shown in Fig. 5. Upon upward movement of the piston 176 from the position of Fig. 5 the valves 253 and 257 first will move upwardly into contact with their seats and thereafter the springs 273 will be compressed by the bar 243. Concomitantly upward movement of the bar 243 first will effect expansion of the springs 275 until the bar 243 makes contact with the flanges 269 of the stems 263, 267. Thereafter the valves 255, 259 will be lifted from their seats.

An auxiliary control fluid, such as compressed air, may be delivered to the relay through pipe 277. For the position of the piston 176 as shown in Fig. 5 this compressed control air will flow through the open valve 257 of the box 249 and outwardly through the pipe 279 connected by a T branch to boxes 249 and 251. Flow is prevented into the box 251 since the valve 259 is closed. The pressure delivered through the pipe 279 will open check valve 281 in the head of an operating cylinder 283 to bring the pressure of the control air upon the piston 284 to which the rod 181 is connected. Such pressure introduced above the piston 284 will produce downward movement thereof to effect control of the fuel pumps as about to be described. Such downward movement of the piston 284 effects exhaust of the control air which is beneath the piston with downward opening movement of the

check valve 285. This exhaust air passes through the pipe 287 connected by a T branch to the boxes 245 and 247. The valve 255 in the box 247 is closed so that flow into this box is prevented. The valve 253 in the box 245, however, is open and the exhaust control air may be discharged through this box and through the exhaust pipe 289.

When upon reduction of the steam pressure the piston 176 in the steam pressure responsive device 175 moves upwardly, being impelled by the spring 179 the bar 243 moves upwardly and closes the valves 253 and 257 and thereafter opens the valves 255 and 259. The compressed control air then passes from pipe 277 into the box 247 through the valve 255, now open, and into the pipe 287, being prevented from entering the box 245 since the valve 253 is closed. This brings the pressure upon the check valve 285 to close this check valve in the lower end of the cylinder 283 and upon check valve 291 to open this check valve to admit the control air to the under side of the piston 284, thereby to effect upward movement thereof and of the rod 181. As the valve 257 is now closed the compressed control air is prevented from entering box 249 and the air previously admitted to the space above the piston 284 may pass out through the check valve 293 concomitantly with the closing of the check valve 281 and through pipe 279 and the valve 259 now open in the box 251 to be exhausted through pipe 295.

It will be apparent, therefore, that the rod 181 is moved downwardly with increase of the steam pressure exerted upon the upper face of the piston 176 and is moved upwardly upon reduction of this pressure in a manner similar to the rod 181 but with a difference of action which will be described hereinafter.

In the embodiment of Fig. 5 the rod 181 is connected by a bell crank lever 305 to a horizontally extending rod 307 which is connected to means for controlling the discharge of the fuel feed pumps 309 the pistons of which are actuated from a cam shaft 311 having cams 312 thereon for mechanically engaging in succession the piston rods of these pumps. The horizontally extending rod 307 also is continued to the left for actuating the means for controlling the delivery of fuel from the pumps 313 for feeding the fuel to the burner 11 of the steam generator 1. The pistons of these pumps are actuated by cams 315 carried on cam shaft 316.

The fuel discharged from the pumps 309 is carried through the pipes 317 to cylinders 319, 321, 323 and 325 of internal combustion engines the pistons of which are directly connected to the pistons of air compressors 327, 329, 331, 333. The compressor 327 is utilized for compressing the air for combustion of the fuel in the internal combustion engine cylinders, being delivered thereto through the pipe 335. The compressor cylinder 329 is a low pressure cylinder of a three-stage compressor, the air compressed therein being delivered through pipe 337 to the intermediate stage cylinder 331. The air compressed in the intermediate stage cylinder 331 is delivered through the pipe 338 to the high pressure cylinder 333 from which it is discharged through pipe 339 to the burner housing 340 of the steam generator 1 for delivery within the casing 3 thereof for combustion in the combustion chamberof the fuel supplied to the burner 11.

In the embodiment of Fig. 5, if the pressure of the steam generated in the steam generating

tubes and applied upon the upper face of the piston 176 increases the supply of the fuel both to the burner 11 and to the internal combustion engines driving the air compressor is reduced, thereby to reduce both fuel and air to reduce the combustion of fuel and the release of heat in the combustion chamber. If, on the other hand, the steam pressure decreases upward movement of the rod 181 is effected and the supply of the fuel to the burner 11 and to the engines 319, 321, 323, 325 is increased to increase the supply of fuel to the burner and the delivery of air for the combustion of this fuel, thereby to increase the steam pressure to restore it to the desired pressure. The relay device shown within the dotted rectangle A which includes the bar 243 and the valve boxes 245, 247, 249, 251 and the valves therein operating in the manner described is effective to produce movement of the piston 284 and therefore of the rod 181 controlling the pumps 309 and 313 with sufficient lag behind the action of the piston 176 to avoid hunting. To this end the adjustment of the valves 253, 255, 257 and 259 with respect to their seats and in relation to the bar 243 and the flanges 269, 271 is such that the valves 253, 257, for example, close before the valves 255, 259 open and vice versa so that the compressed control air is locked in the cylinder 283 at both sides of piston 284 and the rod 181 is held in the position to which it has been moved. When, however, the steam pressure in the steam generator is restored to the desired pressure opposite movement of the piston 176 in response thereto will become effective to operate the relay A to reverse the movement of rods 181 and 307 to correspondingly decrease the supply of the fuel and delivery of the compressed air. A smooth control operation thereby is secured of the devices for supplying fuel to the burner and for operation of the compressors to supply the combustion air to the combustion chamber in accordance with the amount of fuel delivered to the burner in response to variations of the steam pressure.

In Fig. 5 also is shown the differential device 220 corresponding to that of Fig. 4. The space at the upper side of the piston 221 of the differential device 220 is connected through pipes 223 and 177 to the steam pipe 205 through which the steam from the steam generator 1 is delivered to the steam turbine 207. The space at the under side of the piston 221 is connected through the pipe 225 to the pipe 213 delivering the combustion gases from within the casing 3 of the steam generator to the gas turbine 215. Within the rectangle B drawn in dotted outline in Fig. 5 is shown a relay structure associated with the differential device 220 corresponding to that shown within the rectangle A associated with the device 175 which is responsive to the steam pressure. The parts within the rectangle B bear reference numerals corresponding to those within the rectangle A but different therefrom by 100. Thus, the cross bar 343 associated with the differential device 220 and the valves 353, 355, 357 and 359 and the respective valve stems and springs function in the same manner as do the parts within the rectangle A when the bar 343 is moved by rod 222 upon movement of piston 221 of the device 220. The compressed control air supplied through the pipe 377 under the control of the relay device B may be delivered through the pipes 379 and 387 to the spaces in the two cylinders 383 and 393 respectively above and below the pistons 384 and 394 in these cylinders. These cylinders are provided with check valves in the heads therein arranged and functioning the same as do the check valves of the cylinder 283 to bring the pressure of the compressed control air simultaneously upon the upper side of the pistons 384 and 394 and to exhaust this pressure therefrom and to bring the pressure upon the lower side of these pistons and to exhaust the pressure therefrom upon operation of the valves 353, 355, 357 and 359 of the device associated with the differential device 220. Both pistons 384 and 394, therefore, are adapted to move downwardly and upwardly in their respective cylinders concomitantly respectively with increase and decrease in the pressure of the steam relative to the pressure of the combustion gases to which the differential device 220 is responsive.

In the apparatus of Fig. 5 the pressure of the steam is intended to be controlled so as to be somewhat less than the pressure of the combustion gases, this difference being measured by the spring 397 bearing on the lower head of the cylinder of the device 220 and upon a flange 358 fastened upon the piston rod 222, thus to bias the piston rod downwardly. Increase in the pressure of the steam relative to the gas pressure aided by the spring 397 will move the bar 343 downwardly to a position such as is shown in Fig. 5 to effect delivery of the compressed control air from pipe 377 through the pipe 379 to move the pistons 384 and 394 downwardly and to exhaust the pressure beneath these pistons through pipe 387 to the discharge pipe 389. Such downward movement of the piston 394 is effective through the piston rod 399 connected to the valve disc 227 in valve 229 inserted in the steam pipe 205 to move this valve disc in the direction away from its seat thereby to increase the delivery of steam to the turbine 207. Similarly, downward movement of the piston 394 connected by the rod 401 to the valve disc 231 of valve 233 inserted in the pipe 213 delivering the combustion gases to the gas turbine 215 effects closing movement of the disc 231 to decrease the flow of the gases to the turbine 215. Conversely, decrease of the steam pressure relative to the gas pressure will effect upward movement of the piston 221 of the differential device 220 resulting in upward movement of the pistons 384 and 394 to effect respectively closing and opening movement of the valve discs 227 and 231. Such movement will reduce the flow of the steam to the steam turbine 207, thereby reducing the outflow of steam from the steam generating tubes of the steam generator 1 to allow the pressure therein to build up and correspondingly will increase the flow of the gases from the combustion space within the casing 3 to reduce the pressure of the combustion gases within this space. Thus, the differential device 220 is effective to control the pressure of the steam generated in the steam generator 1 and of the combustion gases produced in its combustion chamber to maintain the difference between these two pressures substantially constant, the pressure of the steam generated relative to the atmospheric pressure being maintained substantially constant in the conventional manner by the control device 175 which functions through the relay device of the rectangle A controlling the fuel supplies to the burner 11 and to the internal combustion engines 319, 321, 323, 325 driving the compressors to increase and decrease both the fuel and the compressed air supplied to the com-

bustion chamber responsive to decrease and increase of the steam pressure.

Similarly to the embodiment of Fig. 4 the speed of the combined steam turbine-gas turbine unit is controlled by governor 209 of the steam turbine operating the governor valve 211. In the embodiment of Fig. 5, as in Fig. 4, no governor is utilized for control of the gases to the gas turbine, the operation of these turbines with respect to control of the speed and in response to variations in the load being effected in the same manner as described in connection with Fig. 4. It will be understood where the equipressure steam generator of the invention is combined with steam utilizing and gas utilizing prime movers, such as steam and gas turbines, that the steam generator may be located in close proximity to the turbines so that the pipes conducting the steam and the gases to these turbines may be short. Moreover, because of the shortness of the connecting pipes it is possible to make these pipes of large diameter without undue cost. The pressure drop developed in these pipes producing flow of the steam and the gas therethrough, therefore, may be quite small. Pressures of the steam and of the gas as delivered respectively to the steam and gas turbines thus may be not substantially less than the pressures of the steam generated in the steam generator and of the gases as discharged from the casing 3. In the drawings, particularly Figs. 4 and 5, the lengths of the connecting pipes and the diameters thereof are not significant, these pipes and the arrangement of several parts of the apparatus being shown diagrammatically for clearness and to show the principle of operation and of control of the steam generator and the power producing plant of the invention.

In the embodiments of Figs. 1, 2, 3 and 4, hand controlled valves 19 and 23 are shown respectively in the fuel supply line 17 and in the air delivery pipe 21. It will be understood consistent with the above description that the method of operating a steam generator to generate steam by the heat of fuel burned in a combustion chamber within the pressure resisting casing 3 so that the combustion gases may be produced at a pressure of the same degree as the steam pressure may be carried out by hand control of the fuel supply and of the air delivered by a suitable compressor. If the valve 120 in Figs. 1, 2 and 3 is blocked open the fuel supplied through valve 19, for example, may be regulated by hand to supply the heat for generating the steam to be discharged through the discharge pipe 73 and to maintain the desired pressure conditions. The delivery of the compressed air through the valve 23 likewise may be regulated by hand to maintain the pressure within the casing 3 substantially constant concomitantly with discharge of the gases through the pipe 41 and in the desired relation to the pressure of the generated steam or equal thereto. In the apparatus of Fig. 1 the link 125 may be disconnected for this purpose and in Fig. 3 the valve 159 may be blocked open.

In carrying out the equipressure method by hand operation, if the pressure of the steam in the steam generating tubes increases relative to the pressure of the gases within the casing 3, the valve 19 may be throttled to reduce the supply of fuel to the burner 11 sufficiently to decrease the heat release in the combustion chamber sufficiently to reduce the pressure of the steam to the desired degree. Concomitantly with such rise of steam pressure relative to the pressure of the combustion gases the supply of compressed air to the combustion chamber either may be kept constant by hand operation of the valve 23 to allow the steam pressure to become reduced again and so restore the equipressure relation or the valve 23 may be operated to increase the delivery of the compressed air to the combustion chamber in order to increase the pressure of the gases within the casing 3 and thereby reduce the difference between the steam and the gas pressure steam. Conversely, upon reduction of the pressure of the generated steam the valve 19 may be operated to increase the supply of fuel to the burner 11 and the valve 23 may be operated to maintain the pressure of the gases substantially constant or may be throttled to reduce the delivery of the compressed air to the combustion chamber, thereby to reduce the pressure of the gases within the casing 3 to restore the desired difference between the steam pressure and the pressure of the combustion gases.

The method of equipressure steam generation may also be carried out if desired by utilizing a conventional device, such as the device 175 of Fig. 4 which is responsive to the steam pressure, for controlling the supply of fuel to burner to decrease and increase the supply of this fuel as the steam pressure increases and decreases. The delivery of the air to the combustion chamber then may be controlled by hand operation of the valve 23 so as to cause the pressure of the combustion gases to follow the variations of the steam pressure, that is, to increase the delivery of the air if the steam pressure has risen and to decrease the supply of air if the steam pressure has fallen. On the other hand, the device 175 responsive to the steam pressure may be connected to the air delivery control device to increase and decrease delivery of the compressed air to the combustion chamber in response to increase and decrease of the steam pressure, the fuel supply being respectively reduced and increased by operation of the valve 19 by hand.

Although the methods and control devices above described which provide for increase and decrease of the air delivery to increase and decrease the combustion gas pressure concomitantly with decreasing and increasing the supply of fuel to the burners may in some cases adversely affect the desired efficiency of combustion, such methods are primarily effective to insure that the essential predetermined difference or equality of the steam and gas pressures is secured. Auxiliary means may be used to modify the delivery of air relative to fuel supply to secure efficiency while maintaining the requisite pressure control. Without such auxiliary means, however, upon restoration of the proper pressure relation after departure therefrom, the air or the fuel supply or both may be adjusted to secure efficient combustion.

In each of the embodiments shown in the drawings safety valves may be utilized both for relief of the pressure within the casing 3 as well as of the steam pressure within the steam generating structure. Such valves may be connected, for example, respectively to the gas discharge pipe 41 and to the steam discharge pipe 73 of Figs. 1, 2, 3 and 4 and to the corresponding discharge pipes 213 and 205 of Fig. 5 or these safety valves may be connected otherwise to the gas and steam spaces of the generator 1 to effect discharge therethrough of gas or steam upon the development of excessive pressures. As shown in Fig. 1 provision also may be made for removal of the slag which may accumulate in the lower hemi-

spherical end of the refractory lining 31 when solid fuels are used, this removal being effected through pipe 14 controlled by valve 16.

As shown in Fig. 9, instead of all of the steam generating tubes being of hairpin form as are the tubes 65, certain of these tubes may be constructed by the assembly of tubes 68 connected to a header at the lower end thereof in the same manner as are the tubes 67 and 70 of the superheater connected to header 69.

Preferably in the equipressure steam generator of the invention the water to be evaporated is circulated through steam generating tubes under forced circulation. While in the embodiment shown in the drawings this forced circulation is represented as a single passage in succession through the various sections of the heating surface, that is, through the economizer, the several steam generating tubes in succession and through the superheater, other types of steam generating structure may be utilized in which forced recirculation of the water within the structure is provided.

Within the scope of the invention also the structures which have been described in connection with the drawings for the generation of steam and for the development of power therefrom and for the production of combustion gases at high pressure and the development of power therefrom may be utilized for the generation of vapor from other liquids, such as mercury, liquid hydrocarbons, etc. The apparatus and method of operating to maintain equi-pressure conditions lend themselves to use in heating a wide variety of vaporizable liquids as well as gaseous fluids. Various adaptations and modifications of the structure different from those described in connection with the drawings may be utilized for the generation of vapor and the production of combustion gases at a pressure of the same degree or equal to the pressure of the generated vapor and for the control of the operation to maintain the predetermined relation of pressures of vapor and gas. Such variations and modifications are intended to be comprehended within the scope of the appended claims.

This application is a continuation in part of my application Serial No. 472,217, filed January 13, 1943, now abandoned.

I claim:

1. In a vapor generator, a pressure resistant casing enclosing a combustion chamber wherein high pressures approximating the vapor pressures generated in said generator may be maintained, means for supplying fuel to said chamber, means for delivering a combustion supporting gas into said chamber under a pressure of at least 5 kilograms per square centimeter for combustion of the fuel supplied thereto, vapor generating elements within said chamber, and means responsive to variations of the vapor pressure generated within said vapor generating element relative to the pressure of the combustion gases within said chamber for varying the flow of gases through said chamber for maintaining the pressure of the gases within said chamber outside said elements within a predetermined narrow range approximating the pressure of the vapor produced in said elements so that stresses on the heated elements of said generator are limited and only the cool casing is required to withstand high pressure.

2. In a vapor generator, a pressure resistant casing enclosing a combustion chamber wherein high pressures approximating the vapor pressures generated in said generator may be maintained, means for supplying fuel to said chamber, means for delivering a combustion supporting gas into said chamber for combustion of the fuel supplied thereto, a vapor generating element within said chamber, and means responsive to decrease and increase of the pressure of the vapor generated in said vapor generating element relative to the pressure of the combustion gases within said chamber and operatively connected to said means for supplying fuel and to said means for delivering said combustion supporting gas to said chamber for increasing and decreasing the supply of the fuel to said chamber to increase and decrease the pressure of the generated vapor and concomitantly to control the delivery of said combustion supporting gas to said chamber to maintain the pressure of the combustion gases within said chamber in a predetermined relation to the pressure of said vapor.

3. In a vapor generator, a pressure resistant casing enclosing a combustion chamber wherein high pressures approximating the vapor pressures generated in said generator may be maintained, means for supplying fuel to said chamber, means for delivering a combustion supporting gas into said chamber for combustion of the fuel supplied thereto, a vapor generating element within said chamber, and means responsive to decrease and increase of the pressure of the vapor generated in said vapor generating element relative to the pressure of the combustion gases within said chamber and operatively connected to said means for supplying fuel and to said means for delivering said combustion supporting gas to said chamber for increasing and decreasing the supply of the fuel to said chamber to increase and decrease the pressure of the generated vapor and concomitantly to control the delivery of said combustion supporting gas to said chamber to decrease and increase the pressure of the combustion gases within said chamber to maintain the pressure of the combustion gases within a predetermined narrow range with respect to the pressure of the generated vapor.

4. In a vapor generator, a pressure resistant casing enclosing a combustion chamber wherein high pressures approximating the vapor pressures generated in said generator may be maintained, means for supplying fuel to said chamber, means for delivering a combustion supporting gas into said chamber for combustion of the fuel supplied thereto, a vapor generating element within said chamber, means responsive to variations from a predetermined difference between the vapor pressure generated in said vapor generating element and the pressure of the combustion gases within said chamber and operatively connected to said means for supplying said fuel for controlling the supply of said fuel to control the pressure of the generated vapor, and means responsive to variations in the pressure of the gases in said combustion chamber and operatively connected to said means for delivering said combustion supporting gas into said chamber for controlling the delivery of said combustion supporting gas concomitantly with the control of the fuel supplied to said combustion chamber so as to maintain said predetermined difference between the vapor pressure and the pressure of the combustion gases within said chamber substantially constant.

5. In a vapor generator, a pressure resistant casing enclosing a combustion chamber wherein high pressures approximating the vapor pressures generated in said generator may be maintained,

means for supplying fuel to said chamber, means for delivering a combustion supporting gas into said chamber for combustion of the fuel supplied thereto, a vapor generating element within said chamber, means responsive to decrease and increase of the pressure of the vapor generated in said vapor generating element relative to the pressure of the combustion gases within said chamber and operatively connected to said means for supplying fuel to said chamber for increasing and decreasing the supply of fuel to said chamber to increase and decrease the pressure of said generated vapor relative to the pressure of the combustion gases within said chamber, and means responsive to variations in the pressure of said combustion gases within said chamber and operatively connected to said means for delivering said combustion supporting gas thereto for operating said delivery means to maintain said pressure of said combustion gases within said chamber substantially constant.

6. In a vapor generator, a pressure resistant casing enclosing a combustion chamber wherein high pressures approximating the vapor pressures generated in said generator may be maintained, means for supplying fuel to said chamber, means for delivering a combustion supporting gas into said chamber for combustion of the fuel supplied thereto, a vapor generating element within said chamber, means responsive to decrease and increase of the pressure of the vapor generated in said vapor generating element relative to the pressure of the combustion gases within said chamber and operatively connected to said means for supplying fuel and to said means for delivering said combustion supporting gas to said chamber for increasing and decreasing the supply of the fuel and the delivery of said combustion supporting gas to said chamber to increase and decrease the heat of said combustion gases within said chamber to effect increase and decrease of the pressure of the generated vapor relative to said pressure of the combustion gases, and means responsive to variations in the pressure of the combustion gases within said chamber and operatively connected to means for delivering said combustion supporting gas to said chamber for effecting delivery of combustion supporting gas to said chamber so as to maintain said pressure within said combustion chamber substantially constant.

7. In a boiler for working with a combustion air pressure of 5 to 120 kg./cm.^{2} and for generating a steam pressure, a regulatory apparatus comprising a spring piston connected at one end to said air pressure and on the other end to said steam pressure, control means for feeding fuel and combustion supporting air to the boiler, connecting means between said piston and said control means to regulate the supply of fuel and combustion supporting air in response to displacement of the piston resulting from deviations from a substantially equal air pressure and steam pressure.

8. The improved method of operating a vapor generating system wherein a combustion chamber and vapor generating elements are enclosed within a pressure resisting casing, which comprises delivering fuel and a combustion supporting gas to and effecting combustion of fuel in said chamber to produce high temperature combustion gases of high pressure therein, and controlling the feeding of fuel and combustion supporting gas to said combustion chamber while withdrawing the combustion gases therefrom in such manner as to maintain the pressure of the combustion gases in said chamber within a predetermined narrow range with respect to the pressure of the vapor generated in said vapor generating elements.

9. The method of operating a vapor generating system wherein a combustion chamber and a vapor generating element are enclosed within a pressure resisting casing, which comprises supplying fuel to said chamber for combustion therein to generate the vapor by the heat of said fuel at a pressure elevated substantially above atmospheric pressure, delivering a combustion supporting gas into said chamber for support of the combustion of the fuel supplied thereto to produce high temperature combustion gases at a pressure of the degree of the pressure of the generated vapor, increasing and decreasing the supply of the fuel to said combustion chamber in response to decrease and increase in the pressure of said vapor relative to the pressure of said combustion gases in said chamber to increase and decrease the pressure of the generated vapor, and concomitantly decreasing and increasing the delivery of the combustion supporting gas to said chamber to decrease and increase the pressure of the combustion gas in said chamber, thereby to maintain a substantially constant difference between said vapor pressure and the pressure of the combustion gases within said chamber.

10. The method of operating a vapor generating system wherein a combustion chamber and a vapor generating element therein are enclosed within a pressure resisting casing which comprises supplying fuel to said chamber for combustion therein to generate the vapor by the heat of said fuel at a pressure elevated substantially above atmospheric pressure, delivering a combustion supporting gas into said chamber for support of the combustion of the fuel supplied thereto to produce high temperature combustion gases at a pressure of the degree of the pressure of the generated vapor, increasing and decreasing the supply of fuel and the delivery of said combustion supporting gas to said chamber in response to decrease and increase in the pressure of said vapor relative to the pressure of said combustion gases in said chamber to increase and decrease the pressure of the generated vapor, and controlling the delivery of combustion supporting gas to said chamber so as to maintain the pressure of the combustion gases therein substantially constant.

11. The method of operating a steam generating system wherein a combustion chamber is enclosed within pressure confining walls and steam generating tubes are positioned within said chamber in heat insulating relation to said walls which comprises delivering a combustion supporting gas and a fuel to said chamber, effecting combustion of the fuel in said chamber to generate steam in said steam generating tubes at a pressure substantially above atmospheric pressure and to produce combustion gases in said chamber in heat transferring relation to said steam generating tubes, said combustion being effected at a pressure of the degree of the steam generated within said tubes, and controlling the delivery of said combustion supporting gas to said chamber and the combustion of fuel within said chamber in accordance with variations of the pressure of the combustion gases in said chamber relative to said pressure of the generated steam so as to maintain said pressures in a predetermined relation to each other.

12. In a vapor generator, a casing enclosing a combustion chamber, a vapor generating element within said chamber for generating vapor at a pressure substantially above atmospheric pressure, said casing being constructed to confine the combustion gases within said chamber at a pressure substantially the same as the pressure of said vapor, means for supplying fuel to said chamber for combustion therein, means for delivering a combustion supporting gas into said chamber against the pressure therein for support of the combustion of the fuel supplied thereto, means for withdrawing the generated vapor from said vapor generating element, means for withdrawing said combustion gases from said combustion chamber, means responsive to variations of the pressure of said vapor relative to the pressure of the combustion gases and operatively connected to said means for withdrawing said vapor and to said means for withdrawing said combustion gases for controlling the withdrawal of said vapor and of said combustion gases so as to maintain the pressure of said vapor substantially in a predetermined relation to the pressure of said combustion gases.

13. In a vapor generator, a casing enclosing a combustion chamber, a vapor generating element within said chamber for generating vapor at a pressure substantially above atmospheric pressure, said casing being constructed to confine the combustion gases within said chamber at a pressure substantially the same as the pressure of the vapor generated in said vapor generating element, means for supplying fuel to said chamber for combustion therein, means for delivering a combustion supporting gas into said chamber against the pressure therein for support of the combustion of the fuel supplied thereto, means responsive to variations in the pressure of the generated vapor and operatively connected to said means for supplying fuel to said chamber and to said means for delivering said combustion supporting gas into said chamber for controlling the supply of fuel and the delivery of said gas to control the pressure of the generated vapor, means for withdrawing from said vapor generating element the generated vapor substantially at the pressure at which it is generated, means for withdrawing from said combustion chamber the combustion gases substantially at the pressure within said chamber, means responsive to variations of the pressure of said vapor relative to the pressure of the combustion gases and operatively connected to said means for withdrawing said vapor and to said means for withdrawing said combustion gases for controlling the withdrawal of said vapor and of said combustion gases so as to maintain said pressure of said generated vapor substantially in a predetermined relation to the pressure of said combustion gases.

14. In a vapor generator, a casing enclosing a combustion chamber, a vapor generating element within said chamber for generating vapor at a pressure substantially above atmospheric pressure, said casing being constructed to confine the combustion gases within said chamber at a pressure of the degree of the pressure of the vapor to be generated in said generating element, means for supplying fuel to said chamber for combustion therein, means for delivering a combustion supporting gas into said chamber against the pressure therein for support of the combustion of the fuel supplied thereto, means responsive to increases and decreases in the pressure of the generated vapor and operatively connected to said means for supplying fuel to said chamber and to said means for delivery of said combustion supporting gas into said chamber for decreasing and increasing the supply of fuel and the delivery of said combustion supporting gas to said chamber to decrease and increase the heat of said combustion gases to decrease and increase the pressure of said generated vapor, thereby substantially to maintain a predetermined vapor pressure, means for withdrawing from said vapor generating element the generated vapor substantially at the pressure at which it is generated, means for withdrawing from said combustion chamber the combustion gases substantially at the pressure within said chamber, means responsive to variations of said vapor pressure relative to said pressure of the combustion gases and operatively connected to said means for withdrawing said vapor and to said means for withdrawing said combustion gases for controlling the withdrawal of said vapor and of said combustion gases so as to maintain the pressure of said generated vapor substantially in a predetermined relation to the pressure of said combustion gases.

15. In a water tube boiler, a pressure resistant casing enclosing a combustion chamber wherein superatmospheric pressures approximating the steam pressures generated in said boiler may be maintained, means for supplying fuel to said chamber, means for delivering air under pressure into said chamber for combustion of the fuel supplied thereto, steam generating tubes within said chamber, and means responsive to deviations from a predetermined difference in the steam pressure with respect to the pressure of said combustion gases within said chamber for controlling the supply of the fuel and of the air in such a manner as to control the pressure of the steam and the pressure of the combustion gases within the chamber so as to maintain the difference between said steam pressure and the pressure of said combustion gases within said chamber substantially constant.

16. In a vapor generator, a casing enclosing a combustion chamber capable of confining gases therein at a pressure approximating the pressure of the vapor to be generated in said generator, a vapor generating element within said chamber, means for supplying fuel to said chamber, means for delivering a combustion supporting gas under pressure into said chamber for combustion of the fuel therein to produce combustion gases in heat exchanging relation to said vapor generating element at a temperature to generate vapor in said element at a selected pressure and to develop pressure of said combustion gases in said combustion chamber approximating said vapor pressure, means for withdrawing combustion gases from said combustion chamber cooperating with said means for delivering combustion supporting gas thereto so as to produce flow of gases through said chamber, means operable to control said flow of said gases so as to control the pressure thereof within said combustion chamber, and means responsive to the pressure of the vapor generated in said vapor generator relative to the pressure of the gases within said combustion chamber and cooperating with said means for supplying fuel to said chamber and with said gas flow controlling means for controlling the flow of said gases through and the pressure thereof in said chamber in relation to the generation of vapor in said vapor generating element so as to

maintain the difference between the pressure of said vapor and said gases within a predetermined range.

17. In a vapor generator, a casing enclosing a combustion chamber capable of confining gases therein at a pressure approximating the pressure of the vapor to be generated in said generator, a vapor generating element within said chamber, means for supplying fuel to said chamber, means for delivering a combustion supporting gas under pressure into said chamber for combustion of the fuel therein to produce combustion gases in heat exchanging relation to said vapor generating element at a temperature to generate vapor in said element at a selected pressure and to develop pressure of said combustion gases in said combustion chamber approximating said vapor pressure, means for withdrawing combustion gases from said combustion chamber cooperating with said means for delivering combustion supporting gas thereto so as to produce flow of gases through said chamber, means operable to control said flow of said gases so as to control the pressure thereof within said combustion chamber, and means responsive to the pressure of the vapor generated in said vapor generator relative to the

pressure of the gases within said combustion chamber and operatively connected to said gas flow controlling means for controlling the flow of said gases through said combustion chamber so as to maintain the difference between the pressure of said vapor and of said gases within a predetermined range.

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