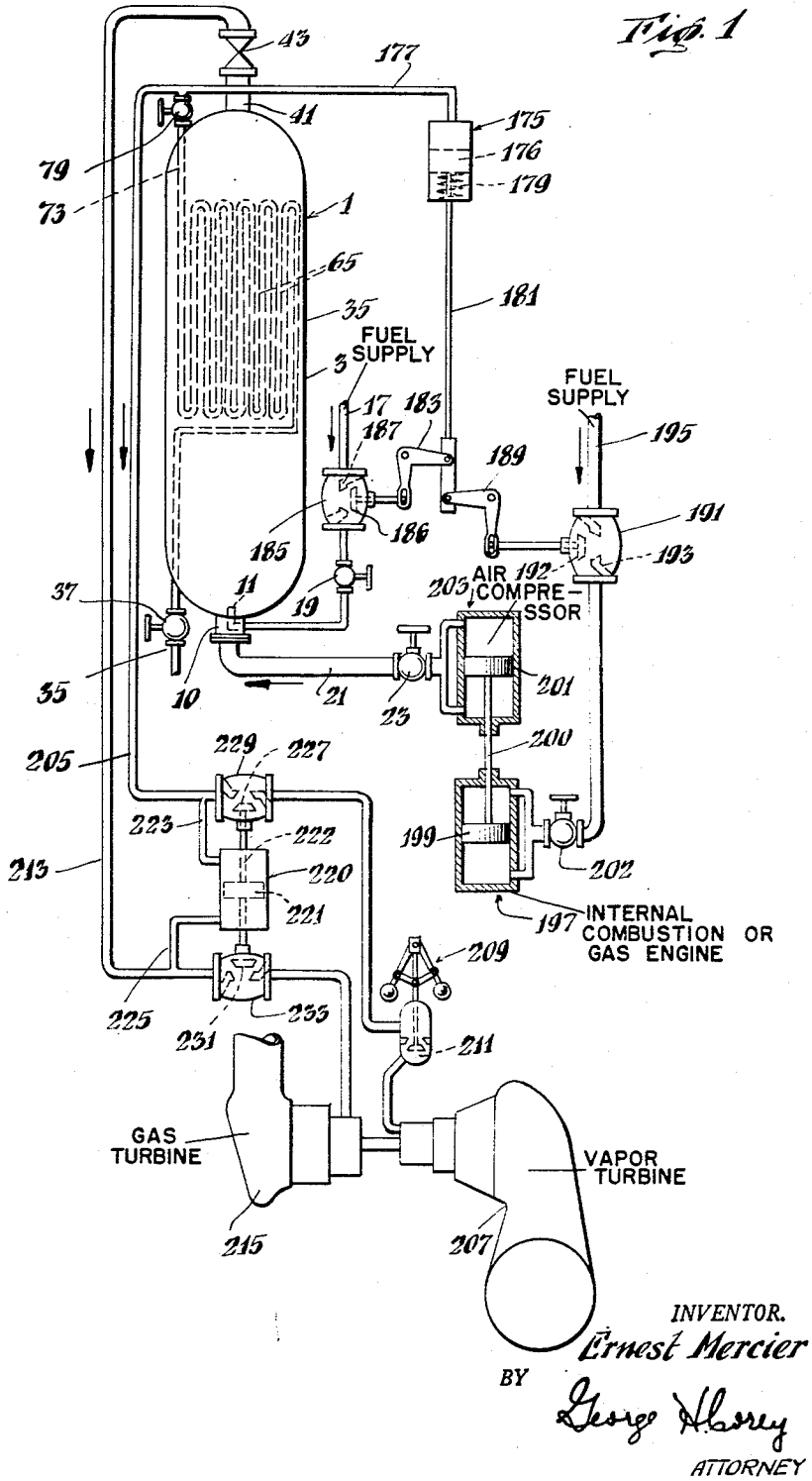
Feb. 22, 1955 E. MERCIER 2,702,453

EQUIPRESSURE POWER GENERATING PLANT AND METHOD OF OPERATING SAME

Original Filed July 9, 1949 2 Sheets-Sheet 1

Fig. 1



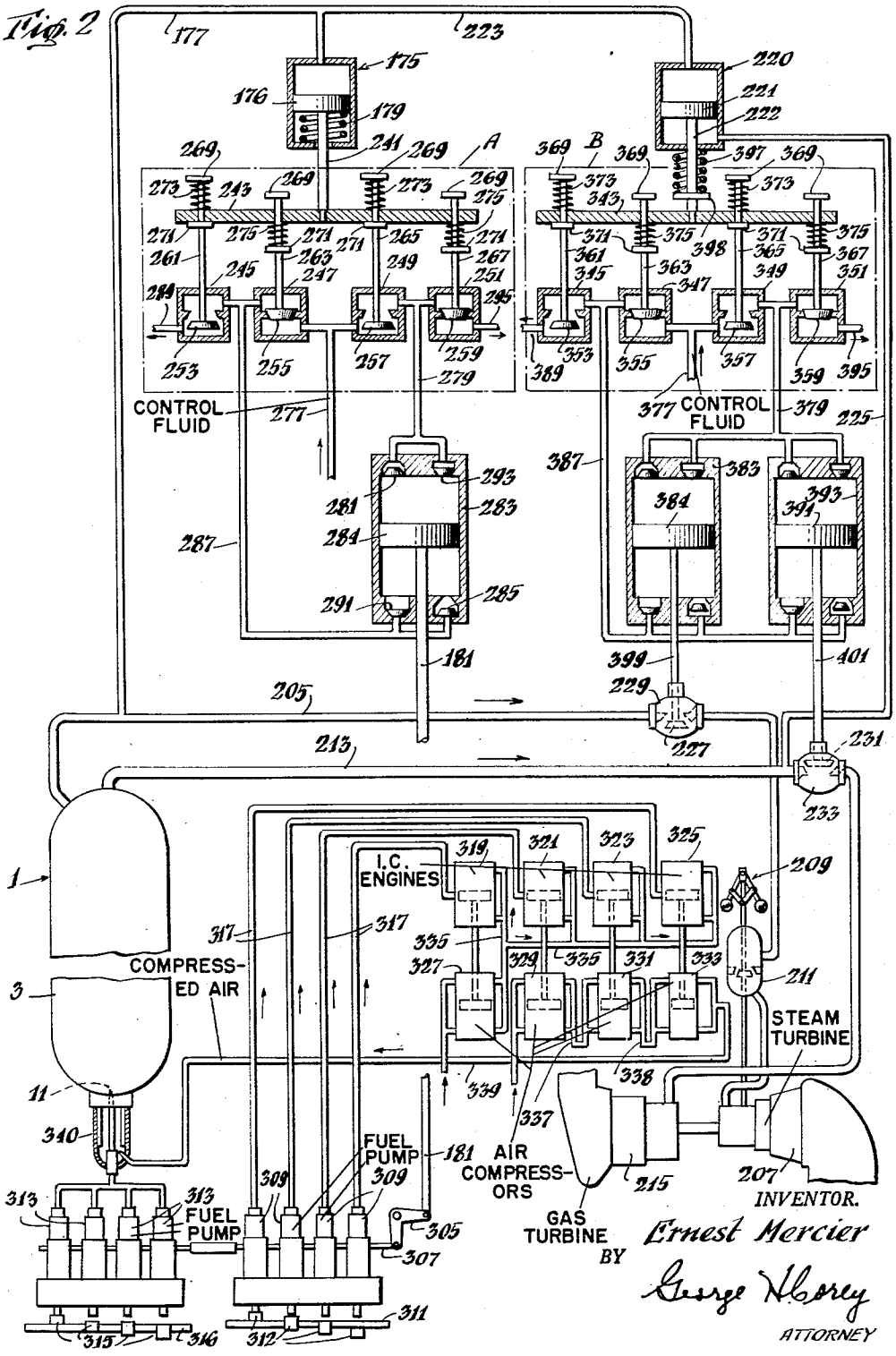
INVENTOR.
Ernest Mercier
BY
George H. Harvey
ATTORNEY

Feb. 22, 1955 E. MERCIER 2,702,453

EQUIPRESSURE POWER GENERATING PLANT AND METHOD OF OPERATING SAME

Original Filed July 9, 1949 2 Sheets-Sheet 2

Fig. 2



United States Patent Office 2,702,453
Patented Feb. 22, 1955

2,702,453

EQUIPRESSURE POWER GENERATING PLANT AND METHOD OF OPERATING SAME

Ernest Mercier, Paris, France, assignor, by mesne assignments, to Mercier Development Corp., New York, N. Y., a corporation of New York

Original application July 9, 1949, Serial No. 103,893, now Patent No. 2,547,135, dated April 3, 1951. Divided and this application March 2, 1951, Serial No. 213,532

17 Claims. (Cl. 60—39.18)

This invention relates to apparatus for the development of power from fluid pressure media under pressures substantially above atmospheric pressure. The invention in particular relates to the development of power in prime movers by utilizing at least two fluids under pressure to develop power respectively in the prime movers concomitantly with reduction of the pressure of these fluids.

In a particular aspect the invention relates to the control of the delivery of the fluids to the respective prime movers in response to variations in the pressures of these fluids with respect to each other so as to maintain the pressures of the fluids in a predetermined relation.

In my copending application Serial No. 103,893, filed July 9, 1949, now Patent No. 2,547,135, issued April 3, 1951, of which the present application is a division, I have disclosed and claimed a vapor generator and the method of operating such a generator in which a vapor generating element is enclosed within a combustion chamber wherein the combustion gases are maintained at a high pressure which approximates the pressure of the vapor generated in the vapor generating element, means being provided for controlling the supply of fuel and the delivery of a combustion supporting gas to the chamber so as to maintain the pressure of the combustion gases within the chamber in a predetermined relation to the pressure of the generated vapor.

As disclosed also in this prior application Serial No. 103,893, the desired predetermined relation of the pressures of the combustion gases and the vapor generated may be maintained by controlling the withdrawal of the vapor and of the combustion gases from the vapor generating element and from the combustion chamber in response to variations from a predetermined difference between the pressure of the vapor relative to the pressure of the combustion gases. Various means are disclosed in the prior application for controlling the combustion of the fuel and the pressure of the gases within the combustion chamber to secure and maintain this desired predetermined relation of the pressures of the generated vapor and of the combustion gases. A differential device responsive to the pressure of the generated vapor and to the pressure of the combustion gases is utilized to actuate the different control means as disclosed in the application Serial No. 103,893.

The present invention relates to an aspect of the disclosure of the earlier application in which the vapor withdrawn from the vapor generating element is delivered to a vapor utilizing prime mover and the combustion gases withdrawn from the combustion chamber are delivered to a gas utilizing prime mover respectively for developing power in these prime movers from the vapor and from the combustion gases. Preferably, as disclosed in the earlier application, the pressures of the vapor so withdrawn and of the combustion gases withdrawn from the combustion chamber are of the same order or substantially equal, and these pressures may be of the degree, for example, of 80 to 120 atmospheres or higher. Moreover, the combustion gases may be produced in the combustion chamber at temperatures ordinarily developed by conventional combustion of 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

generation of the vapor may become reduced, for example, to 500° C. as the gases are discharged from the casing. These gases at substantially the same pressure and temperature are delivered to the gas utilizing prime mover. 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.

The vapor generated, ordinarily steam from water, may be generated in thin walled vapor generating elements, as disclosed in my earlier application Serial No. 103,893 and in prior application Serial No. 7,586, filed February 11, 1948, now Patent No. 2,618,247, issued Nov. 18, 1952, since the pressure of such vapor may be of the same order or equal to the pressure of the combustion gases enveloping the vapor generating elements disposed within the combustion chamber. The vapor or steam utilizing prime mover which may receive the vapor at substantially the same pressure at which it is generated in the vapor generating element may be of conventional construction capable of utilizing such vapor to develop power therefrom, for example, steam at a pressure of 80 to 120 atmospheres superheated to any desired degree.

It is an important feature of the invention that delivery or flow of the vapor to the vapor utilizing prime mover and the delivery or flow of the combustion gases to the gas utilizing prime mover are controlled in such a manner as to maintain the pressure of vapor and of combustion gases in a predetermined relation to each other. Preferably, the means for controlling the delivery or flow of the vapor to the vapor utilizing prime mover and for controlling the delivery or flow of the combustion gases to the gas utilizing prime mover both are operatively connected to means responsive to variations in a predetermined difference between the pressure of the vapor and the pressure of the gases as they flow toward the respective prime movers, that is, in the preferred embodiment, as they flow respectively from the vapor generating element and from the combustion chamber.

It is a significant feature of the invention that this control is effected by means, such as a differential device connected so as to be responsive both to the pressure of the generated vapor and to the pressure of the combustion gases, that is, responsive to the difference between these pressures, which effects an increase in the delivery or flow of a given one of these fluids to the corresponding prime mover when the pressure of such given fluid increases with respect to the pressure of the other fluid. Concomitantly the device effects decrease of the flow of the other fluid to the prime mover receiving this other fluid. Preferably, the device utilized for thus controlling the deliveries of the respective fluids to the prime movers cooperates with a conventional governor or speed regulating device which is responsive to the variations in speed produced, for example, by the load carried by the prime mover.

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

Fig. 1 shows diagrammatically a power plant including a steam generator 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 from these gases in these prime movers.

Fig. 2 shows a modification of the power plant of Fig. 1, in which the pressure responsive controls include relays for controlling an auxiliary or control fluid for operating the fuel supply control means and the means for delivering air to the combustion chamber, as well as for operating the steam and gas flow control means.

In Fig. 1 is shown more or less diagrammatically a steam generator or equipressure boiler 1 having a casing 3 which may be constructed as a steel cylinder having hemispherical upper and lower ends. At the lower end of the casing 3 a flanged nozzle 10 is provided for the admission of air and for the insertion of the burners 11

disposed at the entrance of the nozzle into the chamber within the casing 3. The air for combustion may be delivered through the pipe 21 connected to the nozzle 10, this pipe being controlled by a hand valve 23 and by control of the air compressor about to be described.

Within the casing 3 are disposed the steam generating elements or tubes 65 which in the embodiment shown in Fig. 1 are of serpentine form, the feed water being delivered to these tubes through the pipe 35 controlled by valve 37. The steam generated in the elements 65 may be discharged through the pipe 73. If desired, in accordance with the construction disclosed in my earlier application Serial No. 103,893, or by conventional means, the steam generated in the tube 65 may be superheated to any desired superheat temperature before discharge through the pipe 73, this discharge being controlled by the valve 79 in pipe 73. The combustion gases after passing over the steam generating tubes 65 and over the superheater, if such is provided, are discharged from the casing 3 through pipe 41 controlled by 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 pipe 177 to the steam outlet pipe 73 so that the pressure of the generated steam is brought from the upper face of the piston 176. At the underside of the piston 176 is a spring 179 compressed upon increase of the steam pressure and effective to move the piston 176 upwardly upon reduction of the steam pressure. Increase and decrease of the steam pressure produce respectively downward and upward movement of the rod 181. To this rod is connected a horizontally extending arm of a bell crank 183 the downwardly extending arm of which is connected to the stem of valve 185 inserted in the fuel supply pipe 17 leading to the burner 11. Downward movement of the rod 181 moves the valve disc 186 of the valve 185 toward its seat 187, thereby to decrease the flow of fuel to the burner 11. Downward movement of the rod 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 connected to the stem of valve 191 moves the valve disc 192 toward the valve seat 193, the valve 191 being connected in pipe 195 which supplies fuel to an internal combustion engine or a gas engine 197. The supply of fuel to this engine thus is reduced. The piston 199 of this engine in the embodiment of Fig. 1 is connected by the piston rod 200 to the piston 201 of an air compressor 203, this compressor being connected to the air delivery pipe 21 to deliver the compressed air to the combustion space within the casing 3, as above referred to.

It will be apparent as the steam pressure increases, thus effecting downward movement of rod 181, both the supply of fuel to the combustion chamber through valve 185 and the supply of fuel to the engine 197 through the valve 191 will be decreased, thereby also decreasing the delivery of the compressed air to the combustion chamber because the compressor 203 will be slowed down. This simultaneous decrease of the supply of fuel and air to the combustion chamber decreases the heat release in the combustion chamber and, therefore, decreases the generation of steam and effects the reduction of the pressure of the steam as the steam is gradually withdrawn from the steam generating tubes 65 through the pipe 205. Conversely, upon decrease of the steam pressure the piston 176 is moved upwardly by the spring 179 and the supply of fuel to the combustion chamber and to the prime mover 197 is increased, the supply of compressed air from the compressor 203 correspondingly being increased. The release of heat in the combustion chamber therefore is increased to increase generation of steam in the steam generating tubes 65, thereby to restore the pressure of the steam and correspondingly to reactuate the piston 176 downwardly to a balanced position. In this manner the pressure of the steam generated may be maintained substantially constant or within a predetermined degree of variation of such pressure.

As shown in Fig. 1 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. 1 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. 1 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 the connections and the length thereof in Fig. 1 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 undue 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 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. The speed of both turbines, however, is the same or in a predetermined relation 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 because of the reduced gas supply thereto, 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 flowing toward the steam turbine and the pressure of the com-

bustion gases flowing toward the gas turbine by increasing such flow of the steam when the steam pressure increases and concomitantly reducing the flow of the gases.

If, on the contrary, the pressure of the steam flowing from the tubes **65** falls relative to the pressure of the gases flowing from 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. 1 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. 2 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. 2 certain of the parts like those of Fig. 1 have reference numerals corresponding to those of Fig. 1.

In Fig. 2 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. 1. As in Fig. 1 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. 1 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** and **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. 2, 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 **176** 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. 2. Upon upward movement of the piston **176** from the position of Fig. 2 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. 2 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 the 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 and 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 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**, Fig. 1 but with a difference of action which will be described hereinafter.

In the embodiment of Fig. 2 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 shafts **311** and **316** may be driven by any suitable means.

The fuel discharge 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 chamber of the fuel supplied to the burner **11**.

In the embodiment of Fig. 2, 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 fuel to the burner **11** and to the engines **319**, **321**, **323**, **325** is increased to increase simultaneously 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 the 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 modify the supply of fuel and delivery of the compressed air. A smooth control operation thereby is secured of the device 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. 2 also is shown the differential device **220** corresponding to that of Fig. 1. 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. 2 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 is responsive.

In the apparatus of Fig. 2 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 **398** 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. 2 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 combustion chamber responsive to decrease and increase of the steam pressure.

Similarly to the embodiment of Fig. 1 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. 2, as in Fig. 1, 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. 1. It will be understood where the equipressure steam generator of the invention is combined with steam utilizing and gas utilizing prime movers, such as gas and steam 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 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 embodiment of Fig. 1 hand controlled valves 19 and 23 are shown respectively in fuel supply line 17 and the air delivery pipe 21. It will be understood that the steam generator may be operated by hand operation of the valves 19 and 23 to generate steam by the heat of the fuel burned in the combustion chamber so that the combustion gases may be produced at a pressure of the same degree as the steam pressure. Such operation may be accomplished with the apparatus of Fig. 1 by blocking open the valve discs 186 and 192 respectively of the fuel supply valve 185 and the fuel supply valve 191. The compressor 203 then may be controlled by the hand operated valve 202 in the pipe 195 supplying fuel to the internal combustion engine 197.

In carrying out the equipressure method by hand operation, if the pressure of the steam in the steam generating tubes 65 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 thereby 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 to 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 pressure and the gas pressure. 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 combustion 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 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. 1 which is responsive to the steam pressure, for controlling the supply of fuel to burner 11 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.

In each of the embodiments shown in the drawings safety valves may be utilized both for the release of the pressure within the casing 3 as well as of the steam pressure within the steam generating and superheater structure. Such valves may be connected, for example, respectively to the gas discharge pipe 41 and to the steam discharge pipe 73 of Fig. 1 and to the corresponding discharge pipes 213 and 205 of Fig. 2, or these safety valves may be connected otherwise to the gas and steam spaces of the generator 1 or of the pipes leading to the prime movers 215 and 207 to effect discharge therethrough of gas or steam upon the development of excessive pressures.

Preferably, in the equipressure power plant of the invention the liquid to be vaporized is circulated through the vapor generating tube 65 under forced circulation. While in the embodiment shown diagrammatically in Fig. 1 the path of this circulation is represented as a single passage in succession through the various sections of the heating surface, that is, through the economizer, the several vapor generating tubes in succession and through the superheater, other types of vapor generating structures may be utilized in which forced circulation of the liquid within the structure is provided, the vapor which may be superheated, if desired, being delivered at the outlet of the tube, that is, through the discharge pipe 73.

Within the scope of the invention also the structures which have been described in connection with the drawings for the generation of steam at high pressure and for the development of power therefrom and for the production of combustion gases at high pressure and temperature and the development of power therefrom may be utilized for the generation and utilization of vapor from other liquids such as mercury, liquid hydrocarbons, etc. The apparatus for and the method of operating the power plant of the invention to maintain equipressure conditions not only in the generation of vapor and gas but also in the delivery of these fluids to respective prime movers lend themselves to the heating of a wide variety of vaporizable liquids as well as gaseous fluids. Various adaptations and modifications of the structure different from those described and shown in the drawings may be utilized for the generation of vapor and the production of combustion gases at a pressure of the same degree as the pressure of the generated vapor and for control of the operation of the prime movers to maintain the desired predetermined relation of the pressures of vapor and gas. Such variations and modifications are intended to be comprehended within the scope of the appended claims.

I claim:

1. A power generating plant for developing power from two fluid pressure media under pressures substantially above atmospheric pressure which comprises a pair of prime movers respectively adapted to utilize said fluid pressure media to develop power therefrom, means respectively connected to said prime movers for delivering the respective fluid pressure media respectively at said pressures to said prime movers, means respectively operatively connected to said two delivery means for controlling delivery of the respective fluids to said prime movers, and means responsive to variations from a predetermined difference between the pressures of said fluids and operatively connected to said two delivery control means for operating said two control means to control said deliveries so as to maintain substantially constant said predetermined difference between the pressures of said fluid pressure media.

2. A power generating plant for developing power from two fluid pressure media under pressures substantially above atmospheric pressure which comprises a pair of prime movers respectively adapted to utilize said fluid pressure media to develop power therefrom, means respectively connected to said prime movers for delivering the respective fluid pressure media respectively at said pressures to said prime movers, means respectively operatively connected to said two delivery means for controlling delivery of the respective fluids to said prime movers, and means responsive to variations from a predetermined difference between the pressures of said fluids and operatively connected to said two delivery control means for operating said two control means to control said deliveries so that respectively upon increase and decrease of the pressure of a given one of said fluid pressure media relative to the pressure of the other fluid pressure medium the delivery of said given fluid pressure medium to the corresponding prime mover is increased and decreased and the delivery of the other fluid pressure medium to the other prime mover is decreased and increased.

3. A power generating plant for developing power from two fluid pressure media under pressures substantially above atmospheric pressure which comprises a pair of prime movers respectively adapted to utilize said fluid pressure media to develop power therefrom, means respectively adapted for generating said fluid pressure media at said pressures thereof substantially above atmospheric pressure, means respectively connecting said two generating means to said prime movers for delivery of the respective fluid pressure media to said prime movers for developing power therefrom, means respectively operatively connected to said two delivery means for controlling respectively the delivery of said fluid pressure media from said two generating means to said prime movers, and means responsive to variations from a predetermined difference between the pressures of said fluid pressure media

and operatively connected to said two delivery control means for operating said two delivery control means to control delivery of said fluid pressure media to said prime movers so that respectively upon increase and decrease of the pressure of a given one of said fluid pressure media relative to the pressure of the other fluid pressure medium the delivery of said given fluid pressure medium to the corresponding prime mover is increased and decreased and the delivery of said other fluid pressure medium to the other prime mover is decreased and increased.

4. A power generating plant for developing power from two fluid pressure media under pressures substantially above atmospheric pressure which comprises a casing providing a chamber and constructed to confine within said chamber a gaseous fluid at a pressure elevated substantially above atmospheric pressure, an element for confining therein an expansible fluid at a pressure substantially above atmospheric pressure and for transferring to said fluid therein heat received by said element, means connected to said chamber for producing within said chamber said gaseous fluid at said elevated pressure in heat transferring relation to said element and at a temperature elevated so as to effect transfer of heat to said element and to said fluid therein, a prime mover connected by fluid conveying means to said element to receive therefrom said heated expansible fluid at said elevated pressure to develop power by expansion of said expansible fluid in said prime mover, a gas utilizing prime mover connected by gas conveying means to said chamber to receive therefrom said gaseous fluid at said elevated pressure for utilization in said gas utilizing prime mover to develop power therefrom, means connected to said fluid conveying means for controlling delivery of said expansible fluid from said element to said prime mover connected to said element, means connected to said gas conveying means for controlling delivery of said gaseous fluid from said chamber to said gas utilizing prime mover, and means responsive to variations from a predetermined difference between the pressure of said expansible fluid and the pressure of said gaseous fluid and operatively connected to said means for controlling delivery of said expansible fluid and to said means for controlling delivery of said gaseous fluid respectively to said prime movers for operating said two control means to control said deliveries so that respectively upon increase and decrease of the pressure of a given one of said fluids relative to the pressure of the other fluid the delivery of said given fluid to the corresponding prime mover is increased and decreased and the delivery of the other fluid to the other prime mover is decreased and increased.

5. A power generating plant for developing power from two fluid pressure media under pressures substantially above atmospheric pressure which comprises a casing enclosing a combustion chamber, a vapor generating element within said chamber for generating vapor at a pressure elevated substantially above atmospheric pressure, said casing being constructed to confine the combustion gases therein at a pressure elevated substantially above atmospheric pressure and in heat transferring relation to said element, means for supplying fuel to said combustion chamber for combustion therein, means for delivering a combustion supporting gas into said chamber against the pressure therein for support of the combustion at said elevated pressure of the fuel supplied to said chamber to generate the vapor at said elevated pressure in said element, a vapor utilizing prime mover connected by a vapor conveying conduit to said vapor generating element to receive therefrom said generated vapor substantially at said elevated pressure for utilization in said prime mover to develop power therefrom, a gas utilizing prime mover connected by a gas conveying conduit to said combustion chamber to receive therefrom said combustion gases substantially at said elevated pressure for utilization in said gas prime mover to develop power therefrom, means connected to said vapor conveying conduit for controlling the delivery of said vapor from said vapor generating element to said vapor utilizing prime mover, means connected to said gas conveying conduit for controlling the delivery of the combustion gases from said combustion chamber to said gas utilizing prime mover, and means responsive to variations from a predetermined difference between the pressure of the generated vapor and the pressure of the combustion gases and operatively connected to said means for controlling the delivery of said vapor and to said means for controlling the delivery of said combustion gases respectively to said prime movers for operating said two control means to vary the delivery of the vapor inversely with respect to the delivery of the gas and directly with variation of the pressure of the vapor relative to the pressure of the gas so as to maintain substantially constant said predetermined difference between the pressure of said vapor delivered to said vapor utilizing prime mover and the pressure of said combustion gases delivered to said gas utilizing prime mover.

6. A power generating plant for developing power from two fluid pressure media under pressures substantially above atmospheric pressure which comprises a casing enclosing a combustion chamber, a vapor generating element within said chamber for generating vapor at a pressure elevated substantially above atmospheric pressure, said casing being constructed to confine the combustion gases therein at a pressure elevated substantially above atmospheric pressure and in heat transferring relation to said element, means for supplying fuel to said combustion chamber for combustion therein, means for delivering a combustion supporting gas into said chamber against the pressure therein for support of the combustion at said elevated pressure of the fuel supplied to said chamber to generate the vapor at said elevated pressure in said element, a vapor utilizing prime mover connected by a vapor conveying conduit to said vapor generating element to receive therefrom said generated vapor substantially at said elevated pressure for utilization in said prime mover to develop power therefrom, a gas utilizing prime mover connected by a gas conveying conduit to said combustion chamber to receive therefrom said combustion gases substantially at said elevated pressure for utilization in said gas prime mover to develop power therefrom, means connected to said vapor conveying conduit for controlling the delivery of said vapor from said vapor generating element to said vapor utilizing prime mover, means connected to said gas conveying conduit for controlling the delivery of the combustion gases from said combustion chamber to said gas utilizing prime mover, and means responsive to variations from a predetermined difference between the pressure of the generated vapor and the pressure of the combustion gases and operatively connected to said means for controlling the delivery of said vapor and to said means for controlling the delivery of said combustion gases respectively to said prime movers for operating said two control means to control said deliveries so that respectively upon increase and decrease of the pressure of a given one of said fluids relative to the pressure of the other fluid the delivery of said given fluid to the corresponding prime mover is increased and decreased and the delivery of said other fluid to the other prime mover is decreased and increased.

7. A power generating plant as defined in claim 5, in which said means responsive to variations from a predetermined difference between the pressure of the generated vapor and the pressure of the combustion gases is adapted to maintain said vapor pressure and said combustion gas pressure substantially equal.

8. A power generating plant as defined in claim 5, in which said means responsive to variations from a predetermined difference between the pressure of said generated vapor and the pressure of said combustion gases comprises means for preventing hunting of said means for controlling delivery of vapor and of said means for controlling delivery of said combustion gases respectively to said prime movers.

9. A power generating plant as defined in claim 5, which comprises means responsive to variations in the pressure of the vapor delivered to said vapor utilizing prime mover and operatively connected to said means for supplying fuel to said combustion chamber and operatively connected to said means for delivering a combustion supporting gas into said chamber for controlling the supply of fuel and the delivery of the combustion supporting gas to said chamber to control the pressure of the vapor generated in said vapor generating element.

10. A power generating plant as defined in claim 9, in which said means responsive to variations in the pressure of the vapor delivered to said vapor utilizing prime mover comprises means for preventing hunting operation of said means for supplying fuel to said combustion chamber and of said means for delivering a combustion supporting gas into said chamber.

11. A power generating plant as defined in claim 5, in which said means responsive to variations from said predetermined pressure difference comprises a relay responsive to said variations from said predetermined difference between the pressure of generated vapor and the pressure of the combustion gases and operatively connected to said means for controlling the delivery of said vapor and to said means for controlling the delivery of said combustion gases respectively to said prime movers for controlling said deliveries so as to maintain said predetermined difference substantially constant.

12. A power generating plant as defined in claim 5, which comprises a relay responsive to variations in the pressure of the vapor delivered to said vapor utilizing prime mover, and control means actuated by said relay and operatively connected to said means for supplying fuel to said combustion chamber and operatively connected to said means for delivering a combustion supporting gas into said chamber for controlling the supply of fuel and the delivery of the said combustion supporting gas to said chamber to control the pressure of vapor generated in said vapor generating element.

13. A power generating plant as defined in claim 5, in which said means for delivering a combustion supporting gas to said combustion chamber comprises a compressor for compressing said combustion supporting gas to the pressure within said combustion chamber for delivery thereto, a fuel utilizing prime mover operatively connected to said compressor to drive said compressor, means for feeding fuel to said fuel utilizing prime mover for operation thereof to drive said compressor, and means responsive to variations in the pressure of the vapor delivered to said vapor utilizing prime mover and operativly connected to said means for supplying fuel to said combustion chamber and operatively connected to said means for feeding fuel to said fuel utilizing prime mover for controlling the supply of fuel to said combustion chamber and for controlling the feeding of the fuel to said fuel utilizing prime mover to control the delivery of said combustion supporting gas to said combustion chamber, thereby to control the pressure of the generated vapor.

14. A power generating plant as defined in claim 5, in which said prime movers are operatively connected together to maintain their respective speeds in constant relation to each other, and a governor for one of said prime movers responsive to the speed thereof and controlling the flow of the fluid thereto to control in cooperation with said means responsive to variations from said predetermined difference between the pressure of said vapor and the pressure of said combustion gases the speed and the operation of both said prime movers.

15. A power generating plant as defined in claim 5, in which said means responsive to variations from said predetermined pressure difference comprises a member responsive to said pressure difference and moved respectively in a given direction and in an opposed direction upon increase and decrease of the pressure of a given one of said fluids relative to the pressure of the other fluid, means operatively connecting said member to said vapor delivery controlling means and to said combustion gas delivery controlling means for effecting operation of said two controlling means to respective given control positions and to respective opposed control positions respectively upon movement of said member in said given direction to a predetermined forward position and upon movement of said member in said opposed direction to a predetermined opposed position spaced from said forward position of said member, and means operatively connected to said connecting means for effecting actuation of said connecting means to prevent movement of said vapor delivery controlling means and said combustion gas delivery controlling means in positions of said member intermediate between said predetermined positions thereof.

16. A power generating plant for developing power from two fluids at respective pressures which comprises a pair of prime movers respectively capable of utilizing said fluids at the respective pressures to develop power therefrom, means respectively connected to said prime movers for delivering said fluids respectively at said pressures to the respective prime movers, and control means responsive to variations in the pressures of said fluids relative to each other and operatively connected to said two delivery means for controlling said deliveries of said fluids so as to increase the delivery of a given one of said fluids to the corresponding prime mover concomitantly with decreasing the delivery of the other fluid to the other prime mover upon increase of the pressure of said given fluid relative to the pressure of said other fluid and to decrease the delivery of said given fluid to the corresponding prime mover concomitantly with increasing the delivery of the other fluid to the other prime mover upon decrease of the pressure of said given fluid relative to the pressure of said other fluid.

17. A power generating plant for developing power from a vapor and from a gas at respective pressures which comprises a prime mover capable of utilizing said vapor at said vapor pressure to develop power therefrom, a prime mover capable of utilizing said gas at said gas pressure to develop power therefrom, means respectively connected to said prime movers for delivering said vapor and said gas at the respective pressures to the respective prime movers, and control means responsive to variations in the pressures of said vapor and of said gas with respect to each other and operatively connected to said two delivery means for controlling said deliveries of said vapor and of said gas to increase the delivery of said vapor to said vapor utilizing prime mover concomitantly with decreasing the delivery of said gas to said gas utilizing prime mover upon increase of the pressure of said vapor relative to the pressure of said gas and for decreasing the delivery of said vapor to said vapor utilizing prime mover concomitantly with increasing the delivery of said gas to said gas utilizing prime mover upon decrease of the pressure of said vapor relative to the pressure of said gas.

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