Oct. 2, 1934. P. S. DICKEY 1,975,086

CONTROL FOR VAPOR GENERATORS

Filed Nov. 20, 1931 3 Sheets-Sheet 1

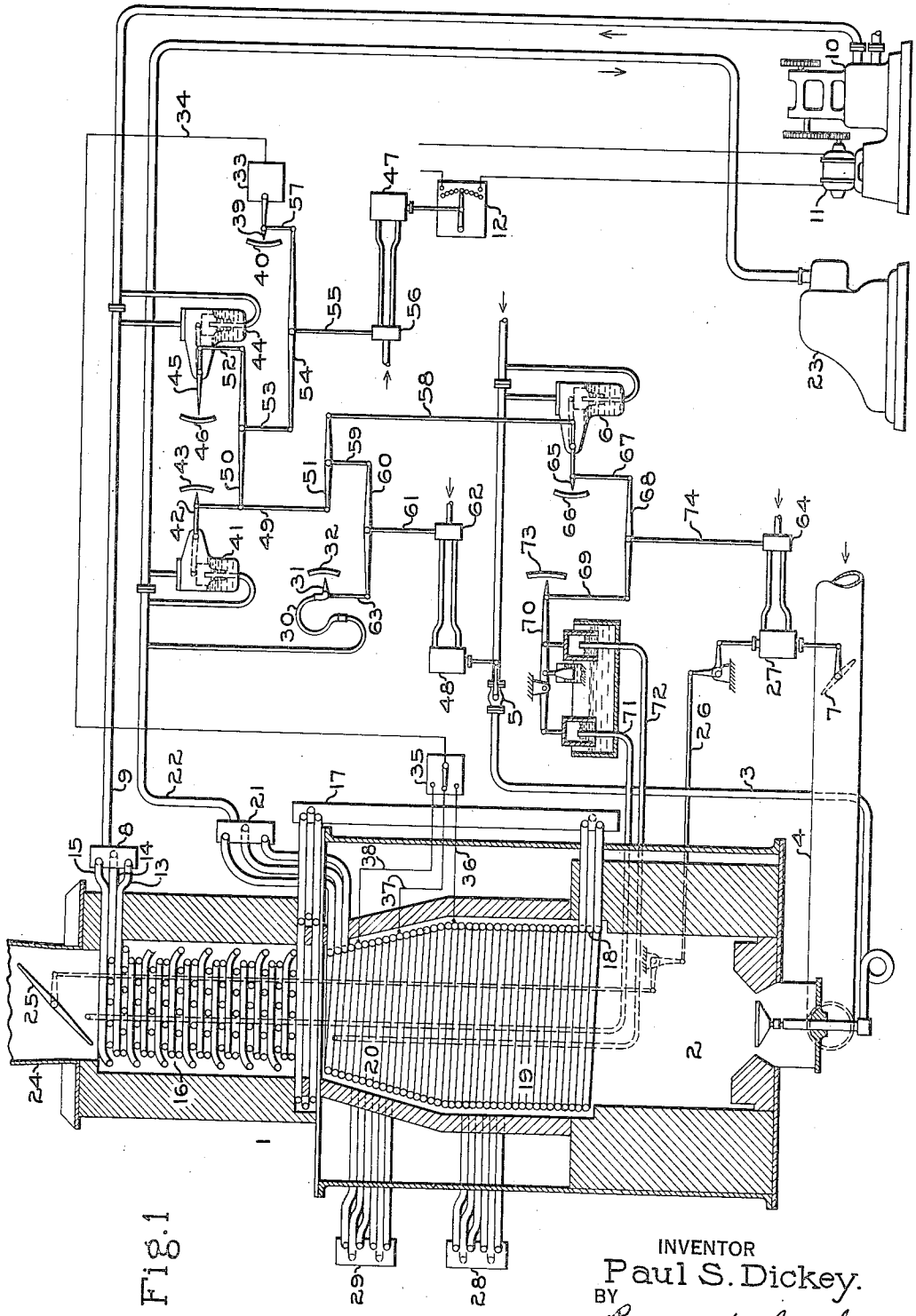


Fig. 1

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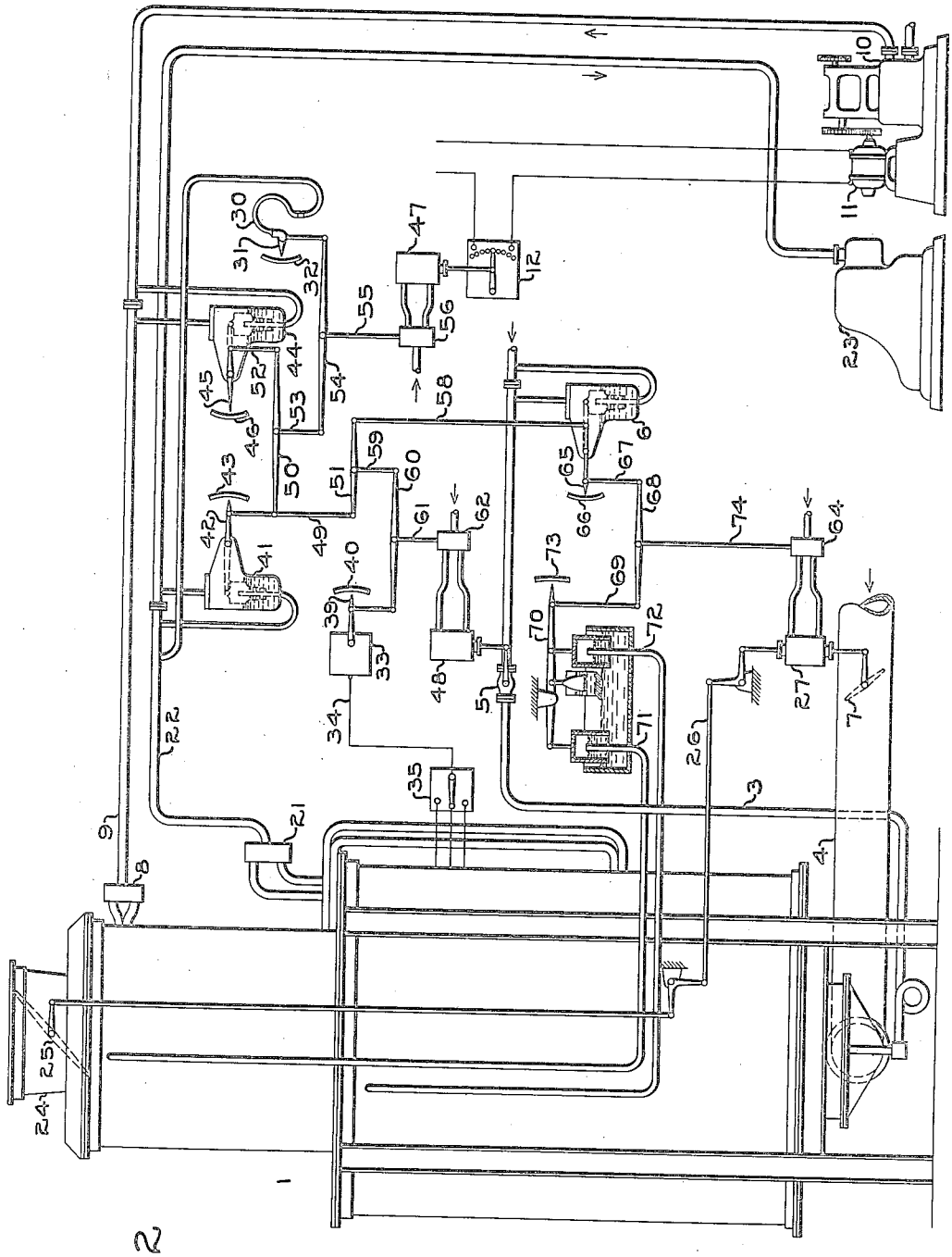


Fig. 2

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Filed Nov. 20, 1931 3 Sheets-Sheet 3

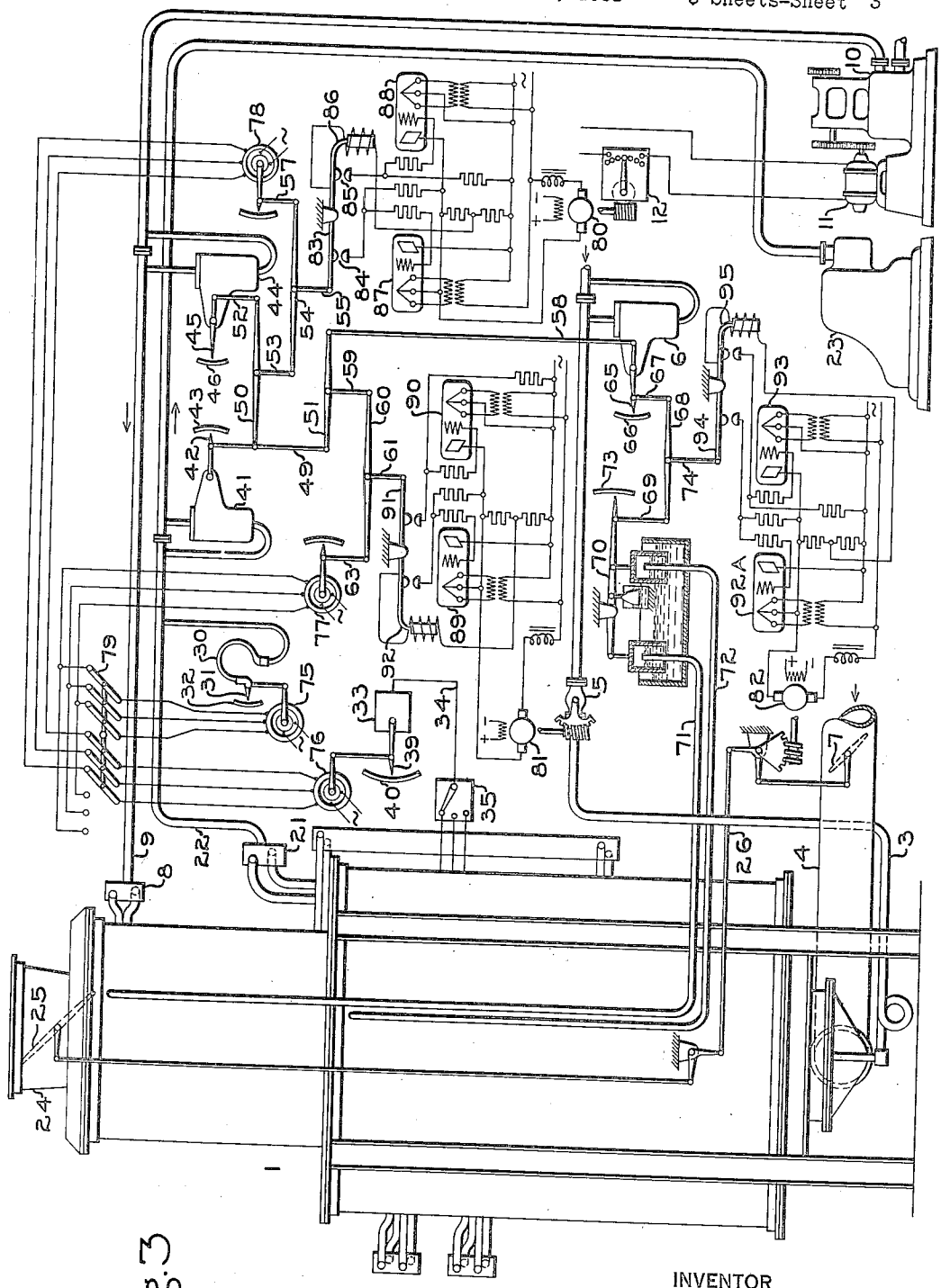


Fig. 3

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Patented Oct. 2, 1934 1,975,086

UNITED STATES PATENT OFFICE

1,975,086

CONTROL FOR VAPOR-GENERATORS

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

Application November 20, 1931, Serial No. 576,256

16 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", Serial No. 574,076 filed in the United States Patent Office November 10, 1931, and the co-pending application of Paul S. Dickey entitled "Control for vapor-generators", Serial No. 574,090 filed in the United States Patent Office November 10, 1931. 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 a 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, substantially equal to the vapor outflow therefrom.

A further object is to control the liquid inflow so as to maintain substantially constant, regardless of the 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 the vapor outflow, with readjusting or modifying control of the liquid inflow from a physical characteristic of the fluid such, for example, as 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 the vapor outflow and to cause a readjusting or modifying of such supply if necessary, from one of the physical characteristics of the fluid flow.

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

Still another 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.

A still further object is to maintain the inflow of liquid substantially equal to the vapor outflow, to maintain substantially equal the supply of heat to the furnace and the vapor outflow, to proportion the supply of air for combustion to the supply of fuel for combustion, and to readjust the control of liquid inflow and fuel

supply separately from the value of physical characteristics of the fluid flow.

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, having diagrammatically shown in connection therewith, control equipment comprising a second embodiment of the invention.

Fig. 3 is similar to Fig. 2, illustrating a third embodiment of my 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 amounts 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, said 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 supplied with air under pressure from any convenient source (not shown), controlled by the positioning within the conduit of a damper 7.

Liquid to be converted to vapor under pressure is fed to a header 8 through a conduit 9 by a pump 10, driven by a motor 11 at a speed depending upon the regulated position of a rheostat 12 inserted in the electric circuit of the motor.

From the header 8 originate three parallel conduits 13, 14 and 15, 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 16 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 16, the parallel conduits lead to a header 17, and from the header 17 enter the furnace at 18, 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 19, while the uppermost portion of the surrounding conduits comprise a superheating section 20, from which the parallel conduits lead to a header 21, from which there passes a conduit 22, to a turbine or other utilizing apparatus 23. Products of combustion pass from the furnace 2 in series heating contact with the steam generating portion 19, the superheating portion 20 and the economizer portion 16 to a stack 24, whose draft is controlled by the positioning therein of a damper 25 through the medium of linkage 26 controlled in parallel with the damper 7 through the agency of a hydraulic piston 27.

It will be observed that the grouping of the parallel conduits is definitely segregated into three sections; namely, an economizer section 16, a generating section 19 and a superheating section 20, wherein the fluid flowing through the conduit is continuously in heating relation with the products of combustion passing from the furnace. Equalizing headers 17, 28 and 29 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 countercurrent 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 30 a pressure responsive device such as a Bourdon tube connected to the conduit 22 and having an indicator pointer 31 adapted to cooperate with an index 32 for advising the instantaneous value of the vapor outlet pressure.

At 33 is indicated a device positioned responsive to temperature, such, for example, as an electrical instrument of known type connected by conductor 34 to a switch 35 selectively with thermocouple wires 36, 37 or 38, adapted respectively to contact with separate portions of the conduit and sensitive to temperature of the fluid at selected points in its flow path. Preferably the thermocouple 36 is located to be sensitive to temperature in the generating section, namely temperature of a mixture of liquid and vapor corresponding to the pressure, while the thermocouple 38 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 39 is positioned relative to an index 40 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 provide a rate of flow meter 41 adapted to position a pointer 42 relative to an index 43 for advising the instantaneous value of the rate of vapor outflow from the generator. The vapor outflow meter 41 is preferably interposed in the delivery conduit in advance of any point of use. That is, I obtain by the position of the indicator 42 relative to the index 43, a continuous indication of the rate of vapor outflow from the generator before any of such vapor is utilized or diverted from the conduit.

As an indicator of liquid inflow to the generator, I provide in connection with the conduit 9 a rate of flow meter 44 adapted to position

an indicating pointer 45 relative to an index 46 for advising the instantaneous value of the rate of flow of liquid through the conduit 9 to the header 8.

The rate of flow meters indicated at 6, 41 and 44 are similar and of 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 respective pointers relative to their respective indexes is in each case by increments directly proportional to increments of rate of flow. I illustrate by dotted lines within each of the flow meters, the outline of its 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.

I show as an operating or positioning power means for the rheostat 12 and the control valve 5, hydraulic power pistons 47 and 48 respectively. I preferably primarily control the liquid inflow to the boiler by means of the rheostat 12, directly proportional to the relation between liquid inflow and vapor outflow, or to the departure of such relation from desired relation wherein the liquid inflow is always equal to the vapor outflow. Similarly, I preferably primarily control the fuel supplied to the furnace for combustion by means of the control valve 5 directly proportional to an indication of relation between vapor outflow and fuel supply, wherein the rate of fuel supply is always desirably directly proportioned to the rate of vapor outflow, and on departure of such relation, I cause an adjustment to be made of the rate of fuel supply.

To this end I show interconnecting the three flow meters 6, 41 and 44, linkage comprising floating beams and rods pivotally connected together in proper manner, as will be explained. From the vapor outflow indicator 42 positioned by the vapor outflow meter 41, depends a rod 49 to which is pivotally connected intermediate its ends a beam 50, and at the opposite end a beam 51. The other end of the floating beam 50 is pivotally connected through the rod 52 with an extension of the fluid inflow indicator 45 positioned by the fluid inflow meter 44. The freely floating beam 50 is thus positioned along a definite path in a plane of space through the agency of the rate of flow meters 41 and 44 to the end that a point intermediate its ends, from which freely depends a rod 53, is positioned (in the drawings) vertically relative to a predetermined location only upon departure of the relation between rate of liquid inflow and rate of vapor outflow from desired relation.

Pivotally connected to the lower end of the depending rod 53 is one end of a floating beam 54 from which, intermediate its ends, depends a rod 55 adapted to position a pilot valve 56 for controlling the supply of a hydraulic fluid to the power piston 47.

Assuming for the moment that the right hand end (in the drawings) of the floating beam 54 is fixedly pivoted, then when the rate of liquid inflow is equal to the rate of vapor outflow, the pilot 56 will be in shutoff position and no movement of the power piston 47 will take place, whereby the rheostat 12 in the electric circuit of the motor 11 will remain at its previously regulated position. The flow meter 41 is adapted to cause the pointer 42 to be at the uppermost position on the index 43 when there is zero rate of vapor outflow, and correspondingly, the rate of flow meter 44 causes the pointer 45 to be at its uppermost position relative to the index 46 when there is zero rate of liquid inflow. The linkage is so arranged that when the rate of liquid inflow changes in value, but to the same extent as the rate of vapor outflow, the intermediate point of the floating beam 50 to which is connected the depending rod 53 remains in predetermined position in space, whereby no motion or positioning of the pilot 56 is accomplished, for no change in the rate of liquid inflow is desired or necessary. If, however, a change occurs in the rate of vapor outflow, for example, to increase the rate of outflow, then the pointer 42 moving downwardly relative to the index 43 causes the rod 49 to move downwardly, and correspondingly the rods 53 and 55 to the end that the pilot 56 is positioned for causing a movement of the power piston 47 whereby the speed of the motor 11 and correspondingly the output of the pump 10 will be increased until the rate of flow meter 44, being sensitive to such increased rate of liquid inflow, causes a vertical upward movement of the rods 52, 53 and 55 to position the pilot 56 again to shutoff position.

In connection with such control I provide a possibility of modifying the relation between liquid inflow and vapor outflow through the agency of means sensitive to the value of a physical characteristic of the fluid flow, such, for example, as an indication of temperature at a location in the flow path. Thus the positioning of the floating beam 54 is also effected responsive to the temperature device 33, to which it is connected through a rod 57. It will be seen that if the relation between vapor outflow and liquid inflow is as desired, but that the proportion of the fluid flow path containing vapor only is longer than desired, as shown by an indication of temperature, for example, at the thermocouple 38, then the indicator 39 of the temperature responsive device 33 will have moved from predetermined desirable position to cause a vertical positioning of the rods 57, 55 whereby the pilot 56 will cause a positioning of the power piston 47 and the rheostat 12 to slightly increase the rate of supply of liquid to the generator, to move the vaporization line along toward the outlet, and thus decrease the percentage of the total path wherein is vapor only. As the vaporization line moves along toward the outlet of the generator, the temperature to which the thermocouple 38 is sensitive will decrease, thus causing the pointer 39 to return to its original desired position and cause a repositioning of the pilot 56 to shutoff position.

In the control of fuel supplied to the furnace for combustion by regulation of the valve 5 through the agency of the power piston 48, I utilize as previously stated, a balance between vapor outflow and fuel supply, both in measured amount. The fuel flow meter 6 causes a positioning of a rod 58 pivotally connected at one end to the floating beam 51 whose other end is positioned by the rod 49 from the flow meter 41. The beam 51 then is positioned along a definite path in a plane of space through the agency of the flow meters 6 and 41 to the end that a point intermediate its ends will remain in a predetermined position regardless of the rate of vapor outflow from the generator, so long as the rate of fuel supplied to the generator is in desirable proportion thereto. Depending from such point

on the beam 51 is a rod 59 which at its lower end is pivotally connected to a freely floating beam 60 which at its opposite end is pivotally suspended from one end of a rod 63 in turn positioned by the Bourdon tube 30. From a point intermediate the ends of the beam 60 is suspended a rod 61 for positioning a pilot 62 to control the supply of fluid to the hydraulic power piston 48.

Assume that the Bourdon tube 30 remains stationary, then the end of the beam 60 connected thereto is oscillatable around a fixed pivot, with its right hand end (on the drawings) positioned vertically through departure of the relation between vapor outflow and fuel feed from desired relation. Such departure will cause a positioning of the pilot 62 for a control or regulation of the valve 5 in a manner such as is explained in connection with the rheostat 12 on liquid inflow control. The positioning of the beam 60 is further modified through positioning of the Bourdon tube 30 sensitive to vapor outlet pressure in the conduit 22.

Having controlled the supply of fuel to the furnace primarily proportionate to the rate of vapor outflow, and secondarily to maintain desirable 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 dampers 7 and 25 in parallel through the agency of the power piston 27 controlled by a pilot valve 64.

The fuel flow meter 6 has an indicator 65 positioned relative to an index 66 and from the indicator depends a rod 67 pivotally connected thereto and to one end of a freely floating beam 68, to the other end of which is pivotally connected a rod 69 depending from one end of a beam 70 of an air flow meter. The beam 70 is pivoted intermediate its ends and from it 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 70 is responsive to a pressure differential transmitted to beneath the bells through pipes 71 and 72 leading respectively above and below the economizer section 16 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 16 to cause a pressure differential thereacross 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, and I indicate such rate of flow through the positioning of one end of the beam 70 relative to an index 73.

It will be seen that the beam 68 is positioned around a point intermediate its ends through the agency of the air flow meter and the fuel flow meter whereby when the two are in desirable relation, the point intermediate the ends will remain in predetermined position; but if the rate of air flow through the generator is not in desirable proportion to the rate of supply of fuel, then there will occur a vertical positioning of a rod 74 which depends from the point intermediate the ends of the beam 68 and to the lower end of which is attached the pilot 64. Such movement vertically of the rod 74 from predetermined position will cause, through the agency of the pilot valve, a positioning of the power piston 27 to the end that a regulation of air flow through the unit will be accomplished.

In operation it will be seen that the disclosure provides a method and means for the control of liquid input to the generator substantially equal to vapor outflow but capable of modification through the agency of an indication of temperature at a location in the fluid flow path, preferably at a location beyond the saturation line in the direction of fluid flow wherein there exists vapor only, slightly superheated above the temperature corresponding to the pressure. I provide further a control of the fuel supply substantially equal to the rate of vapor outflow but with the possibility of modification through the agency of an indication of vapor outlet pressure. I further provide a control of the supply of air for combustion to the furnace in accordance with the rate of supply of fuel to the furnace.

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 outflow of vapor as I have explained and readjust the inflow from an indication of 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 38 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 36, 37 which I may use as a checking control upon the supply of liquid input to the generator through the selectivity of the switch 35 if desired.

In Fig. 2, I illustrate an embodiment of my invention somewhat similar to that of Fig. 1 except that I have chosen a different physical characteristic of the fluid flow for modifying the control of liquid inflow, and a different characteristic of the fluid flow for modifying the supply of fuel, than I showed and explained in connection with Fig. 1. 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 17, 28 and 29. I supply liquid to the boiler through the conduit 9, and vapor from the

boiler passes through a conduit 22. Fuel is supplied to the furnace through a conduit 3, and air for combustion through a conduit 4, as in Fig. 1.

The arrangement of meters, linkage interconnecting the same, pilot valves and power pistons, is the same as in Fig. 1, except that I utilize to modify the control of liquid inflow a measure of vapor outlet pressure, whereas in Fig. 1, I used to modify such control a measure of fluid temperature at a location in the conduit beyond the saturation line. Again in Fig. 2, I utilize to modify the control of fuel to the furnace, a measure of the temperature at a location in the fluid flow path beyond the saturation line, whereas in Fig. 1, I utilize for this modification an indication of vapor outlet pressure. Control of the air for combustion is in proportion to the fuel supply.

In Fig. 3, I illustrate a similar embodiment to those in Fig. 1 and Fig. 2, differing therefrom 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 certain of the variables remotely, and with the possibility of selectivity, between certain physical characteristics of the fluid flow which I may desirably utilize as modifying measures to the primary control effected by relation between measures of liquid inflow, vapor outflow and fuel supply.

The interconnecting linkage between the vapor outflow meter 41 and the liquid inflow meter 44 as well as between the vapor outflow meter and the fuel supply meter 6 is the same as in Figs. 1 and 2. However, in the present illustration I embody the possibility of selectivity so far as a modifying control is concerned. I illustrate the same Bourdon tube 30 as in the other figures connected sensitive to the vapor outlet pressure of the conduit 22, but herein I show a movement of the indicator 31 capable of positioning the rotor of a shelf-synchronous transmitting generator 75. I show the temperature indicator 33 capable of positioning with the indicator 39 the rotor of a self-synchronous transmitting generator 76. At 77 and 78, I indicate receiving motors capable of being positioned respectively in synchronism with the transmitting generator 75 or 76 to which either may be selectively connected. The transmitting generator in each case is operated at a suitable angular rotation of the order of 30° 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 winding of each transmitting generator is energized from a suitable source of alternating current supply. The rotor of the transmitting generator 75 is positioned responsive to vapor outlet pressure, while that of the generator 76 is positioned responsive to temperature at a location in the conduit selectively through the switch 35. The receiving motors 77 and 78 have three-phase stator windings and single phase field rotor windings similar to the transmitting generators.

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 interconnected generator and motor by the single phase field windings. When the rotor of the transmitting generator 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 connected thereto assumes a position of equilibrium relative to the transmitting generator wherein the induced voltages in the three-phase windings are equal and opposite, and consequently no current is set up in the armature windings. If the rotor of the generator is turned and held in a new position, the voltage is no longer counterbalanced 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 a position corresponding to that of the rotor of the transmitting generator. Angular movement imparted mechanically to the rotor of the transmitting generator results in proportional angular positioning of the rotor of the connected receiving motor.

I provide a switch 79 hand operated for selectively connecting the transmitting generator 76 with either the receiving motor 77 or the receiving motor 78 and simultaneously respectively connecting the transmitting generator 75 with the receiving motor 78 or the receiving motor 77. Thus I provide a means for selectively utilizing either the vapor outlet pressure or the temperature in the fluid flow path as a modifying control of the relation between vapor outflow and liquid inflow. I likewise have the selectivity for utilizing the indication of vapor outlet pressure or the indication of temperature at a location in the conduit for modifying the primary control of fuel supply from the relation between vapor outflow and rate of fuel supply.

Further in the present illustration I employ electric means, comprising motors 80, 81 and 82, for the positioning of the liquid supply rheostat 12, the fuel control valve 5 and the air control dampers 7, 25.

Taking first the control of the rheostat 12 for regulating the supply of liquid inflow, I primarily control the position of the rheostat 12 through actuation from the motor 80 by desirable relation between liquid inflow and vapor outflow as indicated by the vertical position of a rod 53 relative to predetermined position, and modify this through vertical positioning of a rod 57 from either vapor outlet pressure or indication of temperature within the conduit as previously explained, to the end that a rod 55 is positioned vertically. Pivotally connected to the lower end of the rod 55 is one end of a contactor bar 83 which is adapted to be oscillated or positioned about a pivot point intermediate its ends relative to a pair of contacts 84, 85 normally open-circuited. Moved with the contactor bar 83 is a solenoid core 86 whose function will be explained shortly. Closing of the circuit of either the contact 84 or the contact 85 results in an energization through thermionic valves 87 or 88 of the motor 80 to operate the rheostat 12 in proper direction.

The circuit of the pilot motor 80 and its contactor 83 is similar to the one disclosed and claimed in the copending application Serial No. 561,006 by John D. Ryder entitled "Motor control circuits" filed in the United States Patent Office September 3, 1931, 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 pilot motor 80 is energized across a source of direct current while the armature is in an alternating current circuit including thermionic valves 87 and 88 whose grid circuits are respec-

tively controlled by the contacts 84, 85 normally open-circuited to the end that when one or the other of the contacts 84, 85 is close-circuited a pulsating direct current in one direction or the other will be applied to the armature 80 for causing a rotation thereof in desired direction. The variable reactance 86 in the motor circuit is for varying the speed thereof in either direction of rotation as disclosed and claimed in the referred to Ryder application.

Similarly, the pilot motor 81 is in an electric circuit including thermionic valves 89, 90 controlled through a pair of contacts actuated by the contactor bar 91 which also carries a variable reactance 92 for varying the speed of operation of the pilot motor in proportion to the amount of departure from a predetermined position of the contactor bar 91.

Similarly, the pilot motor 82 is in an electric circuit including thermionic valves 92A, 93 controlled through movement of the contactor bar 94 which also carries a variable reactance 95.

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 output. 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 and 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 either the supply of liquid inflow to the fluid flow path or the supply of one of the elements of combustion to the furnace, I accomplish the 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 35 whereby I may utilize as a corrective influence a temperature selected between a multiplicity of locations in the fluid path, and I have such possible selections 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 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 38 to the exit from the generator. If, however, I desire to control for a slightly different temperature of the vapor leaving the boiler, I may utilize the thermocouple 37, 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 discharged from the other end without appreciable storage or circulation.

Having thus described my invention and 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 vapor outflow meter interposed in the delivery conduit in advance of any point of use, a liquid inflow meter, an indicator of at least one of the physical characteristics of the fluid flow; 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, and control means positioned by said meters and by said indicator for selectively making effective 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 vapor outflow meter interposed in the delivery conduit in advance of any point of use, a liquid inflow meter, a thermostat sensitive to temperature at a location in the passage wherein is superheated vapor, a meter of one of the elements of combustion, an indicator of condition of the fluid flow; 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; control means positioned jointly by the vapor outflow meter, the liquid inflow meter and the thermostat for selectively making effective 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 jointly by said vapor outflow meter and said meter of one of the elements of combustion and said 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 vapor outflow meter, a liquid inflow meter, a thermostat sensitive to temperature at a location in the passage wherein is superheated vapor, a meter of one of the elements of combustion, an indicator of condition of the fluid flow; control means for controlling the liquid input, said control means actuated by thermionic valves responsive to said vapor outflow meter, to said liquid inflow meter, and to said thermostat; and other control means adapted to regulate the supply of one of the elements of combustion, said other control means actuated by thermionic valves responsive to said vapor outflow meter, to said meter of one of the elements of combustion, and to said indicator of condition.

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 vapor outflow meter, a liquid inflow meter, 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 control means for positioning the regulator, said control means actuated by electron discharge devices responsive to said meters and to said thermostat.

5. Apparatus for automatically controlling the operation of a vapor-generator having a once-through fluid passage receiving liquid under pressure at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, liquid supplying means to said passage, and apparatus for maintaining liquid inflow substantially directly proportional to vapor outflow, said apparatus actuated by thermionic valves responsive to departure from desired proportionality between liquid inflow and vapor outflow.

6. Apparatus for automatically controlling the operation of a vapor-generator having a once-through fluid passage receiving liquid under pressure at one end and delivering superheated vapor at the other and heated by elements of combustion, comprising in combination, supply means for the elements of combustion, and apparatus for maintaining the input of heat substantially directly proportional to the vapor outflow, said apparatus actuated by thermionic valves upon departure of input of heat and vapor outflow from desired proportionality.

7. 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 fuel supply meter, an air supply meter, electron discharge device actuated regulating means of the rate of supply of air for combustion to the furnace, and control means for said electron discharge device actuated means positioned by said meters.

8. Apparatus for automatically controlling the operation of a vapor-generator wherein is established a continuously progressive fluid flow under pressure initiated with liquid entering at one end only and progressively heated for conversion to complete vapor state at another point, comprising in combination, a meter of the liquid inflow, a meter of the vapor outflow, means for automatically continuously determining the ratio of liquid inflow to vapor outflow from said meters, and control means for automatically controlling the liquid inflow, said control means actuated by electron discharge devices responsive to said ratio.

9. Apparatus for automatically controlling the operation of a vapor-generator having small liquid storage with a high rate of evaporation and heated by the elements of combustion, comprising in combination, a meter of the liquid inflow, a meter of vapor outflow, a meter of the fuel supply, and control means for automatically maintaining the inflow of liquid and the input of heat each substantially directly proportional to the outflow of vapor, said control means actuated by electron discharge devices responsive to said meters.

10. In combination with a vapor-generator having a once-through fluid passage receiving a forced flow of liquid at one end and delivering superheated vapor at the other, liquid supplying means to said passage, and control apparatus for maintaining liquid inflow substantially equal to vapor outflow, said apparatus actuated by thermionic valves responsive to departure from desired equality between liquid inflow and vapor outflow.

11. Apparatus for automatically controlling the operation of a vapor-generator having small fluid storage with a high rate of evaporation and heated by elements of combustion, comprising in combination, liquid supplying means to the vapor-generator, and apparatus for maintaining liquid inflow substantially directly proportional to vapor outflow, said apparatus actuated by electron discharge devices responsive to departure from desired proportionality between liquid inflow and vapor outflow.

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, supply means for the elements of combustion, and apparatus for maintaining the input of heat substantially directly proportional to the vapor outflow, said apparatus actuated by electron discharge devices upon departure of input of heat and vapor outflow from desired proportionality.

13. In combination with a vapor-generator having small liquid storage with a high rate of evaporation, liquid supplying means to said vapor-generator, and control apparatus for maintaining liquid inflow substantially equal to vapor outflow, said apparatus actuated by electron discharge devices responsive to departure from desired equality between liquid inflow and vapor outflow.

14. Apparatus for automatically controlling the operation of a vapor-generator having a small liquid storage with a high rate of evaporation, comprising in combination liquid supplying means to said vapor-generator, a meter of the liquid inflow, a meter of the vapor outflow, means for automatically continuously determining the ratio of liquid inflow to vapor outflow from said meters, and control means for automatically controlling the liquid inflow, said control means actuated by electron discharge devices responsive to said ratio.

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

16. 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, ratio determining means of liquid inflow and vapor outflow, and control means for positioning said regulator, said control means actuated by electron discharge devices responsive to said ratio determining means.

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