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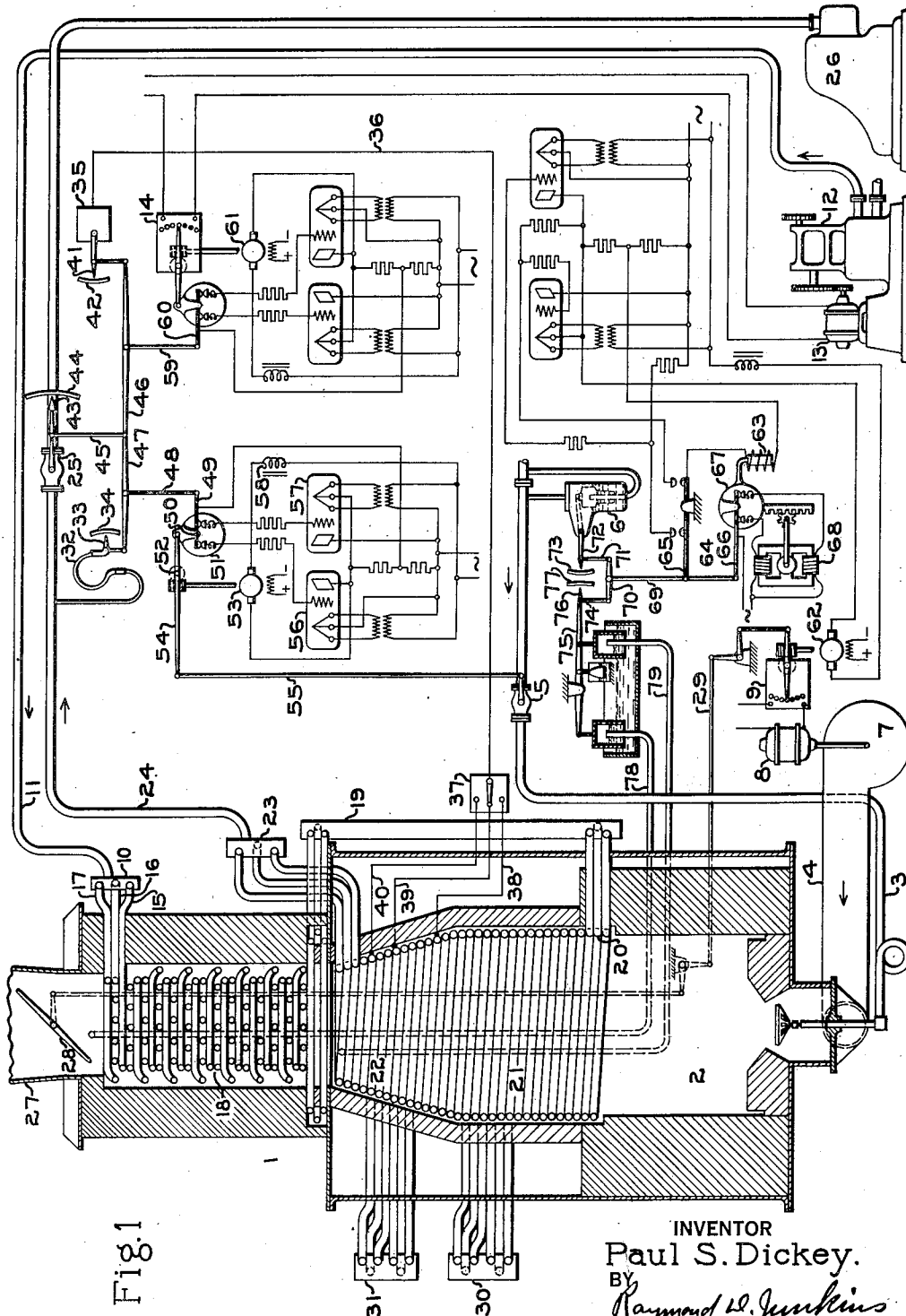
P. S. DICKEY

1,975,085

CONTROL FOR VAPOR GENERATORS

Filed Nov. 10, 1931

3 Sheets-Sheet 1



INVENTOR
Paul S. Dickey.
BY
Raymond W. Jenkins
ATTORNEY

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P. S. DICKEY

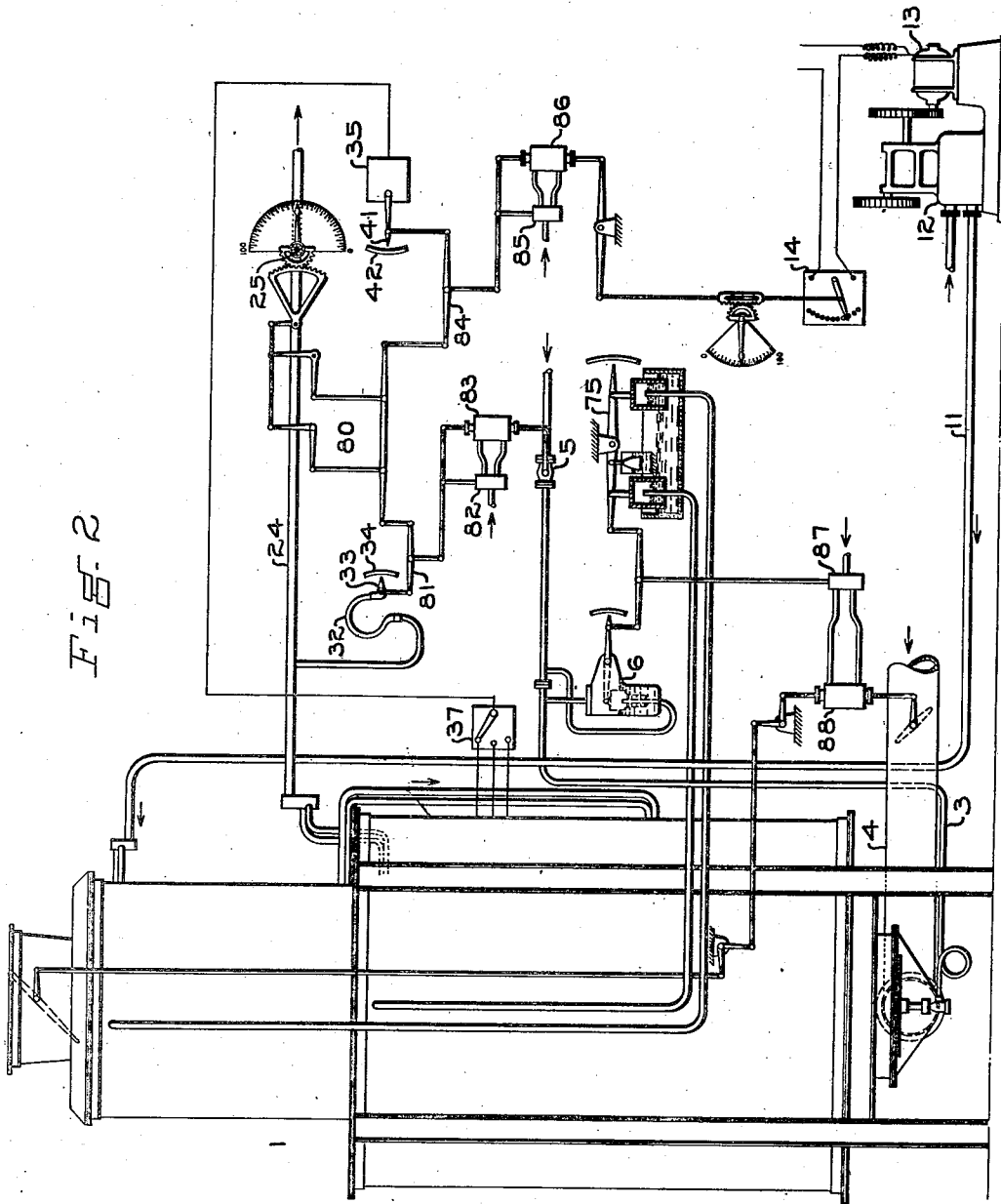
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3 Sheets-Sheet 2

Fig. 2



INVENTOR
Paul S. Dickey.
BY
Raymond W. Jenkins
ATTORNEY

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P. S. DICKEY

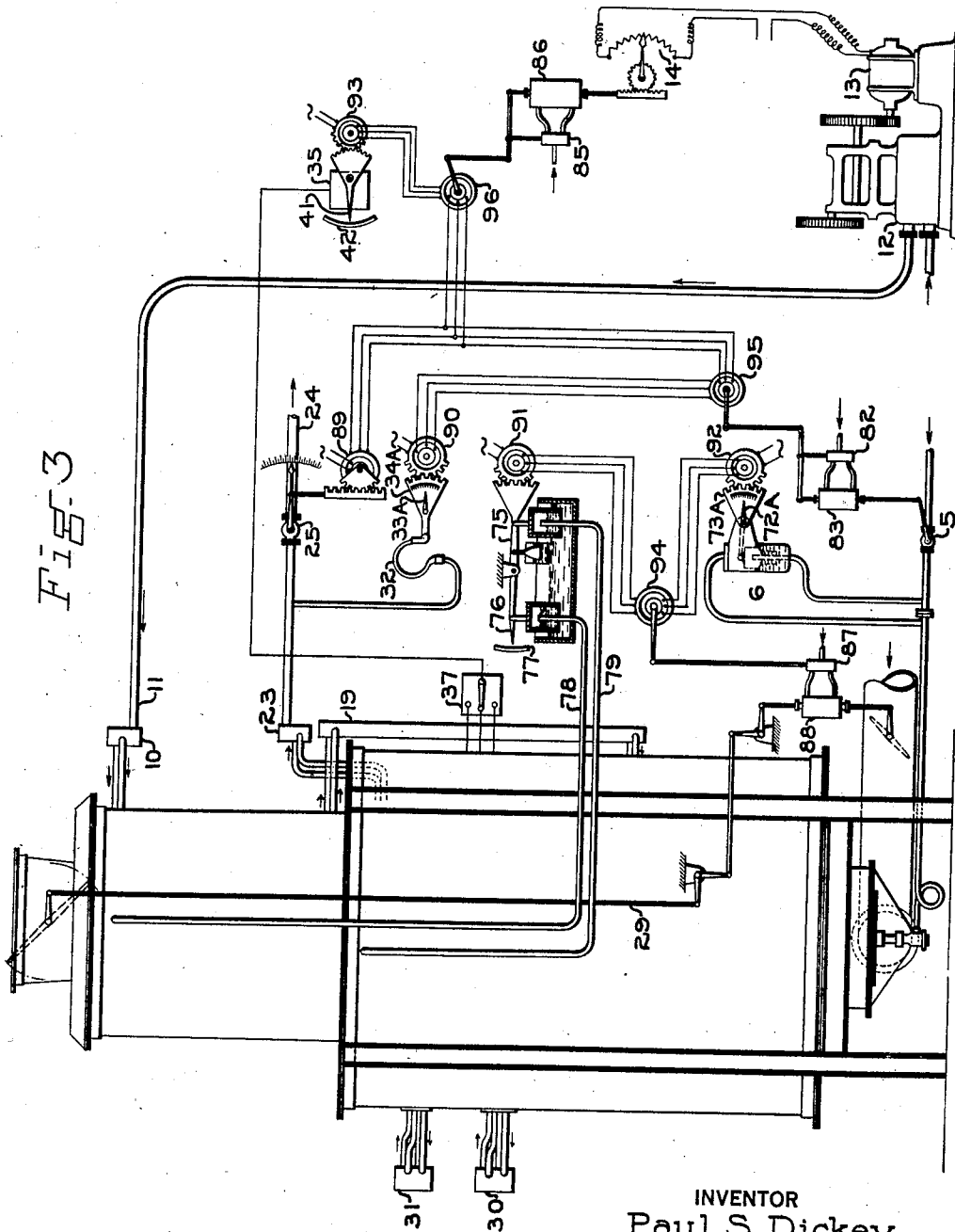
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3 Sheets-Sheet 3

Fig. 3



INVENTOR
Paul S. Dickey.
BY
Raymond W. Jenkins
ATTORNEY

UNITED STATES PATENT OFFICE

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CONTROL FOR VAPOR GENERATORS

Paul S. Dickey, Cleveland, Ohio, assignor to
Bailey Meter Company, a corporation of Delaware

Application November 10, 1931, Serial No. 574,000

5 Claims. (Cl. 122-448)

This invention relates to a method and means for controlling the operation of vapor generators, and has particular reference to that type of drumless vapor generator having fluid flow paths in which the flow in each path is initiated by the entrance of liquid under pressure at one end of the path and characterized by the exit of vapor only at the other end of the path. Such boilers are disclosed in the co-pending application entitled "Method of operating a steam boiler", Serial No. 357,419, filed in the United States Patent Office April 23, 1929 by James Fletcher, and the application of Howard J. Kerr entitled "Steam boiler", Serial No. 450,348 filed in the United States Patent Office May 7, 1930; the present invention being in the nature of an improvement thereto, as well as also being related and in the nature of an improvement to the co-pending joint application of James Fletcher and Paul S. Dickey entitled "Vapor generator and method and means for operating the same", Ser. No. 574,076 filed of even date herewith. It is to be understood that throughout the specification, where I refer to boilers or vapor generators, I mean the same.

In vapor generators of the character mentioned having a once-through fluid flow path without circulation and wherein the liquid volume is always at a minimum, the liquid inflow must of necessity be continuous and at all times proportioned to the demand or generator load. Furthermore this type of unit, having no substantial reserve liquid capacity and the fluid in motion in the circuit varying from liquid to vapor with intermediate percentages of vapor and liquid mixture, cannot be equipped with any liquid level indicating device such as the standard water glass to establish a safe operating condition. Vapor is generated in tubes as needed and the liquid is fed to the tubes at such a rate that the desired proportion is held in a tube between liquid and vapor, so that vapor of the desired amount and quality may be obtained. A method and means for operating such a vapor generator in accordance with varying conditions must be provided. Such a method and means desirably providing for the supply of liquid and heat in proportion to the demand upon the generator for vapor, and such supply desirably readjusted in accordance with other variables such, for instance, as fluid temperature at a location in the flow path just beyond the saturation line, or outlet vapor pressure.

I have found that constant predetermined

quality or temperature of the vapor outflow may be insured regardless of the rate of outflow, through the maintaining substantially constant of the percentage of the fluid flow path within the boiler in which vapor alone exists. The point of conversion to complete vapor state, beyond which in the flow path the fluid exists as vapor only, tends to move along the flow path through several causes such, for example, as variation in the rate of liquid inflow relative to the rate of vapor outflow, and variation in the rate of supply of the elements of combustion for heating or causing change of state or temperature of the fluid.

One object of my invention in connection with a vapor generator of the drumless or once-through type is the control of liquid inflow thereto, proportionate to an indication of load on, or output of, the generator.

A further object is to control the liquid inflow to maintain substantially constant, regardless of rate of vapor outflow, the percentage of fluid flow path within the boiler wherein exists the fluid as a vapor only.

Another object is to control the liquid inflow proportionate to an indication of load upon the boiler, with readjusting or modifying control of the liquid inflow from temperature indication at a location along the fluid flow path.

Still another object is to control the supply of an element of combustion proportionate to an indication of load on the boiler and to readjust such supply from an indication of vapor outlet pressure.

A still further object is to proportion the supply of an element of combustion to the supply of a second element of combustion for most efficient combustion.

A still further object is to so coordinate the control of liquid inflow and the supply of the elements of combustion as to most efficiently provide a vapor outflow from the boiler of desired quantity and quality.

In the illustrative embodiments of my invention, I show herewith:
Fig. 1 is a sectional elevation of a vapor generator according to the present invention, combined with the requisite apparatus to control the functioning thereof, and such apparatus shown in partially diagrammatic fashion.

Fig. 2 is a side elevation of a vapor generator similar to that shown in Fig. 1, and having diagrammatically shown in connection therewith, control equipment comprising a second embodiment of the invention.

Fig. 3 is similar to Fig. 2 to illustrate a third embodiment of the invention.

In the various drawings, identical parts bear the same reference numerals.

Referring now in particular to Fig. 1, I have illustrated a steam generating boiler 1, having a furnace 2 for heating fluid passed through a multiplicity of conduits in heating relation with the combustion and products of combustion. The elements of combustion such as fuel and air, for example, are fed to the furnace 2, in regulated amount through the conduits 3 and 4 respectively. The conduit 3 is adapted, in the present embodiment, to supply oil for combustion to the furnace 2, such supply being regulated through the positioning in the conduit of a regulating valve 5, and the supply is measured by a rate of flow meter 6. The conduit 4 for supplying air for combustion to the furnace 2 is fed by a blower 7 which is driven by a motor 8, at a speed depending upon the controlled position of a rheostat 9 inserted in the electric circuit of the motor.

Liquid to be converted into vapor under pressure is fed to a header 10 through a conduit 11 by a pump 12, driven by a motor 13 at a speed depending upon the regulated position of a rheostat 14 inserted in the electric circuit of the motor.

From the header 10 originate three parallel conduits 15, 16 and 17, each of series type and which are of small diameter and great length, being formed sinuously in layers by suitable bending, in a water heating or economizer section 18 of the flow path, the lower portions of which having much greater length than the upper portions and which extend outwardly into the walls of the flue passage for support. From the economizer section 18, the parallel conduits lead to a header 19, and from the header 19, enter the furnace at 20, whereafter they are coiled upwardly surrounding a secondary combustion space of the furnace. A certain portion of the surrounding conduit wall comprises a steam generating portion 21 while the uppermost portion of the surrounding conduits comprise a superheating section 22, from which the parallel conduits lead to a header 23, from which there passes a conduit 24, through a control or throttle valve 25, to a turbine or other utilizing apparatus 26. Products of combustion pass from the furnace 2 in series heating contact with the steam generating portion 21, the superheating portion 22 and the economizer portion 18 to a stack 27, whose draft is controlled by the positioning therein of a damper 28 through the medium of linkage 29 controlled in parallel with the rheostat 9.

It will be observed that the grouping of the parallel conduits is definitely segregated into three sections; namely, an economizer section 18, a generating section 21 and a superheating section 22, wherein the fluid flowing through the conduit is continuously in heat relation with the products of combustion passing from the furnace. Equalizing headers 19, 30 and 31 are shown in the flow path to bring the fluid of the several conduits into mixing relation to commingle and for equalization of the temperature and distribution, whereafter they again separate into the respective flow paths.

It will likewise be seen that the grouping of the respective portions of the conduit is such that each represents a continuous sinuous fluid path of great length and small diameter from liquid entrance to superheated vapor outlet with some portion thereof having a fluid flow counter-

current to the hot gases passing thereover, while other portions thereof have fluid flow with the gases passing thereover concurrently.

The grouping of the conduit sections and their arrangement with respect to the furnace, secondary combustion chamber, and flue, is such that insofar as arrangement is considered, the heat absorbed by any one conduit is substantially equal to the heat absorbed by any other conduit, with the result that heat input to each conduit for a given combustion condition is approximately constant and the furnace and flue are constructed so that the heat stored therein is at a minimum.

In the operation of such a vapor generator, certain variables are indicated and utilized as the basis for automatically controlling the supply of fluid thereto and the supply of the elements of combustion to the heating furnace.

I indicate at 32 a pressure responsive device such as a Bourdon tube connected to the conduit 24 and having an indicator pointer 33 adapted to co-operate with an index 34 for advising the instantaneous value of the vapor outlet pressure.

At 35 is indicated a device positioned responsive to temperature such, for example, as an electrical instrument of known type, connected by conductor 36 to a switch 37 selectively with thermocouple wires 38, 39 or 40, adapted respectively to contact with separate portions of the conduit and sensitive to temperature of the fluid at selected points in its path. Preferably the thermocouple 38 is located to be sensitive to temperature in the generator section, namely temperature of a mixture of liquid and vapor corresponding to the pressure, while the thermocouple 40 is positioned to be sensitive to temperature of the fluid in the superheater portion, namely being beyond in the direction of fluid flow the location in the flow path of conversion to complete vapor state and where the vapor may be slightly superheated. The temperature responsive apparatus may be of any known commercial type so long as an indicator 41 is positioned relative to index 42 to advise the instantaneous value of the temperature in the fluid flow path at a selected location.

As an indicator of generator output or load upon the generator, I utilize the position of the throttle valve 25 whose handle has an extension forming a pointer 43, cooperating with an index 44. The throttle valve 25 being of a calibrated type to the end that the indication of the pointer 43 relative to the index 44 is representative of the rate of flow of vapor there-through as a measure of the generator output or load.

I preferably primarily control the liquid inflow to the boiler by means of the rheostat 14, and the fuel supplied for combustion to the furnace by means of the control valve 5, directly proportional to an indication of output, namely, in the present illustration, the position of the throttle valve 25. To this end, I connect to the throttle valve handle a depending rod 45, freely pivoted to one end each of two beams 46, 47, the latter pivotally connected at its other end to be positioned by the Bourdon tube 32, and the former pivotally connected at its other end to be freely positioned with the pointer 41, to the end that the beam 47 is positioned along a definite path in a plane of space jointly by throttle position and by vapor outlet pressure. The beam 46 being positioned likewise along a definite path in a plane of space, jointly by throttle position

and by temperature at a selected location along the fluid flow path.

From the beam 47 intermediate its ends, depends pivotally connected thereto a rod 48, pivotally connected at its other end to a contact carrying beam 49, which is adapted to be oscillated or positioned about a pivot point 50, fixed in a contactor case 51. The contactor case 51 itself carries a pair of contacts mating with those carried by the beam 49, and may be raised or lowered, i. e., positioned as a whole about a center 52, through the agency of a motor 53, which in itself is connected in the circuit including the said contacts. A beam 54 oscillatable around the center 52 by rotation of the motor 53, at one end carries the contactor case 51 and at the other end has pivotally connected thereto a rod 55, for positioning the fuel control valve 5.

The circuit of the pilot motor 53 and the contactor 51 is similar to the one disclosed and claimed in the co-pending application Serial No. 561,005 filed September 3, 1931, by John D. Ryder entitled "Motor control circuits", and embodies the use of thermionic valves connected in an alternating current circuit, and arranged each to pass a pulsating direct current comprising one-half of the alternating current wave. The field of the motor 53 is energized across a source of direct current, while the armature is in an alternating current circuit, comprising thermionic valves 56 and 57 whose grid circuits are respectively controlled by the contacts of the contactor 51, normally close-circuited, to the end that the armature of the motor 53 is normally energized in the alternating current circuit. The opposing equal torques of the alternating current half-waves prohibit rotation of the armature and thermal damage to the motor is prevented through the use of a reactor 58. When the grid control circuit to either the valve 56 or the valve 57 is open-circuited as by the contactor 51, that valve ceases to pass current and the torque on the motor armature from the pulsating direct current passing through the other valve causes rotation of the said armature in desired direction. The arrangement is such that when the rod 48 is moved downwardly, then (on the drawings) the left hand contact is open-circuited and the motor 53 is caused to rotate in a direction wherein the contactor case 51 is moved downwardly until the left hand contact is again close-circuited, whereupon a substantially instantaneous application to the armature 53 of opposing equal torques of the full-wave alternating current causes substantially instantaneous plugging or stoppage of rotation thereof. Simultaneously, the motor has caused a positioning of the fuel control valve 5 in desired amount.

A similar arrangement is shown in connection with the operation of the rheostat 14, wherein the beam 46 whose position is determined responsive to position of the throttle valve 25 and of the temperature device 35, causes vertical movement of a freely depending rod 59 to position a contactor bar 60, resulting in rotation of the motor 61 in a desired direction for regulating the rheostat 14 and balancing back on the contactor 60 to cause a stoppage of rotation of the motor 61.

Having controlled the supply of fuel to the furnace, primarily in accordance with an indication of boiler output and secondarily from an indication of vapor outlet pressure, I utilize the rate of supply of fuel to the furnace as a guide to the supply of air for combustion and do this by separately measuring the rate of supply of fuel and

the rate of flow of air, balancing one of the measures against the other to determine the ratio thereof, comparing the ratio to a predetermined desirable ratio, and upon departure of such ratios effecting a control of the forced draft fan motor 8 and the uptake damper 28, through a positioning of the rheostat 9, and the linkage 29 respectively, through the agency of a pilot motor 62.

The pilot motor 62 is similar to the pilot motors 53 and 61 above described, and is in an alternating current circuit controlled by thermionic valves, in turn controlled by a contactor whose position is responsive to departure of the ratio between fuel supply and air supply from predetermined desirable ratio. The motor circuit is further arranged for speed control wherein the speed of the motor 62 varies depending upon the magnitude of departure of the ratio between fuel supply and air supply from a predetermined ratio. Features of the thermionic valve control circuit for the motor 62 are similar to the circuit of the motors 53 and 61 disclosed and claimed in the referred to application of Ryder, Serial No. 561,005, while further features of the circuit comprising the speed control of the reversing pilot motor 62 are disclosed and claimed in a co-pending application of John D. Ryder, entitled "Motor control circuits", Serial No. 561,006, filed September 3, 1931. The latter referred to application discloses and claims means such, for example, as a variable reactance 63 in the motor circuit for varying the speed thereof.

A contactor in general indicated at 64 controls the grid circuit of each of the thermionic valves through an upper contactor bar 65, and the variable reactance 63 through movement of a lower contactor bar 66. The contacts carried by the lower bar 66 relative to those carried by a case 67, when open-circuited one or the other, result in the positioning of a self-starting synchronous motor 68 in one direction or the other through the releasing thereof of one of two opposing equal torque fields normally both energized, and at the same time, the positioning of the contactor case 67 causes the positioning of a core in a reactance 63 for speed control of the motor 62. Certain features of the contactor 64 are disclosed and claimed in a co-pending application Serial No. 589,009 filed January 26, 1932 by Walter E. Dueringer.

For positioning the contact bars 65 and 66, I provide a freely pivoted rod 69, pivotally suspended from intermediate the ends of a floating beam 70. One end of the beam 70, namely (in the drawings) the right hand end, is pivotally suspended from a rod 71, in turn pivotally suspended from the pointer 72 of the flow meter 6, which pointer cooperates with an index 73.

The flow meter indicated in general at 6 for providing a measure of the rate of supply of fuel to the furnace is of a known type, such as is disclosed in the patent to Ledoux No. 1,064,748 granted June 17, 1913. Such a meter is a differential-pressure responsive device adapted to correct for non-linear relation between differential-pressure and rate of flow to the end that angular positioning of the pointer 72 relative to the index 73 is by increments directly proportional to increments of rate of flow. I illustrate by dotted lines within the flow meter 6, the outline of the internal construction, wherein is a liquid sealed bell having walls of material thickness and shaped as described and claimed in the above mentioned Ledoux patent.

Effective upon the left hand end of the floating

beam 70 for positioning the same, is pivotally connected thereto a rod 74 suspended from a beam 75 which is, in turn, pivoted intermediate its ends and carries a pointer 76 adapted to cooperate with an index 77, to indicate thereon the rate of flow of air through the passages of the vapor generator. From the oscillatable beam 75, are suspended two liquid sealed inverted bells as well as a displacing member, the whole comprising a rate of flow meter such as is well known in the art, wherein the positioning of the system comprising the bells, the displacer and the beam 75, is responsive to a pressure-differential transmitted to beneath the bells through pipes 78, 79, leading respectively above and below the economizer section 18 through which is a drop in pressure in known relation to the rate of flow of the air and products of combustion therethrough.

By air flow, I intend to mean the excess of air as well as the products of combustion which pass through the restriction of the economizer section 18, to cause a pressure differential there across, bearing a known relation to the rate of flow therethrough. I have found that by so measuring the total flow of air and products of combustion leaving a furnace such as 2, I have a definite guide or measure of the rate of supply of air for combustion when the system is properly calibrated.

In operation, it will be seen that the disclosure provides a method and means for the control of liquid input to the boiler from a relation between boiler output and temperature at a location along the fluid flow path; a control of the supply of fuel to the furnace responsive to an indication of boiler output and to vapor outlet pressure; and a control of air for combustion in accordance with the rate of supply of fuel to the furnace.

Assume that the system is in operation with liquid inflow to the header 10 substantially equal to vapor outflow through the conduit 24; the quantity and quality of the outflow vapor as desired and the supply of the elements of combustion in desired proportion for most efficient operation. Assume now that by hand control of the throttle valve 25, an increase in output of the boiler is made, then through the automatic control system a positioning of the rod 45 results, through the pilot motors 53 and 61 and their related control circuits, in a positioning of the fuel control valve 5 and of the rheostat 14 in desired proportion, wherein the rate of supply of fuel and liquid to the furnace and boiler respectively is increased proportionate to the increase in output of the boiler. The flow meter 6 responsive to the rate of input of fuel to the furnace causes a positioning of the rod 69 to result, through the pilot motor 62, in a positioning of the rheostat 9 and the linkage 29 wherein the rate of air supplied for combustion is readjusted to remain substantially equal to or proportionate to the supply of fuel for combustion.

Should the vapor outlet pressure to which the Bourdon tube 32 is responsive vary from desirable value, either simultaneously with a variation in boiler output or otherwise, a positioning of the fuel control valve 5 will result to cause the proper variation in rate of fuel supply and heat input to the furnace and boiler for restoring the pressure to its predetermined desirable value. Simultaneously such change in rate of supply of fuel will cause, as above described, a change in the rate of supply of air for combustion, whereby the combustion is always accomplished in most efficient manner.

Effective upon the rate of supply of liquid to the boiler, in addition to the position of the throttle valve 25 as a main load control for paralleling the liquid input and the vapor output, is the device 35 responsive to a selected temperature at a location in the conduit or fluid flow path. Preferably I control the rate of supply of liquid inflow to the boiler from the location along the flow path beyond the point of complete conversion to vapor state as indicated, for example by the location of the thermocouple 40, just within the superheater section or portion of the conduit. I have found that primarily in the control of a boiler such as is described, it is essential in maintaining the vapor outflow in desired quantity and quality, that I maintain a fixed percentage of the flow path or conduit to have vapor only being superheated and it will be seen that the best way to so maintain the predetermined portion of the flow path as desired, is to proportion the inflow of liquid to the output of the boiler as I have explained and readjust the inflow from a temperature at a location in the flow path, which temperature will vary responsive to a change in the amount of the flow path which I desire to have remain constant.

For example, if the thermocouple 40 is sensitive to temperature just beyond the point of complete conversion to vapor state, then it will be sensitive to a temperature which is equal to the temperature corresponding to pressure plus whatever superheat is present in the vapor. Such a location has preference over a thermocouple located exactly at the point of complete conversion to vapor state, for until the vapor begins to be superheated, there is no temperature change between that of the liquid and that of the vapor so that it is not practical to attempt to determine exactly the location in the flow path of complete conversion to vapor state. I provide, however, the thermocouples 38, 39 which I may use as a checking control upon the supply of liquid input to the generator through the selectivity of the switch 37, if desired.

In Fig. 2, I illustrate an embodiment of my invention similar to that of Fig. 1 except that I employ hydraulic means for the positioning of the various controlled factors rather than the electric means just described. The vapor generator illustrated in general at 1, is shown in side elevation rather than in sectional elevation. The internal construction is the same as in Fig. 1 except that I have dispensed with the equalizing or mixing boxes 19, 30 and 31. I supply a liquid to the boiler through a conduit 11, and the vapor outflow from the boiler passes through the conduit 24, having a throttle valve 25 for the control thereof. Fuel is supplied to the furnace through a conduit 3 and air through a conduit 4 as in Fig. 1.

The position of the throttle 25 is transmitted through linkage 80 to one end of a beam 81, the other end of which is positioned by vapor outlet pressure for the control of a pilot valve 82 to cause a positioning of a hydraulic power piston 83 for adjusting the fuel regulating valve 5.

The linkage 80, representative of throttle position, is further effective in positioning a beam 84, the other end of which is positioned responsive to temperature at a location in the fluid flow path, and effective for the positioning of a pilot valve 85 controlling a hydraulic power piston 86 to move the rheostat 14 for control of the liquid inflow pump 12.

The fuel supply meter 6 and the air supply meter 75 are similar to those shown in Fig. 1 and serve to control a pilot valve 87 for positioning

the hydraulic power piston 88, for regulating the air supply dampers.

It will be seen then that the arrangement of equipment for indicating the instantaneous value of the variables and the equipment for utilizing such indications to control the supply of liquid input and the elements of combustion, is similar to that I have described in detail in Fig. 1, except that herein I utilize hydraulic power pistons controlled by pilot valves.

In Fig. 3, I illustrate a similar embodiment to those of Fig. 1 and Fig. 2, differing therefrom only in that herein I employ a combination of self-synchronous electric motor remote positioning devices for transmitting the position corresponding to the instantaneous value of the variables to the point of control wherein desirable control is attained through hydraulic means.

I indicate such self-synchronous or Selsyn transmitting generators for transmission of position at 89, 90, 91, 92 and 93, while the self-synchronous receiving motors are indicated at 94, 95 and 96. The transmitting generator in each case is operated at a suitable angular rotation of the order of 30 degrees maximum through angular positioning of the rotor or single-phase field winding. The stator or armature is in each case provided with a three phase winding. The field windings of each transmitting generator are energized from a suitable source of alternating current supply. The rotor of the transmitting generator 89 is positioned responsive to throttle position, that of the generator 90 responsive to the vapor outlet pressure, that of the generator 91 responsive to the air flow, that of the generator 92 responsive to rate of fuel supply, and the rotor of the generator 93 responsive to temperature at a location in the fluid flow path.

The receiving motors 94, 95 and 96 have three-phase rotor windings and three-phase stator windings and are commonly known as differential self-synchronous motors for, in each case, they are responsive to two of the transmitting generators to assume a rotor position corresponding to differential effect from the two related transmitters. For example, the receiving motor 94 has its rotor positioned responsive to a differential between the position of the rotor 91 and that of the rotor 92, or corresponding to the relation between air supply and fuel supply. Correspondingly, the receiving motor 95 has its rotor positioned responsive to a differential between the position of the rotor 89 and that of the rotor 90, or dependent upon the throttle position modified by vapor outlet pressure value. The rotor of the receiving motor 96 is positioned responsive to the throttle position from the transmitting generator 89 modified through the agency of the transmitting generator 93 representative of temperature at a location in the fluid flow path.

The operation of systems of this general character for the transmission of angular movement is well known in the art. Voltages are induced in the three-phase stator windings of the generator and motor by the single-phase field winding on the associated generator rotor. When the rotor of either of the related motors is moved from a predetermined position with respect to its stator, a change is effected in induced voltage in the armature windings and the rotor of the receiving motor assumes a position of equilibrium relative to the transmitting generators wherein the induced voltages in the three-phase windings are equal and opposite, and consequently no current is set up in the armature winding. If the rotor

of one of the generators is turned and held in a new position, the voltage is no longer counter-balanced, whereby equalizing currents are caused to flow in the armature windings. The equalizing currents exert a torque on the rotor of the receiving motor, causing it to take up the position corresponding to a differential between the position of the transmitting generators. Angular movement imparted mechanically to the rotors of the transmitting generators 89 and 90 result in an angular positioning of the rotor of the receiving motor 95. Similar action occurs between the transmitting generators 89, 93 and the receiving motor 96; and between the transmitting generators 91, 92 and the receiving motor 94.

The fuel oil control valve 5 positioned through hydraulic piston 83 is controlled in its positioning by the pilot 82, in turn positioned relative to a neutral point through movement of the rotor of the receiving motor 95. Thus responsive to throttle position from the transmitting generator 89 modified by position of the transmitting motor 90 responsive to temperature at a location along the fluid flow path. Linkage connecting the rotor of the motor 95 with the pilot 82 and the power piston 83 provides a balanced follow-up wherein movement of the pilot 82 resulting in movement of the power piston 83 causes a repositioning of the pilot 82 to shut off position, so that a control is provided commonly known as positioning control wherein each position of the rotor of 95 results in a definite positioning of the power piston 83 and correspondingly of the throttle valve 5.

Control of the liquid input to the vapor generator is accomplished through regulation of the rheostat 14 from the power piston 86, controlled through the pilot 85 from position of the rotor 96, which is set up by throttle position from 89 and modified by 93, an indication of temperature at a location along the fluid flow path.

A balance is established between rate of fuel supply and rate of air flow as indicated by the rotor positions 92 and 91 wherein if said balance is obtained, the rotor 94 is in a predetermined position wherein the pilot 87 is in shut-off position. Should the balance deviate in one direction or the other from that desired, the rotor 94 is positioned in proper direction to move the pilot 87 wherein the power piston 88 is moved to cause a change in the value of air flow for positioning the rotor 91 to cause the rotor 94 to move the pilot 87 to shut-off position.

In general, in the operation and control of such a vapor generator and furnace, I contemplate a method and means for controlling the liquid inflow and supply of elements of combustion in the most efficient manner for insuring a vapor outflow of desired quantity and quality. The control of such a drumless vapor generator as I have described, presents a problem differing considerably from the ordinary storage type of vapor generator and it is necessary to appreciate in connection therewith the fact that in each conduit comprising a fluid flow path through the generator, there will be at all times a location which I term the "vaporization line", at the inlet side of which is the water heating section and at the outlet side, a combination of vapor and liquid. There is further in the series flow path a location which I designate as the "saturation line" or "point of conversion to complete vapor state" beyond which exists vapor only. A water heating or economizing portion of the fluid flow path is first in the series flow before the vaporization line is reached as may also be part of the vapor

generator or heating surface. Between the vaporization line and the saturation line exists a mixture of vapor and a liquid, and beyond the saturation line, in what I term the superheater section, is vapor only in varying degree of superheat.

One of the main features of my invention is the discovery that by maintaining substantially constant the percentage of the fluid flow path comprising the superheater section beyond the location in the fluid flow path of complete conversion to vapor state, regardless of rate of output of the boiler, I will maintain substantially constant the quality of the vapor outflow. The temperature of the vapor at the saturation line will be the same as the temperature just preceding the line for it will be the temperature corresponding to the pressure, regardless of whether at that point exists liquid or vapor. Beyond the saturation line, however, where vapor only exists and is still subjected to the heating effect of the furnace and products of combustion, the vapor may have a temperature superheated or substantially higher than that at the point of complete conversion to vapor state and usually progressively higher from the saturation line to the point of outflow from the generator. Thus, by taking a temperature measurement in the flow path just beyond the saturation line, I obtain a temperature which is indicative of complete vapor state with a slight amount of superheat and by using this temperature as the readjusting control, in regulating the supply of liquid inflow to the fluid flow path, wherein the primary control of liquid inflow is in accordance with boiler output or throttle position, I accomplish my desirable feature of maintaining substantially constant the portion of the fluid flow path wherein exists vapor only.

I have illustrated and described the use of the selective switch 37 whereby I may utilize as a corrective influence a temperature selective between a multiplicity of locations in the fluid path and I have such possible selection for the purpose of basically changing the amount or portion of the fluid flow path wherein exists vapor only, through the control selectively from one of the said temperatures and for the purpose of selecting between desired quality of the outflowing vapor. Thus for example, should I desire the vapor outflow to have a temperature of 750° F. representing a certain amount of superheat, I may control to maintain a certain portion of the flow path to have vapor only therein such, for example, as that portion slightly greater in length than from the location of the thermocouple 40 to the exit from the boiler. If, however, I desire to control for a slightly different temperature of the vapor leaving the boiler, I may utilize the thermocouple 39, thereby increasing the percentage of the fluid flow path wherein exists vapor only.

I show in Fig. 1 three parallel conduits comprising three similar fluid flow paths through the boiler with the utilization of equalizing or mixing boxes at various points along the path. In Fig. 2 and Fig. 3, I show two parallel conduits and in Fig. 2, they are carried completely through the boiler as separate flow paths having no equalizing boxes. It will be apparent that I am not limited in my invention to two or three flow paths nor to the use of equalizing boxes, but I contemplate broadly the utilization of one or more conduits comprising a continuous fluid flow path wherein liquid under pressure enters at one end and vapor of desired quantity and quality is dis-

charged from the other end, without storage or circulation.

Having thus described my invention in preferred embodiments thereof, I desire it to be distinctly understood 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. Apparatus for automatically controlling the operation of a vapor generator having a once-through fluid passage receiving liquid at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, a generator output indicator, a thermostat sensitive to temperature at a location in the passage wherein is superheated vapor; a control circuit comprising a motor having a field winding and an armature, a source of direct current for energizing the field winding, the armature connected in an alternating current circuit, two thermionic valves in the armature circuit, such valves oppositely connected in parallel with each other and in series with the armature, the valves normally effective to pass full-wave alternating current to the armature for opposing equal torques whereby the armature is held from rotation; and control means positioned by said indicator and by said thermostat for selectively making ineffective either of said valves to effect a rotation of the armature in a desired direction, said motor adapted to regulate the rate of liquid inflow to the generator.

2. Apparatus for automatically controlling the operation of a vapor generator having a once-through fluid passage receiving liquid at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, a generator output indicator, a thermostat sensitive to temperature at a location in the passage wherein is superheated vapor; a pressure indicator positioned responsive to vapor outlet pressure; a control circuit comprising a motor having a field winding and an armature, a source of direct current for energizing the field winding, the armature connected in an alternating current circuit, two thermionic valves in the armature circuit, such valves oppositely connected in parallel with each other and in series with the armature, the valves normally effective to pass full-wave alternating current to the armature for opposing equal torques whereby the armature is held from rotation; control means positioned by said indicator and by said thermostat for selectively making ineffective either of said valves to effect a rotation of the armature in a desired direction, said motor adapted to regulate the rate of liquid inflow to the generator, a second similar motor and control circuit therefor, and regulating means positioned by said indicator and by said pressure indicator for selectively effecting a rotation of the second motor armature in a desired direction, said second motor adapted to regulate the rate of supply of an element of combustion to the furnace.

3. Apparatus for automatically controlling the operation of a vapor generator having a once-through fluid passage receiving liquid at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, a generator output indicator, a thermostat sensitive to temperature at a location in the passage wherein is super-

heated vapor, a pressure indicator of vapor outlet pressure, and meters of the rate of supply of the elements of combustion, control means including electron discharge devices responsive to said indicator and to said thermostat and adapted to control the liquid input, control means including electron discharge devices responsive to said indicator and to said pressure indicator and adapted to regulate the supply of one of the elements of combustion, and control means including electron discharge devices responsive to said meters and adapted to control the supply of another element of combustion.

4. Apparatus for automatically controlling the operation of a vapor generator having a once-through fluid passage receiving liquid at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, a generator output indicator, a thermostat sensitive to temperature at a location in the passage wherein is superheated vapor, a regulator of the rate of liquid inflow to the generator, and electric means including electron discharge devices interconnecting said indicator, said thermostat and said regulator whereby the regulator is positioned responsive to both the generator output and the said temperature.

5. Apparatus for automatically controlling the operation of a vapor generator having a once-through fluid passage receiving liquid at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, a generator output indicator, a thermostat sensitive to temperature at a location in the passage wherein is superheated vapor, a regulator of the rate of liquid inflow to the generator, hydraulically actuated means for positioning such regulator, and electric means interconnecting said indicator, said thermostat and said hydraulic means whereby the hydraulic means is positioned responsive to both the generator output and the said temperature.

6. Apparatus for automatically controlling the operation of a vapor-generator having a once-through fluid passage receiving liquid at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, a generator output indicator, a regulator of the rate of liquid inflow to the generator, and control means for positioning said regulator, said control means actuated by electron discharge devices responsive to said indicator whereby the regulator is positioned responsive to the generator output.

7. Apparatus for automatically controlling the operation of a vapor-generator having a once-through fluid passage receiving liquid at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, a generator output indicator, a regulator of the rate of supply of the elements of combustion to the generator, and control means for positioning said regulator, said control means actuated by electron discharge devices responsive to said indicator whereby the regulator is positioned responsive to the generator output.

8. Apparatus for automatically controlling the operation of a vapor-generator having small liquid storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, an indicator of the load on the generator, measuring means of each of the elements of combustion, ratio determining means of said measures, means for comparing the ratio with a

predetermined ratio, a regulator of the supply of one of the elements of combustion, control means for positioning said regulator, said control means actuated by electron discharge devices responsive to said ratio comparing means, a second regulator controlling the supply of the second element of combustion, and other control means for positioning said second regulator, said other control means actuated by electron discharge devices responsive to said indicator.

9. Apparatus for automatically controlling the operation of a vapor-generator having small liquid storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, measuring means of each of the elements of combustion, ratio determining means of said measures, means for comparing the ratio with a predetermined ratio, a regulator of the supply of one of the elements of combustion, and control means for positioning said regulator, said control means actuated by electron discharge devices responsive to said ratio comparing means.

10. Apparatus for automatically controlling the operation of a vapor-generator having small liquid storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, a generator output indicator, an indicator of vapor outflow pressure, a regulator of the rate of supply of fuel to the generator, hydraulically actuated means for positioning said regulator, and electric means interconnecting said indicators and said hydraulic means whereby the hydraulic means is positioned responsive to both generator output and vapor outflow pressure.

11. Apparatus for automatically controlling the operation of a vapor generator having small liquid storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, an air flow meter, a fuel flow meter, a regulator of the rate of supply of air for combustion to the generator, hydraulically actuated means for positioning such regulator, and electric means interconnecting said meters and said hydraulic means whereby the hydraulic means is positioned responsive to metered air flow and metered fuel flow.

12. Apparatus for automatically controlling the operation of a vapor-generator having small liquid storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, a generator output indicator, a regulator of the rate of liquid inflow to the generator, and control means for positioning said regulator, said control means actuated by electron discharge devices responsive to said indicator whereby the regulator is positioned responsive to the generator output.

13. Apparatus for automatically controlling the operation of a vapor-generator having small liquid storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, a generator output indicator, a regulator of the rate of supply of the elements of combustion to the generator, and control means for positioning said regulator, said control means actuated by electron discharge devices responsive to said indicator whereby the regulator is positioned responsive to the generator output.

14. Apparatus for automatically controlling the operation of a vapor generator having a once-through fluid passage receiving liquid at one end under pressure and delivering superheated vapor

at the other end and heated by the elements of combustion, comprising in combination, a regulator of the rate of liquid inflow to the generator, and control means for positioning the regulator, said control means actuated by electron discharge devices.

15. Apparatus for automatically controlling the operation of a vapor generator having small liquid

storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, a regulator of the rate of liquid inflow to the generator, and control means for positioning the regulator, said control means actuated by electron discharge devices.

PAUL S. DICKEY.

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