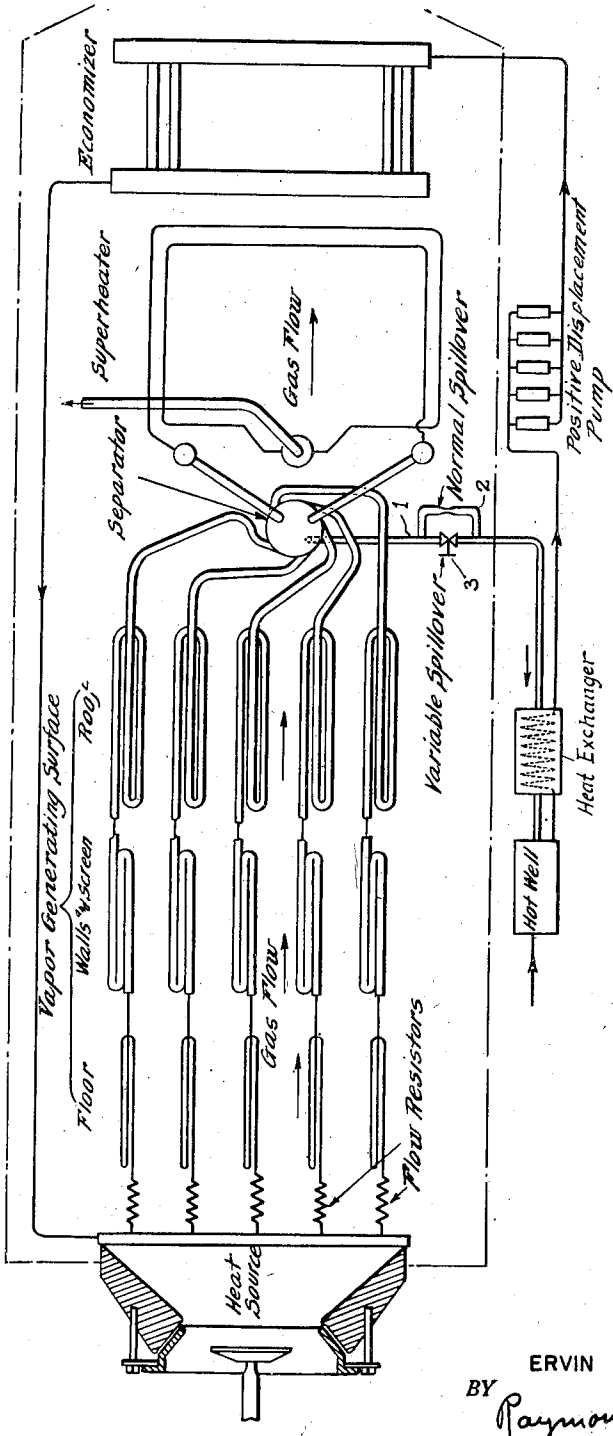
Dec. 3, 1940. E. G. BAILEY 2,223,658

VAPOR GENERATOR

Original Filed Dec. 18, 1935 7 Sheets-Sheet 1

Fig. 1



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VAPOR GENERATOR

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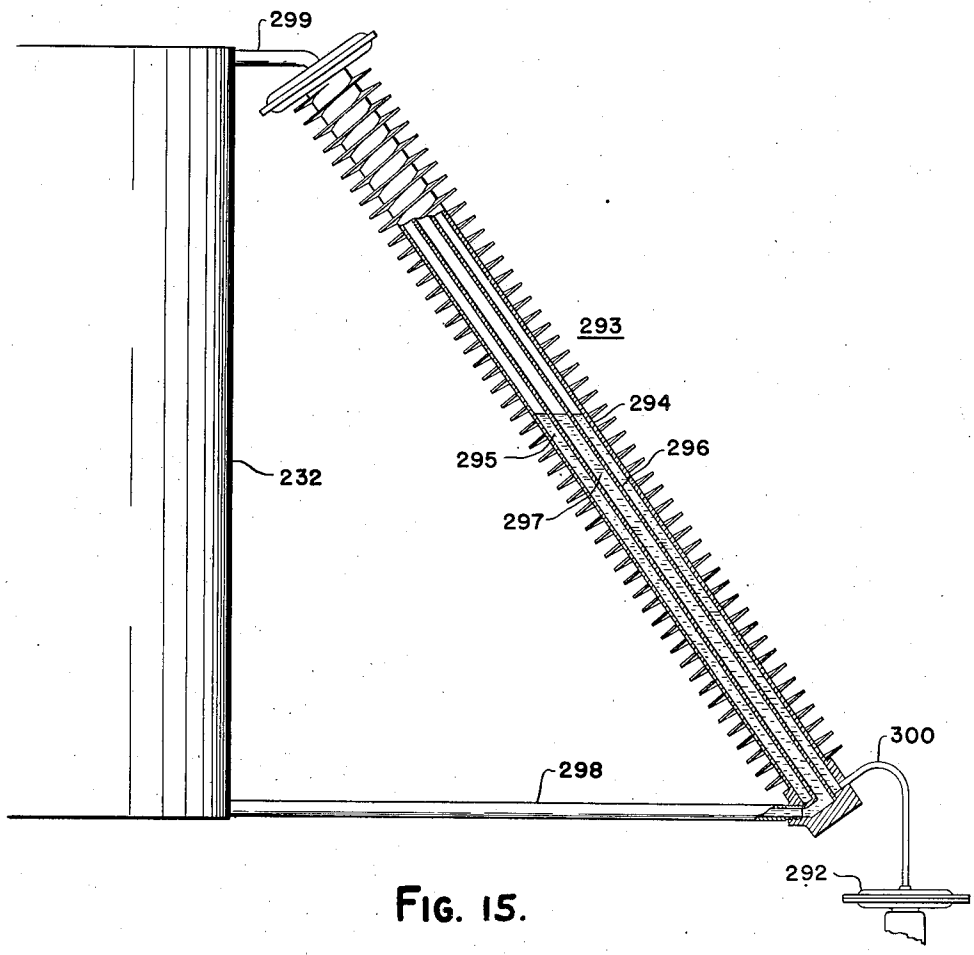


FIG. 15.

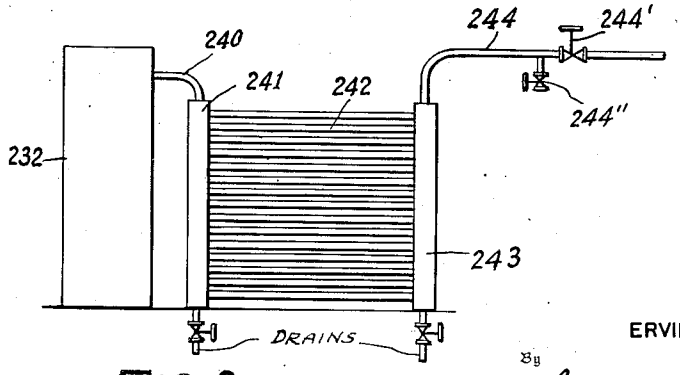


FIG. 2.

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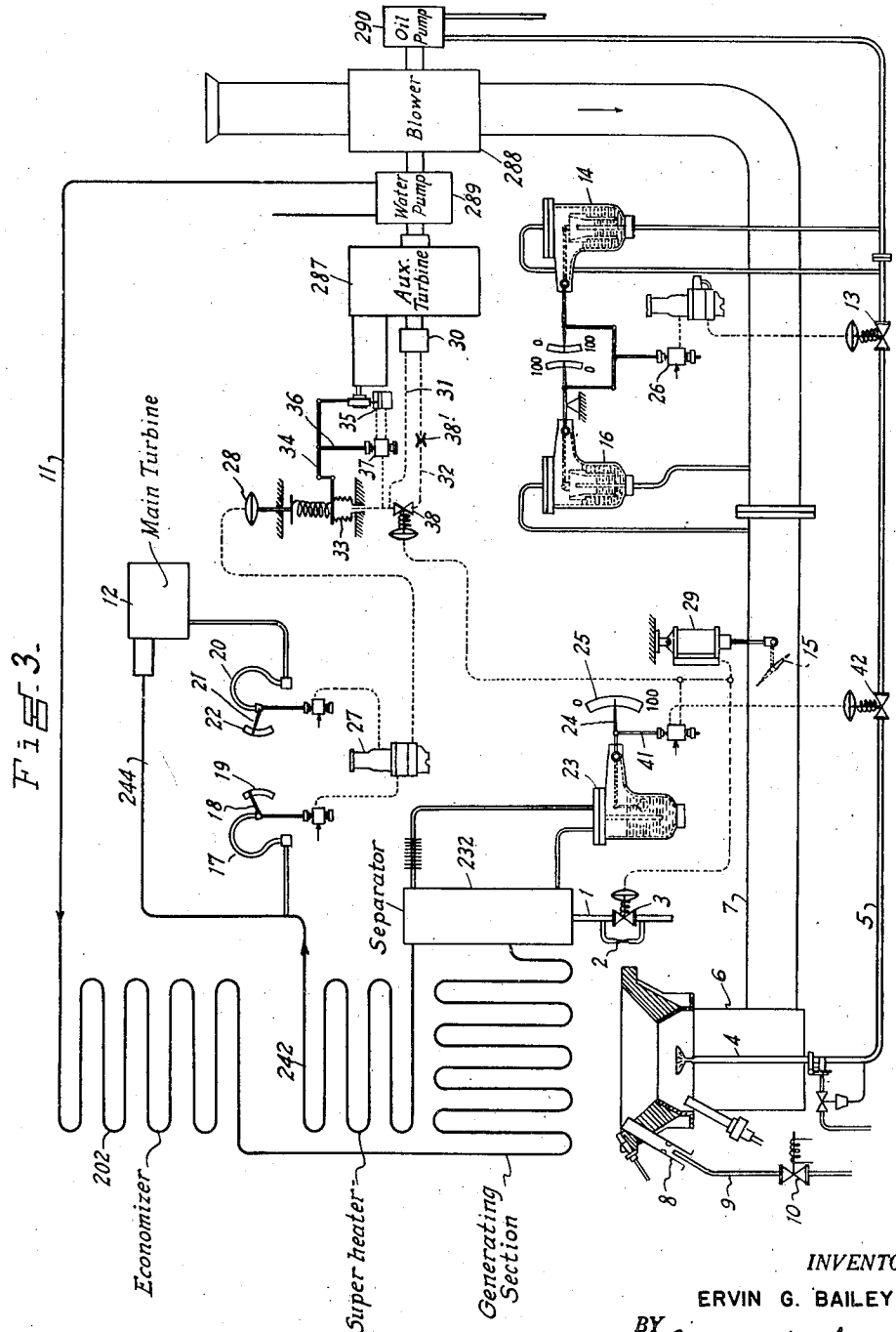
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VAPOR GENERATOR

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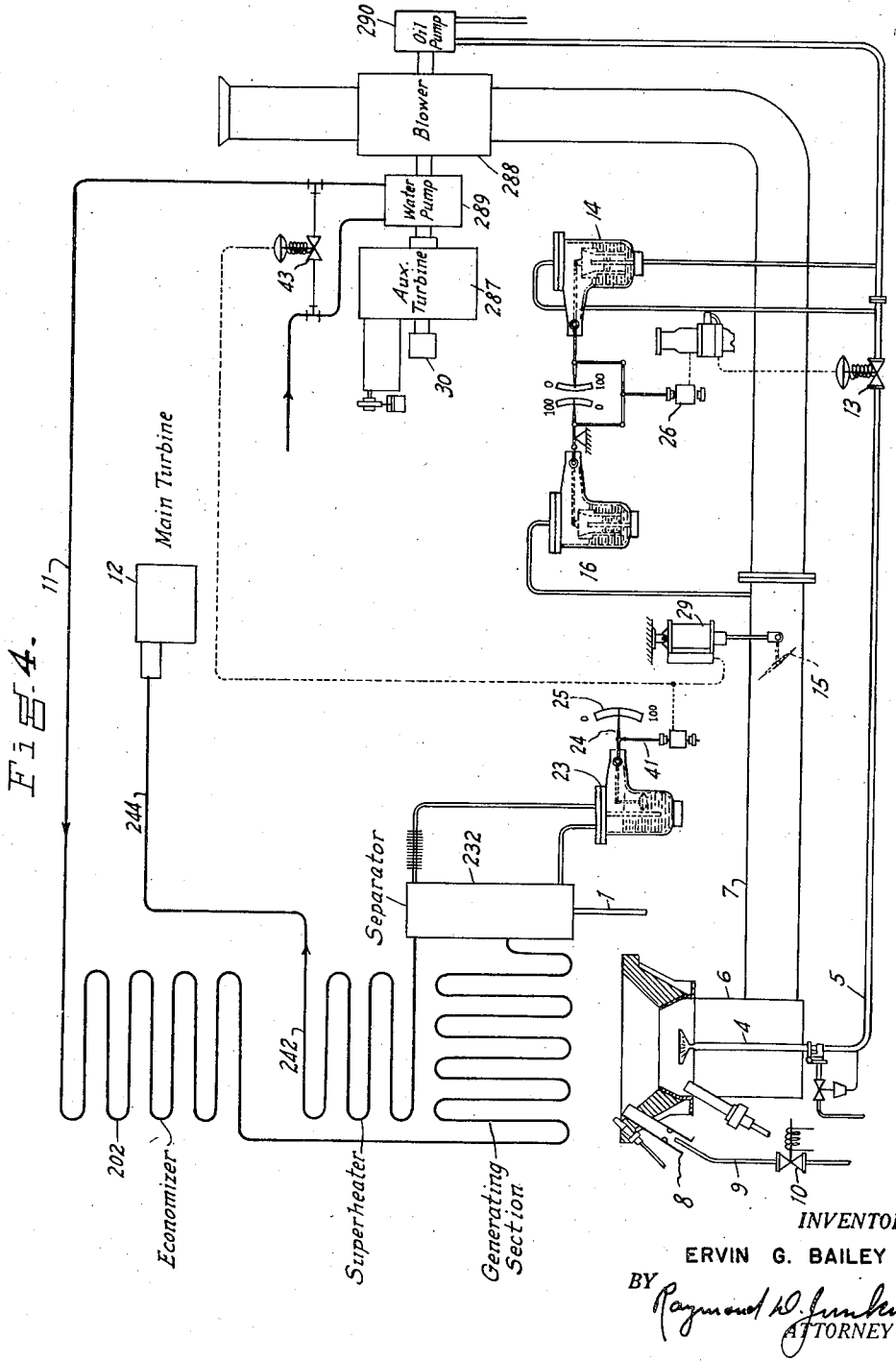


Fig. 4.

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VAPOR GENERATOR

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Fig. 5.

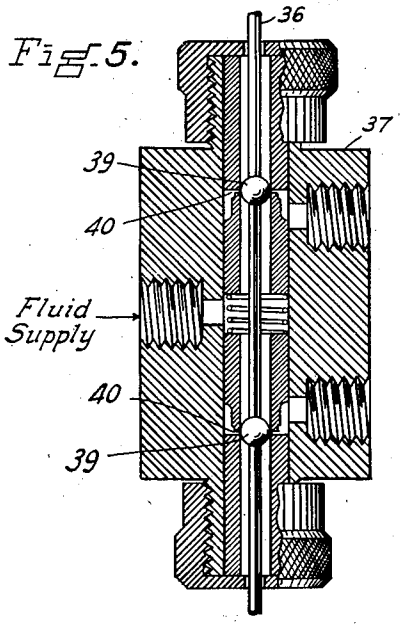


Fig. 9.

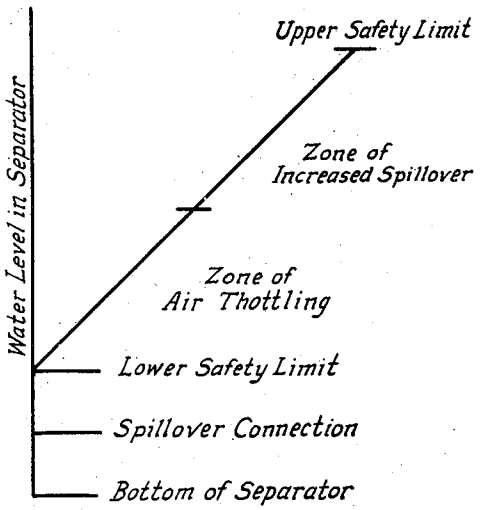


Fig. 11.

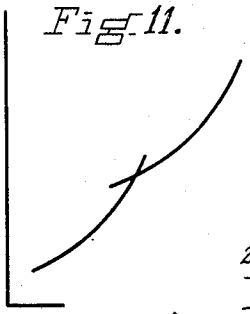


Fig. 12.

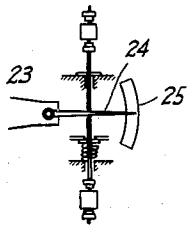
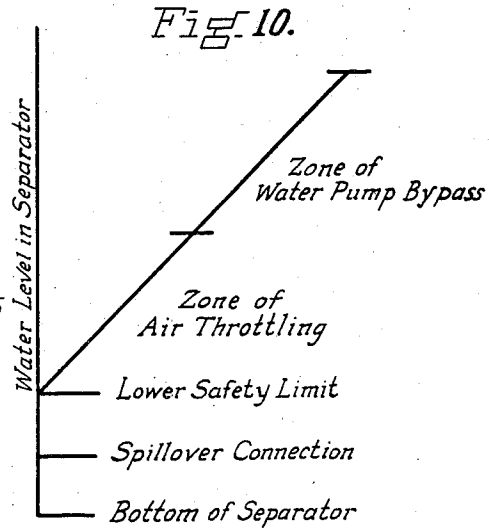


Fig. 10.



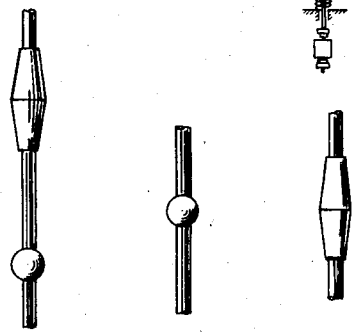


Fig. 6. Fig. 7. Fig. 8.

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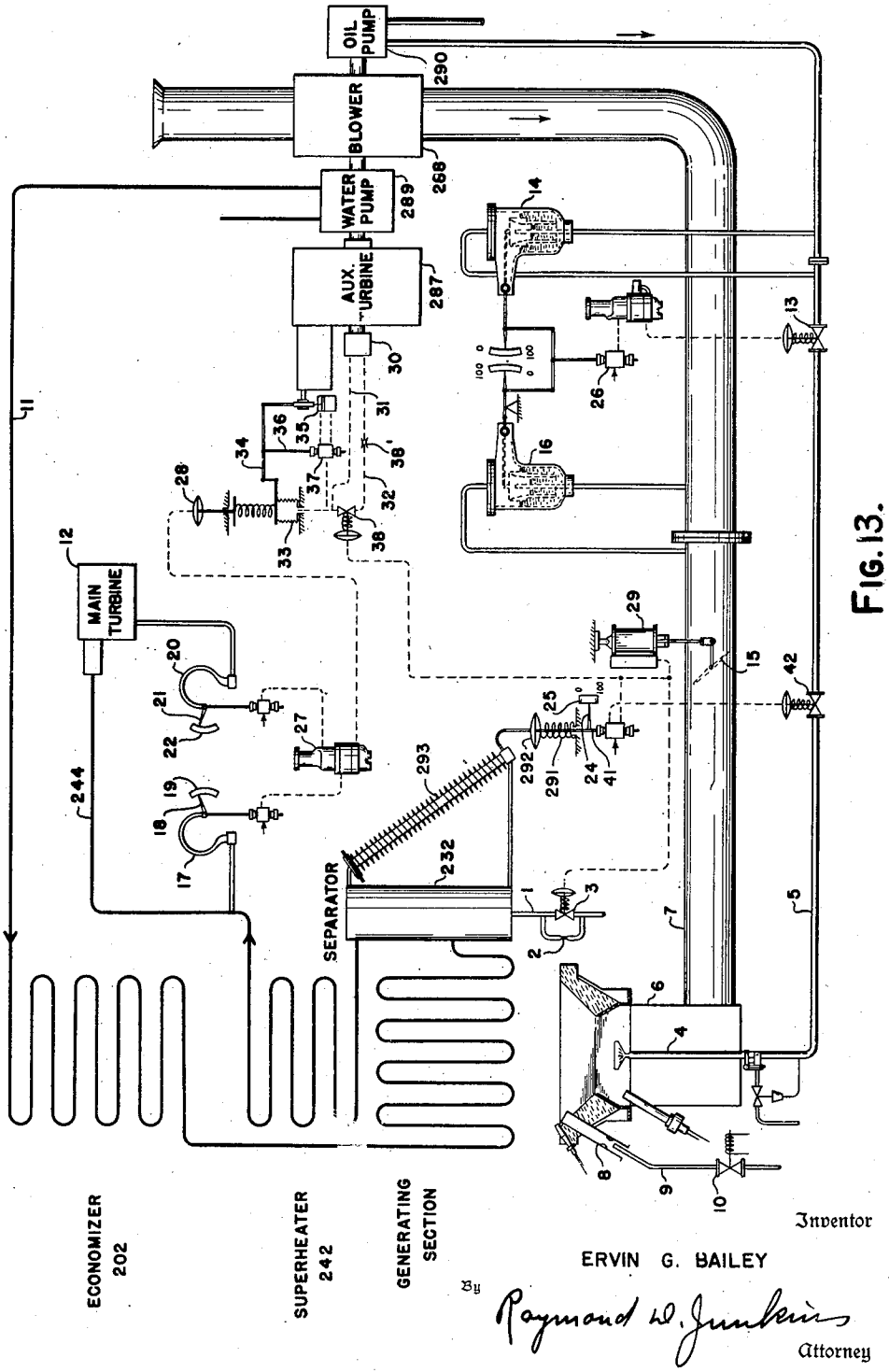


FIG. 13.

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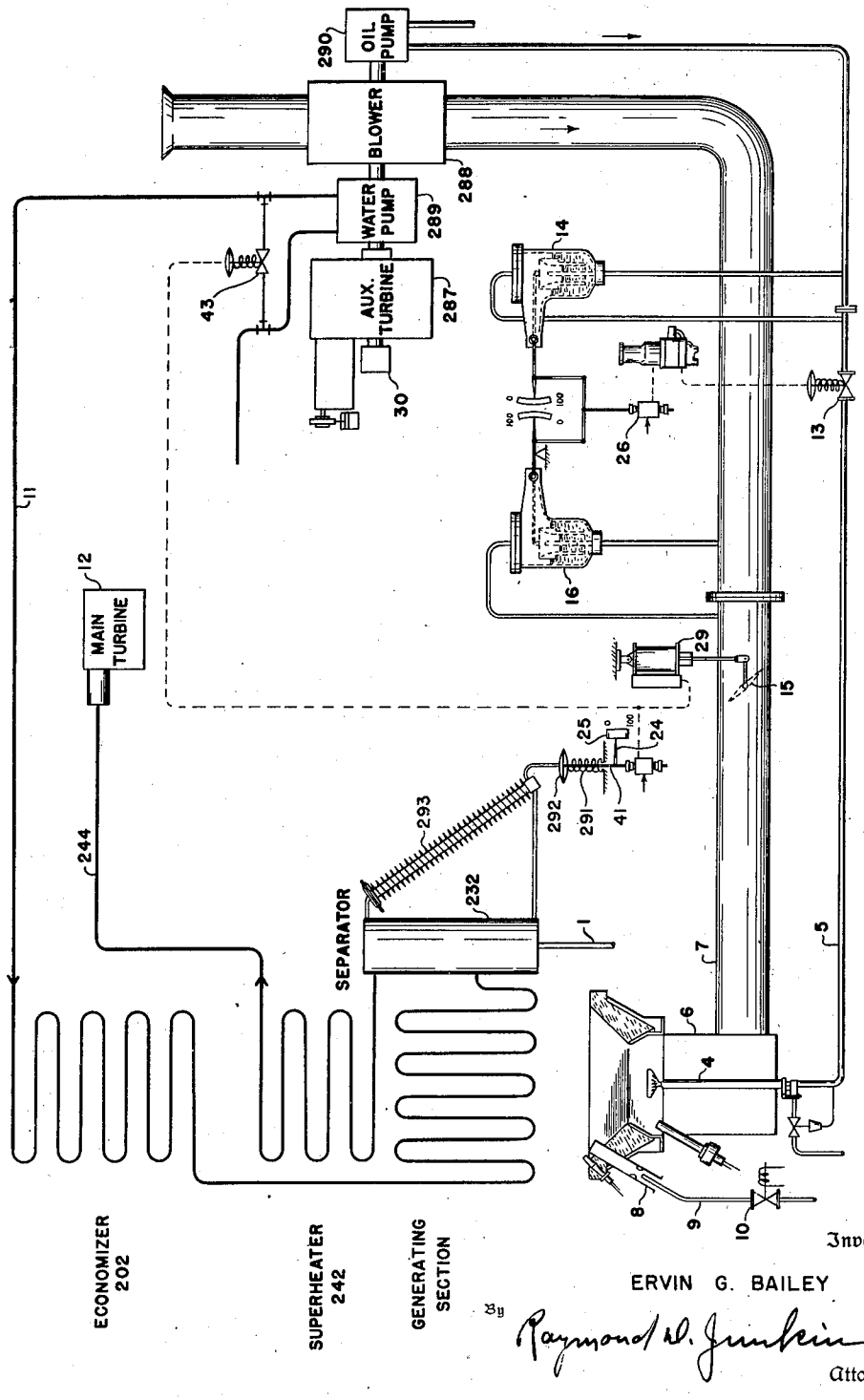


FIG. 14.

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UNITED STATES PATENT OFFICE

2,223,658

VAPOR GENERATOR

Ervin G. Bailey, Easton, Pa., assignor, by mesne assignments, to Bailey Meter Company, Cleveland, Ohio, a corporation of Delaware

Original application December 18, 1935, Serial No. 55,020. Divided and this application November 27, 1937, Serial No. 176,928

6 Claims. (Cl. 122—448)

This invention is a vapor pressure power generator of the drumless forced flow type distinguished, however, by the fact that it is suitable for service where load conditions are of wide range over a short time interval as, for instance, is characteristic in the mobile service to which power plants are subjected in locomotive and marine applications, and for which great flexibility is a requisite.

Heretofore, engineering development has failed to provide any practicable vapor pressure power plant of high efficiency, adapted, in principle and construction, for a large range of sizes, and capable of meeting the same operating conditions of mobile service, but requiring more power than small automobiles, while still retaining the desirable light weight and small dimension characteristics necessary for competition with internal combustion engines requiring special high priced fuels.

Present day accepted, or standard, vapor generating equipment leaves the problem of a light weight, efficient and reliable vapor generator unsolved in that such modern equipment depends upon large bulk of metal and refractory mass, with great liquid storage, thus rendering it unsuitable for quick change of vapor output volume by reason of the capacity for heat storage inherent in the bulk of solid and liquid masses, and which masses further render such equipment unsuitable due to enormous weight and lack of compactness.

For quick changes of vapor capacity required for stops, starts and alteration of speed or, in other words, to meet the requirement of flexibility, heat storage in the generator must always be at a minimum so that feed of fuel and working liquid may be synchronized with vapor output, and standby and upkeep charges kept at a minimum. In addition to reduction of heat storage to as near zero as possible, flexibility, in a unit of this character, also demands automatic maintenance of proportioning of elements of combustion, heat liberated and absorbed, to working liquid fed, with maintained balance of working liquid feed to rate of delivery or use of vapor generated; such regulation would be impossible without low enough heat storage, and without suitable controls.

In order to have high efficiency in utilization of power from vapor pressure, high vapor pressure is essential; for such high pressures metal enclosures of lightest weight are required and must be made of steel tubes of the smallest practicable diameters, and there must be the least possible use of larger diameter headers and drums, those which are used must be of the smallest possible diameter. Such metal enclosure limitations preclude the use of natural circulation of the liquid with conversion of liquid to vapor and therefore dictate some other means of avoiding overheating of metal used to transfer heat of the fuel to the liquid being vaporized and to the vapor being superheated.

High efficiency of vapor generation from fuel heat requires not only that combustion be completed within the furnace space, and that the least possible excess air is present at all loads from zero to maximum, but, also, that the heating surface shall be properly disposed with reference to the furnace and the products of combustion to promote heat absorption to the greatest degree through heating surface exposed within the furnace area and beyond it. This requirement for least weight thus imposes a need for high rates of heat absorption per square foot of heating surface in order that the high degree of absorption of heat for high efficiency is attained with a minimum of surface area.

For the greatest compactness, the furnace must be as small as possible, and the shape of it must be flat sided. Smallest possible furnace size requires the highest possible heat liberation rate from combustion of fuel, B. t. u./hr./cu. ft., and for highest efficiency this must be accomplished with the least possible excess air and no unburned fuel. Flat furnace sides or boundaries, associated with the requirement of a minimum refractory use require that "small bore" tubes be arranged side by side in contact to provide the necessary flat walls with substantially continuous metal surface, for the furnace and other hot gas zones, in addition to arrangement for other requirements.

Further, invention resides in the means for insuring synchronization of total heat liberated to total liquid fed, and equalization of the latter to total vapor delivered, continuously and automatically, by controls and auxiliaries cooperating with the other features enumerated.

Also, a feature of the invention is in preventing overheating of tubes when vapor is being generated, this feature residing in the arrangement of tubes and in the cooperation of the auxiliaries and control means to insure that such vapor generating parts of the lengths of the tubes are maintained wet inside, while promoting vaporization to as near complete as practicable, consistent with adequate terminal wetness.

A further feature is in the superheating of the

vapor produced, by a minimum of tube surface without overheating the tubes, such being accomplished by removal of unvaporized liquid before the fluid enters the superheater, and by arrangement of the superheater tubes with reference to other tubes to insure that radiant heat of the furnace shall be screened therefrom while gases approaching the superheater are hot enough, but not too hot, and are no more than sufficient to serve to provide the maximum vapor temperature desired when most efficiently swept by the hot gases.

Still another feature is the superheater arrangement which prevents damage by overheating while starting the vapor generator, during the period after combustion begins but before vapor flow through the generator is established, while maintaining at a minimum the time lag in the delivery of superheated vapor, in combination with the features of the control system.

The invention embodying all of these features, and others, has for its general object, the successful fulfillment of all the conditions that must be met as to high efficiency, high flexibility, low weight, and small space occupied for motive power units capable of competing with internal combustion engines in sizes larger than those for small automobiles. No vapor generator known thus far has been able to fulfill these conditions, whereas the vapor generator of the present invention does fulfill them, there already being in operation one generator built according to the present invention and which has been and is now being subjected to long and severe tests, and which has a capacity of 22,000 pounds of steam per hour, weighs 22,000 pounds, and occupies a space 8'9'' high x 4'8'' wide x 20'0'' long.

In the accompanying drawings illustrative of the invention:

Fig. 1 is a diagrammatic view of the arrangement of the heat absorbing surface of a vapor generator according to the present invention and indicative of the path of gas flow and flow of working fluid.

Fig. 2 is a diagrammatic representation of the horizontal flat superheater coils between vertical inlet and vertical outlet headers, with saturated vapor connection from the separator-collector, and superheated vapor delivery connections to the throttle valve that controls the flow of vapor to use and to a bleeder valve placed in advance and used in starting prior to opening the throttle.

Fig. 3 diagrammatically illustrates the drumless forced flow vapor generator of the present invention adapted to and combined with the requisite auxiliary and control apparatus for the functioning thereof, as the generator of steam for a steam prime mover of a transportation motive power plant.

Fig. 4 diagrammatically illustrates the drumless forced flow vapor generator of the present invention, with a somewhat different and alternate arrangement of control apparatus than that of Fig. 3.

Fig. 5 is a sectional elevation of a pilot valve.

Figs. 6, 7 and 8 are valve elements of pilot valves to an enlarged scale.

Figs. 9, 10 and 11 are graphs explanatory of the operation of the control apparatus in relation to the functioning of the generator.

Fig. 12 is a detail of a part of the control apparatus of Figs. 3 and 4, in modified form.

Fig. 13 illustrates the same diagrammatic arrangement as Fig. 3 except insofar as the level responsive device for the separator, and the control therefrom, is concerned.

Fig. 14 is similar to Fig. 4 as a somewhat diagrammatic showing of the control arrangement but with level responsive apparatus similar to that of Fig. 13.

Fig. 15 is a partially sectioned elevation, to enlarged scale, of the level responsive apparatus of Figs. 13 and 14.

In detail—

The forced flow vapor generator constituting this invention is diagrammatically illustrated in Fig. 1 to indicate gas flow, working fluid flow and sequence of contact with sections of the heat absorbing surface as contained within the enclosure represented by the dot and dash line indicative of the casing walls.

The flow path for the liquid and its vapor is comprised of several long small bore tubes connected in parallel, five being here shown, interrupted by an enlargement at the end of the vapor generating section which acts as a separator or collector **232** to divide vapor and liquid, the saturated vapor passing therefrom without liquid to a superheater **242**, a portion of the entering liquid being carried through the tubes to the separator **232** for the purpose of tube metal wetness and preventing solid deposits. This unvaporized liquid is finally diverted out of the flow path at the separator **232** and withdrawn under regulated conditions as will be hereinafter set forth.

The generator includes an economizer **202** at the cooler end of the gas passage receiving liquid from a pump **289**, the speed of which determines the quantity fed, as shown, connected to the hot well or other liquid source with a suitable feed liquid heating device.

Liquid from the economizer is divided into equal parts to the several long tubes of the generating section. In this instance, there are five long small bore tubes in the generating section, and five fluid flow resistors, each of which resistors has a greater flow resistance, or pressure drop, than the particular long generating tube which it serves, to insure equal division of the liquid delivered to each of the long tubes constituting the generating section of the assembly and which comprises flat floor, two side walls, and roof portions of the furnace, and a tube bank at the end of the furnace.

The separator **232** is a cylindrical chamber or bulge in the flow path of the working fluid at the end of each of the multiple parallel flow generating tubes. The generator tube portions enter the separating chamber at a location midway of its height, and with their entrances directed tangentially so that, as the fluid is discharged through these generator tube portions into the separator, a swirling effect is produced and by centrifugal force concentrates the liquid next to the wall and separates the vapor from the liquid. Inasmuch as liquid level in the separator is an important factor of control and regulation as explained later, it becomes essential that, once the separation has taken place, the swirling motion of the liquid should immediately cease so that a free gravity formed liquid level may be attained. To that end there has been included in the separator chamber, below the level of delivery openings of the generator tube portions, an upright structure including a conical cap, and between it and the bottom of the separating chamber several vanes which eliminate the swirl of the liquid resulting from the tangential discharge and per-

mit the liquid to come to rest with a free gravity level in the separator, and the lower part of the separator thus becomes a liquid collecting chamber in which a pool of liquid may be retained, the level of which depends on the relation of rate of liquid inflow to outflow.

By means of the arrangement of the superheater tubes horizontally at different levels between vertical inlet and outlet headers, any liquid in the superheater, when the generator is started for example, will gravitate to the bottom of the headers and fill the lower level tubes, leaving the upper tubes entirely free of liquid pockets and free for the flow of steam, and thus prevent the overheating of a superheater tube which would happen if a water pocket prevented vapor flow through it while flowing through other tubes free of steam pockets. In this superheater hot gases cannot damage any tube because each one is either full of liquid or is internally cooled by steam flow, and as the liquid in a lower level tube evaporates, the superheater acts temporarily as a water tube boiler, in part, until the liquid has been wholly and safely evaporated, while the rest of it functions as a superheater, and ultimately all of it. This feature of my superheater is shown diagrammatically in Fig. 2, where **232** is the separator delivering saturated vapor to the vertical inlet header **241** through connection **240**. The horizontal bent superheater tubes are indicated at **242** delivering to the vertical outlet header **243** from which superheated vapor leaves by pipe **244** at a rate controlled by the throttle valve **244'**. A second valve at **244''** is a drain opened for starting and before the throttle **244'** is opened, and kept open until all liquid in the superheater has disappeared.

Equalization of heat absorbed by the vapor generator tubes is also assured by their position, and by providing for equalization or proportioning of liquid feed quantity and temperature to each of the five long small bore tubes in parallel, equalization of quality of vapor or ratio of liquid unvaporized to vapor produced is assured, and each generating tube is kept wet internally by control of ratio of heat made available to quantity of feed, thereby overheating is prevented and, as will be described later, this is accomplished with a minimum of excess liquid.

To assure equalization of heat absorbed by each of the several parallel connected generator tubes, each one is so bent and so located as to be equally exposed to radiant heat of the furnace and equally swept by hot gases. Each tube occupies a portion of the height of each furnace side wall from end to end at a given level and a portion of the end wall at the same level, and each one makes one or more transverse passes across the gas stream in the furnace within the same level limit. Each tube also occupies a portion of the width of the furnace bottom and of the furnace roof from end to end of each. At the same time the burner is in one end of the furnace, the flame and the gases flowing longitudinally straight through it, so there is thermal-symmetry all around the cross section of the furnace, and any change in gas temperature or intensity of radiation longitudinally affects each of the several generating tubes to the same extent no matter how the load changes.

To insure that the full capabilities of my vapor generator are realized in operation, auxiliary apparatus of proper cooperative kind, and with appropriate controls, are provided, so that the combination has all of the use characteristics required for motive power service of the type previously described involving flexibility over the whole range from zero to maximum capacity per unit, high efficiency, light weight and small space requirements for any size above that used in small automobiles.

These cooperative auxiliaries and controls which insure that the vapor generator will operate to the best advantage, producing superheater vapor at any rate required by the prime mover, without overheating or damage to any of the parts, and with so little heat storage as to be immediately responsive to changes of vapor quantities required for the operation of the vehicle to be driven, and the corresponding change in feed, are of a certain kind of arrangement, and they are provided with automatic controls responsive to the rate of delivery or withdrawal of vapor.

Prior to starting, the vapor generator is filled with water up to the stop or throttle valve **244'**, Fig. 2, which is closed and the vent valve **244''** which is also closed after filling or open only slightly. This prevents overheating of any part after the burner begins to operate and before flow of liquid and vapor inside of the tubes is established, as it is necessary to avoid the heating of a tube that is dry inside and through which there is no flow, or an adequate flow of fluid to absorb enough heat from it to keep its temperature low enough to be safe.

To start the operation of the vapor generator after it has been filled with water, the gas is turned on at the starting gas burner and ignited. At the same time an auxiliary starting motor supplies air, and fuel is also supplied to the burner, which then ignites from the gas flame, and when ignited the gas is turned off. Burning of the oil causes the liquid in the generator to heat and some of this hot liquid, followed by vapor, escapes from the valve **244''** which has been opened enough to serve as a vent but not enough to prevent loss of pressure developed. As soon as pressure vapor is discharged from the vent the vent valve is closed, and a valve **244'** is opened to deliver the vapor to an auxiliary turbine driving all the normally operating auxiliaries which include a blower **288** for combustion air, a liquid feed pump **289** and a liquid fuel pump **290**. From this time on the entire operation is automatic, the delivery from these auxiliaries being controlled in proportion to vapor output on the one hand, and on the other hand so as to insure an excess of liquid in the vapor generator tubes from end to end, the level of liquid thus secured in the separator acts as a cooperative control to maintain the proper rates of fuel to water or other liquid feed.

As illustrated in Figs. 13, 14 and 15 control means are provided operable upon the presence of vapor in the separator to function in the control of the unit as a whole.

In front of the firing end of the vapor generator, is a platform which carries an auxiliary turbine **287** driving, through suitable gearing, the blower **288** furnishing air to the windbox, and at the same time also driving the feed pump **289** delivering working liquid to the generator, as well as the oil pump **290** for fuel oil.

An auxiliary fan, driven by a motor independent of the turbine **287**, on starting, supplies air for the ignition burner; as soon as pressure

is developed in the vapor generator, vapor is supplied to the turbine 287 for driving the feed pump 289, fuel oil pump 290, and blower 288. Variation in the speed of the auxiliary driving turbine 287, produces corresponding variations of delivery of working liquid to the generator, and in the fuel and air to produce the heat to vaporize and superheat it, and, as will be described later, the auxiliary turbine speed is controlled automatically by the rate of superheated vapor delivery.

After the auxiliary driving turbine has begun operation and the superheater has lost its initial starting liquid by evaporation, and vapor is flowing through it, and liquid is being supplied to the generating tubes to replace the vapor formed, the separator prevents any liquid from reaching the superheater. To insure that all vapor generator tubes are kept wet the liquid feed is proportioned to the fuel and air supply so as to be more than can be evaporated, and to always deliver liquid to the separator. This excess liquid is constantly withdrawn from the separator and such withdrawn liquid is termed the "spillover." The continuous supply of excess liquid to the vaporizer, and the also continuous withdrawal of it from the vaporizer has the effect of establishing a pool of liquid in the separator at a level determined by the adjustment of the area of the outflow. Variations in the level are caused to control the spillover area automatically in a manner to be hereinafter described in connection with the control system.

The automatic control system which cooperates with the vapor generator is shown diagrammatically in Figs. 3, 4, 13, 14 and 15.

Referring now in particular to Fig. 3, I illustrate the fluid flow path as a single sinuous tube, to the economizer section 202 of which, liquid is supplied under pressure through a pipe 11 from a pump 289, which may be of any suitable type and which I have therefore illustrated merely diagrammatically. From the economizer section the fluid passes to and through the generating section discharging into the separator 232. From the separator, vapor passes to and through the superheater 242, leaving by the conduit 244 to a main turbine 12 illustrative of a vapor utilizing device. Products of combustion pass successively through the generating section, superheater, and economizer and air heater, and may contact a part or all of the separator.

An auxiliary vapor motor here shown as a turbine 287 drives the liquid feed pump 289, the air blower 288, and the fuel oil burner supply pump 290. While I have illustrated these devices diagrammatically and as though all are located to be driven by the same shaft and at the same speed, it will be understood that the necessary gear reduction, or driving connections between the several devices, are known and would be properly designed as to relative speed, power, auxiliary capacity, etc., and that I merely intend to indicate that the auxiliary turbine 287 drives the devices 288, 289 and 290 simultaneously and in unison.

The liquid feed pump is of such capacity in relation to the capacity of the fuel oil pump and air blower, as to insure delivery of a greater quantity of liquid than the heat of combustion of the fuel and air can evaporate, this is to insure an excess of liquid and maintain a continuous spillover from the separator.

Excess liquid is diverted from the fluid flow path in the separator through a pipe 1 to the hot well or to waste. A normal continuous spillover occurs through the restriction 2 while a variable spillover occurs through a regulating valve 3.

The furnace of the vapor generator includes an oil burner 4 supplied by a pipe 5, and an air chamber 6 supplied by a conduit 7. In order to provide for ignition of the oil-firing means, a gas-firing device 8 is supplied by a pipe 9 with a flow of gas under the control of a solenoid actuated valve 10.

The rate of supply of fuel oil to the burner 4 is primarily controlled by the speed of the oil pump 290, but the supply of oil is further regulated by the throttling of a regulating valve 13 located in the pipe 5; and the rate of flow is continuously measured by a meter 14.

The rate of supply of air to support combustion is primarily determined by the speed of the blower 288, but is further under the control of a damper 15 positioned in the conduit 7 between the blower and the air chamber 6. The rate of supply of air is continuously measured by a flow meter 16.

The rate of supply of liquid working fluid under pressure through the conduit 11 is controlled by the speed of the pump 289 in turn under the control of variables in the operation of the system.

The speeds of the liquid pump, air blower and oil pump, have a constant relation one to the other determined by the mechanical connection of each to the driving shaft of the auxiliary driving turbine and the speed of all three varies with the speed of the turbine. To insure the proper relation between the quantities of liquid, fuel oil and air delivered by their respective impellers when these impellers have a fixed speed relation and also to insure the proper relation of all of them to the rate of delivery and use of vapor, certain adjustments are provided and they become operatively responsive to certain variables which are measured, indicated, and utilized as a basis for automatically controlling the supply of liquid thereto and the supply of the elements of combustion to the heating furnace.

I indicate at 17 a pressure responsive device such as a Bourdon tube connected to the conduit 244 and having an indicator pointer 18 adapted to cooperate with an index 19 for advising the instantaneous value of the vapor outflow pressure.

As an indicator of output, rate of vapor delivery or load upon the vapor generator, in relation to the pressure responsive device 17, I provide another pressure responsive device such as a Bourdon tube 20 adapted to position an indicator pointer 21 relative to an index 22. The Bourdon tube 20 is connected by means of a pipe with the turbine 12 at a location such that the Bourdon tube will be sensitive to first stage shell pressure of the turbine, which pressure for a given value of pressure indicated by 17 bears a substantially straight line relation to rate of steam flow. Thus the pointer 21 will indicate on the scale 22 a reading which, relative to that of pointer 18 on scale 19, is representative of rate of flow of steam from the vapor generator and thereby an indication of output or load upon the generator.

Connected to the separator 232 there is a device 23 responsive to liquid level within the separator 232. It has a pressure casing enclosing a mercury U-tube connected across the vertical elevation of the separator. A float is adapted to rise and fall with the surface of the mercury

in one leg and to thus cause a positioning of a pointer **24** relative to an index **25** showing the instantaneous liquid level within the separator.

The flow meters, **14** for fuel oil, and **16** for combustion air, cooperate to position the stem of a pilot valve **26** from predetermined position, should the ratio between air flow and fuel flow depart from that desired. The pilot **26** is adapted to control the positioning of a fuel supply valve **13**.

The Bourdon tubes **17** and **20** each position the stem of a pilot valve for establishing an air loading pressure within the relay mechanism **27** from which a resultant air loading pressure is applied upon the diaphragm loading means **28** controlling the auxiliary turbine.

I preferably primarily control the supply of liquid to the fluid flow path and elements of combustion to the furnace, through variation in speed of the auxiliary turbine, utilizing the vapor outflow pressure and the turbine shell pressure as a basis for such control. Realizing, however, the possible difference in speed-capacity characteristics of the pumps and blower, as well as variations in conditions of operation, I provide readjusting means to supplement the primary control of the elements of combustion. For the air, such readjusting means comprises the damper **15** positioned at the outlet of the blower **288** by a pneumatic actuator **29**. For the fuel, the readjusting means comprises the regulating valve **13** positioned in the pipe **5** responsive to departure from desired relation of the measure of fuel flow and the measure of air flow.

It is primarily desirable to vary the speed of the auxiliary turbine in step with the rate of vapor used by the main turbine so as to roughly proportion liquid and the elements of combustion to the vapor generator according to the main turbine load; then to individually readjust the supply of fuel and air according to other variables in the operation of the system.

To adjustably determine the speed of the auxiliary turbine I preferably provide a pump, compressor or similar device **30** driven by and with the auxiliary turbine to establish a fluid pressure (such as an oil pressure) bearing a known relation to speed. I then utilize this oil pressure in a governing mechanism normally tending to hold the speed of the auxiliary turbine constant regardless of pressure of vapor supplied it. I then load up the oil pressure responsive device according to variations in vapor generator and main turbine operation, thus furnishing the speed requirements that the variable speed governor of the auxiliary turbine must work to.

Oil from the pump **30** passes through a pipe **31** (having a return connection **32**) to an expansible metallic bellows **33**, adapted to position one end of a floating link **34**. The other end of the link **34** is moved by and with a power piston traveling in a cylinder **35** and adapted to move the vapor admission valves of the auxiliary turbine. A pilot stem **36** is suspended from the link **34** intermediate the ends thereof and controls the flow of oil under pressure through a pilot casing **37** to the opposite sides of the piston **35**. A normally open regulable valve **38** is positioned between the pressure pipe **31** and the return pipe **32** to provide a by-pass around the pump **30**. A fixed resistance **38'** is in line **32**.

The pilot valves indicated as at **26** and **37** are shown in detail in Fig. 37 and form the subject matter of the patent to Clarence Johnson, No. 2,054,464, dated September 15, 1936.

Fluid under pressure is supplied to the interior of the casing **37** intermediate the pilot lands **39**, which lands are so spaced along the stem **36** as to coincide with narrow annular ports **40**. When the pilot stem is axially moved in the casing so that the lands **39** are moved relative to the ports **40**, then a definite loading pressure is available in the annular ports bearing a known relation to the amount of such movement. For example, if the stem **36** is moved upwardly there is available at the upper right-hand exit of the casing (Fig. 5) a loading pressure increasing in definite relation to said movement, while if the stem **36** is moved downwardly there is available at the lower right-hand exit a pressure increasing definitely with such movement.

Certain features relating to the turbine governor control herein disclosed but not claimed form the subject matter of the copending application of Paul S. Dickey, Serial No. 55,022, now Patent No. 2,170,344.

The level responsive device **23** (Fig. 3) is adapted to position a pilot stem **41** for emergency and sequential control of variables in the operation of the system. It will be observed that both the upper and lower right-hand exits of the pilot casing are in use; the upper exit being connected to an emergency fuel shutoff valve **42** in the pipe **5**, and the lower exit being connected to the regulated spillover valve **3**, the air actuator **29**, and the by-pass valve **38**.

Referring now to Fig. 10 I illustrate therein, by means of a graph, the operation under the control of the device **23** responsive to level within the separator drum **232**. The spillover connection **1** may coincide on level with the bottom of the separator or may be slightly above it. It is not desirable to have the water level unseal the spillover connection, and therefore I indicate as a lower safety limit a level slightly above the spillover connection. From this zone upwardly to an upper safety limit is the zone of control and this is divided roughly into a zone of air throttling and a zone of increased spillover.

The design of the pilot **41** as well as the various air actuators **3**, **29**, **38**, **42** is such that the air pressure established at the two exits of the pilot valve cause the actuation or positioning of the various actuators in desired manner and sequence. If level within the separator drum is at approximately mid-point, then conditions are as desired. The damper **15** will be at its wide open position and very little if any excess diversion or spillover is passing through the valve **3**. If, however, due to operating conditions the level within the separator begins to rise, then throughout the indicated range on Fig. 10 there is an additional spillover or diversion through the valve **3** as such valve is opened progressively with rise in level. That is, as the level in the separator rises, the pilot **41** is lowered and the air pressure effective upon the valve **3** is increased proportional to the axial movement of the pilot **41**. Should the level continue to rise despite the increase in the amount of spillover and eventually reach the upper safety limit, then when this point is reached the increased air pressure effective upon the by-pass valve **38** will begin to overcome the loading spring and close the by-pass valve, building up the pressure within **33**, to the end that the speed of the auxiliary turbine will be reduced and if the level continues to rise it may in fact stop the auxiliary turbine.

Throughout the zone of increased spillover the damper **15** is left at its widest open position. Should level within the separator fall from ap-

proximately the mid-position or an otherwise predetermined position, then through the zone marked "zone of air throttling" the damper 15 will be throttled toward a minimum opening position and inasmuch as the amount of air flow acts through the fuel flow—air flow ratio meters to control the fuel flow valve 13, this at the same time will control the fuel supply. Thus if for some operating reason the level within the separator decreases below the normal desired value, the supply of fuel and air to the furnace is progressively decreased until a balance is reached and the liquid level returns or tends to return to the desired level.

Should the level continue to drop to the lower safety limit, this action brings into play the uppermost land of the pilot 41 to vary the air loading pressure upon the valve 42 and if the lower safety limit is reached the valve 42 shuts off the fuel supply means and burner. Whenever the level is above this safety limit, however, the burner and fuel supply are normally available unless shut off from some other safety arrangement.

In Fig. 4 I illustrate the same general arrangement as that of Fig. 3 but with a modification insofar as the control from level within the separator 232 is concerned. A graph of operation is shown in Fig. 10 and differs mainly in that the upper portion of level is used as a zone of water pump by-pass rather than as a zone of increased spillover. The upper and lower safety limits may be provided and utilized in manner similar to that of Fig. 3.

The level device 23 is adapted to position the pilot stem 41 for establishing an air loading pressure from the upper right-hand exit of the pilot casing, varying substantially proportional to axial positioning of the pilot stem and therefore according to level within the separator. Such air loading pressure is effective upon the air actuator 29 for positioning the damper 15 and upon the air actuated valve 43 in a by-pass around the water pump 289, Fig. 4. When the level is at the desired elevation in the separator, the damper 15 is at its widest open position and the by-pass valve 43 is closed. Should the separator level increase above this point then the by-pass valve 43 begins to open and a portion of the water pumped will recirculate through the pump, thus decreasing the flow through conduit 11 but without varying the speed of the auxiliary turbine, and thus the rate of supply of fuel and air.

Should the level decrease below the desired value, then with the by-pass valve 43 closed the damper 15 would begin to be throttled and slightly reduce the firing without change in rate of supply of liquid to the system until the liquid level returns to the desired value.

Referring again to Fig. 3 wherein both exits from the pilot casing are used, it is possible to so vary the loading of the different air actuated devices controlled from said pilot that they will pick up in sequence or overlap. Graphs 9 and 10 indicate a substantially straight line control in direct sequence between the different zones of control. Reference to Fig. 11 will illustrate that the zone of air throttling for example may be with a control other than a straight line and that the zone of excess spillover or by-pass of the pump may be in curved relation of the same curvature or difference and that the two curves may overlap.

To illustrate such operation, attention is called to Figs. 6 and 7, which indicate different shapes of pilot lands wherein for example, the long gradual taper of Fig. 7 is of an entirely different sensitivity than the substantially spherical lands of Fig. 6. A different amount of axial movement of the pilot stem in one case is required for the same change in air loading pressure, and correspondingly the same axial movement results in a different change in air loading pressure, and thus the sensitivity is different the one from the other.

I may readily construct a pilot stem as in Fig. 7 having pilot lands of different sensitivity relative to the two exits, and furthermore these may be spaced along the pilot stem so that they will pick up and begin to change the air loading pressure at the different exits either to provide a straight sequential pick-up of the two curves end to end, as in Figs. 9 and 10, or a gap between the two wherein no variation is made in either the amount of spillover or the control of the air, or the curves may overlap and for a central portion of the level variation both spillover and air control be varied. Furthermore, the shape of the pilot lands, as well as the loading and shape of the springs at the valves and at the air actuator 29, may be such as to counteract damper characteristics or functional relation between level within the separator and air flow or damper position.

I indicate in Fig. 12 an arrangement of the level responsive device 23 wherein two pilot valves may be utilized and picked up over different ranges of travel of the arm 24. For example, if the level rises above a mid-point the arm 24 will engage the pilot stem of the uppermost pilot and begins to raise the same. If the level falls below the mid-point then the arm will begin to depress the pilot stem of the lowermost pilot. At a central level no movement of either of the pilot valves will occur.

In Figs. 13 and 14 I illustrate the device which is responsive to level within the separator 232 as of the trapped vapor generating type shown in detail in Fig. 15. I thus provide means sensitive to the presence of vapor in the separator.

Across the vertical elevation of the separator 232 is connected an inclined tubular member 296 joined to the uppermost point of the separator by a pipe connection 299 and to the lowermost point by a pipe connection 298. Thus the level of liquid within the separator 232 is shown by the level of liquid within the passage 297 of the tube 296. Surrounding the tube 296 is an annular space 295 formed by the finned tube 294 and containing a liquid such as water. The annular chamber 295 is closed at the upper end, and at the lower end is connected by a passage 300 to the diaphragm or other expansible type chamber 292 provided with a spring loading means 291 and adapted to position the pilot stem 41, the latter carrying a pointer 24 relative to an index 25. The annular chamber 295, pipe 300, and expansible chamber 292 form a trapped generating system containing liquid, in this case water, adapted to be vaporized through heat transfer from the liquid and/or vapor within the passage 297 and forming a level continuously substantially approximating the level within the chamber 297 and thereby within the separator 232. Vaporization of the liquid in the annular chamber 295 results in a pressure change effective upon the expansible chamber 292 for positioning the pilot stem 41. Such trapped vapor

generating system as that indicated generally at **293** is well known in the art, but so far as I am aware I am the first to utilize it as a means sensitive to the presence of vapor within the separator **232** or as means operable upon the presence of vapor within the separator to actuate control instrumentalities.

The arrangement illustrated in Figs. 13, 14 and 15 is particularly advantageous in the starting up of the present vapor generator, as it is immediately responsive to the presence of vapor within the separator **232** for positioning the various control instrumentalities under the control of the pilot **41** of either Figs. 3 or 4. As previously pointed out, the vapor generator is initially flooded with water and as soon as vapor begins to form in the superheater the superheater acts as a vapor generator and evaporates itself free of liquid. At the same time as soon as vapor begins to collect in the separator **232** then the apparatus **293**, sensitive to the presence of such vapor, is effective in positioning the pilot **41** for the control of the speed of the auxiliary turbine, the positioning of the damper **15**, and/or the positioning of the valve **42**, as previously pointed out in connection with Fig. 3; or in connection with the positioning of the damper **15** and/or the valve **43**, as pointed out previously in connection with Fig. 4. It is not necessarily true that any or all of said control instrumentalities are immediately moved as soon as vapor begins to accumulate in the separator **232** but, as previously described in connection with Figs. 3 and 4, they will be moved individually or collectively when the level of liquid within the separator **232** reaches or passes certain predetermined locations in the separator.

In the initial arrangement of the apparatus **293, 291, 292** the amount of liquid trapped within the annular chamber **295**, the pipe **300**, and the expansible chamber **292**, is such that the desired initial position of the pilot stem **41** is attained when there is no vapor present within the separator **232**. Thus immediately upon the presence of vapor within the separator **232**, and correspondingly within the passage **297**, the heat transfer effect thereof upon the liquid within the annular chamber **295** will cause some vaporization thereof and resulting increase in pressure effective upon the expansible chamber **292**.

As an example of how this system may operate during the starting up period of the vapor generating unit the design and arrangement of the pilot **41**, relative to its effect upon the spillover valve **3**, may be such that as soon as vapor begins to collect within the separator **232** the means which is operable upon the presence of vapor within the separator becomes effective in the regulation of either the spillover valve **3** or the pump by-pass **43** to then confine subsequently introduced liquid into that length of the flow passage in advance of the separator.

This application is a division of my application Serial No. 55,020 filed December 18, 1935, now Patent No. 2,170,342.

While I have chosen to illustrate and describe certain preferred embodiments of the invention, it is to be understood that this is by way of illustration only and that I am not to be limited thereby except as to the claims in view of prior art.

What I claim as new, and desire to secure by Letters Patent of the United States, is:

1. The method of operating a vapor generator of the drumless forced flow type which includes, normally supplying liquid under pressure at one end continuously in predetermined excess over measured vapor outflow from the other, continuously diverting liquid from the fluid flow path at a location in the path, and additionally diverting liquid from the path under regulated conditions sensitive to the presence of separated vapor at such location.

2. The method of operating a vapor generator of the drumless forced flow type which includes, supplying liquid under pressure at one end of the flow path continuously in excess over vapor outflow from the other, diverting the excess of liquid inflow over vapor outflow at a point intermediate the ends of the flow path, heating the path, and regulating the supply of liquid and the elements of combustion to the vapor generator responsive to the presence of separated vapor at a predetermined location in the path.

3. The method of operating a vapor generator of the drumless forced flow type which includes, supplying liquid under pressure at one end of the flow path continuously in excess over vapor outflow from the other, diverting the excess of liquid inflow over vapor outflow at a point intermediate the ends of the flow path, heating the path, and regulating the supply of liquid to the vapor generator responsive to the presence of separated vapor at a predetermined location in the path.

4. The method of operating a vapor generator of the drumless forced flow type which includes, supplying liquid under pressure at one end of the flow path continuously in excess over vapor outflow from the other, diverting the excess of liquid inflow over vapor outflow at a point intermediate the ends of the flow path, heating the path, and regulating the supply of the elements of combustion to the vapor generator responsive to the presence of separated vapor at a predetermined location in the path.

5. The method of operating a vapor generator of the drumless forced flow type which includes, supplying liquid under pressure at one end of the flow path continuously in excess over vapor outflow from the other, diverting the excess of liquid inflow over vapor outflow at a point intermediate the ends of the flow path, heating the path, and regulating the supply of an element of combustion to the vapor generator responsive to the presence of separated vapor at a predetermined location in the path.

6. The method of operating a forced flow vapor generator having a liquid-vapor separator in the path between the normal generating and superheating portions of the flow path, which includes, heating the path, supplying liquid to the generating portion of the path in excess of the vapor outflow from the superheating section of the path, and diverting liquid from the path under regulated conditions sensitive to the presence of vapor in the liquid-vapor separator.

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