

Oct. 8, 1940.

E. G. BAILEY ET AL
CONTROL SYSTEM

Filed July 2, 1938

4 Sheets-Sheet 1

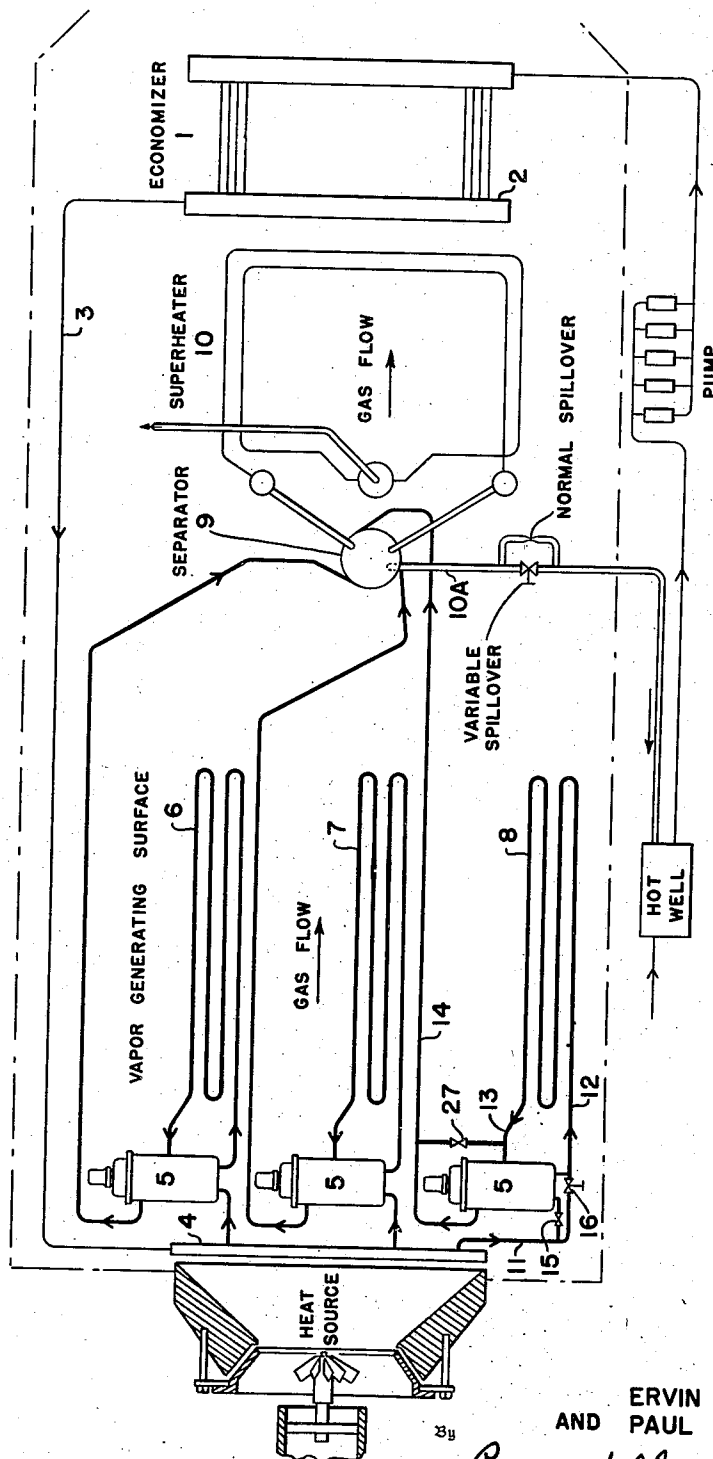


Fig. 1

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4 Sheets-Sheet 2

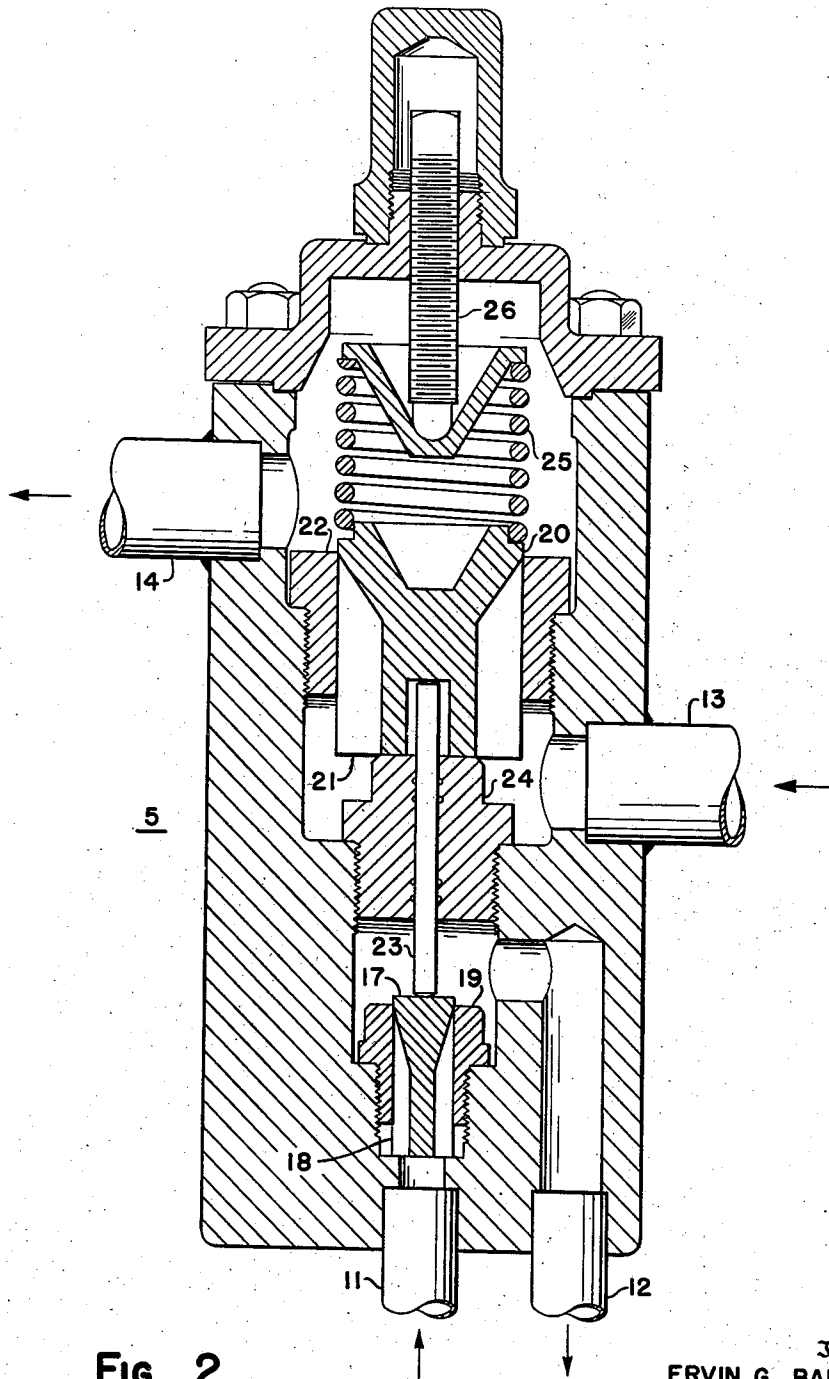


FIG. 2

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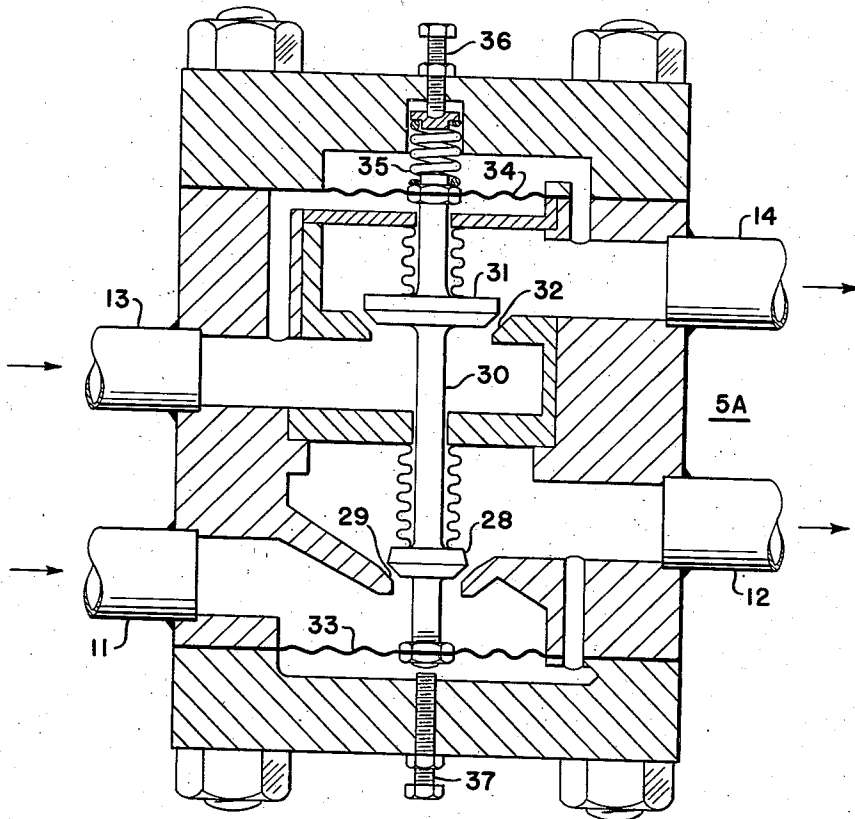


FIG. 3

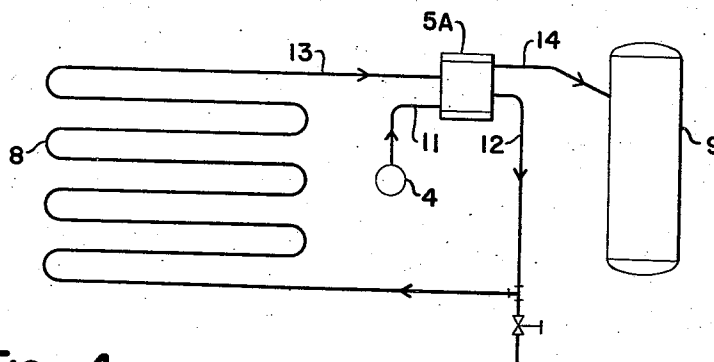


FIG. 4

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4 Sheets-Sheet 4

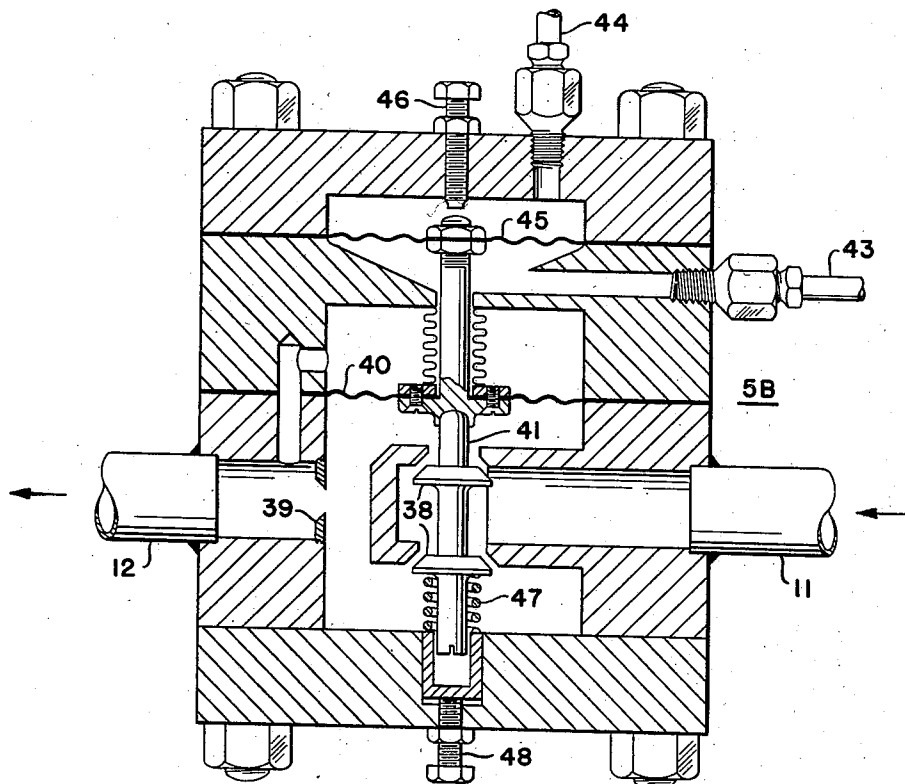


FIG. 5

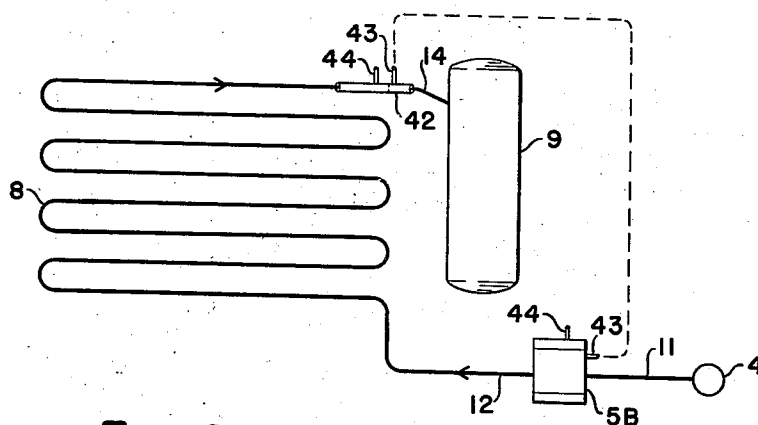


FIG. 6

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CONTROL SYSTEM

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Application July 2, 1938, Serial No. 217,316

12 Claims. (Cl. 122-451)

This invention relates to methods of and apparatus for operating vapor generators; particularly vapor generators of the forced flow type, having a fluid flow path including one or more long small-bore tubes, in which the flow in the path is initiated by the entrance of liquid under pressure at one end, and the exit of vapor only at the other end; characterized by an inflow of liquid normally greater than the outflow of vapor, the difference being diverted from the path intermediate the ends thereof.

Such a vapor generator, having small liquid storage and operated with wide range combustion devices, forms a combination rendering practical extremely high heat release rates with the consequent ability to economically handle practically instantaneous load changes from minimum to maximum, and vice versa, without heavy standby expense, and is particularly suitable for operating conditions such as locomotive service, where load variations are of a wide range and are required to be met substantially instantaneously.

The generator has a minimum liquid storage capacity with a maximum heat absorbing surface so disposed and arranged as to be substantially instantaneously responsive to rapid changes and wide diversities in heat release rate in the furnace. The heat absorbing surface, or flow path for the working medium, is preferably comprised of a plurality of long small-bore tubes with an enlargement, preferably at the end of the generating section, which acts as a separator to divide liquid and vapor. The vapor is then passed through a superheater, while the excess liquid carried through the tubes of the generating section for the purpose of wetness and preventing scale deposit, is diverted out of the separator under regulated conditions and is shown as being returned to the hot well for recirculation through the generator portion of the fluid flow path. It is usual that a portion of the liquid collected in the separator is sent to waste to keep the concentration below a predetermined value. The diversion or spillover of liquid from the separator is preferably through two paths, one of which is a normal or continuous spillover and the other a variable or adjustable spillover, although the control of such diversion does not particularly concern us in the present invention.

The excess of liquid over vapor generated, and which may be completely or partially recirculated, may comprise 20%, 30% or even 50% of the liquid entering the flow path under pressure. So long as such recirculation can be accomplished without loss of heat and without the expenditure

of considerable power, there are material advantages to be gained.

In the multi-circuit path of a forced flow vapor generator it is usual to introduce flow restrictors or equalizers between the economizer and vapor generating sections of the path, to attempt to attain equalization of flow, heating, and other variables through the parallel paths of the generating section and prevent over-heating of one tube as compared to another. The flow restrictors are usually sections of tubing of relatively small diameter introducing a resistance to flow of several times that of the tube path following, so that variations in flow resistance of said following tube path will be of minimized effect relative to the total resistance including the flow restrictors. Through multiplying the flow resistance several times in this manner it is, of course, necessary to overcome such resistance with feed pump power.

We propose to replace such flow restrictors by equalizing valves inserted in the several tube portions of the paths at the entrance to the vapor generating section, utilizing the pressure drop therethrough to automatically regulate the supply of liquid to the individual paths, and with the knowledge that such a plurality of equalizing valves will tend to be self-equalizing insofar as heat and flow distribution between the different tube paths is concerned. Any generating tube which has the tendency, due to unequal application of heat for example, to generate more steam than its parallel tubes tends to become overheated through the presence of generated steam within the tubes rather than a wetting liquid. While the previous flow restrictors or balancing resistors tend to minimize the effect of inequalities in tube resistance and thereby to equalize flow in the parallel tube circuits, the substitution of our improved equalizing valve for each flow restrictor serves not only to retain the advantage of flow equalization, but additionally tends toward an equalization of heat, temperature, density and other properties of the vapor-liquid mixture leaving the tubes.

In particular, the equalizing valve functions to compare the density of the liquid leaving the economizer section for entrance to the vapor generating section, with the density of the liquid-vapor mixture leaving the vapor generation section and prior to its entrance to the separator drum. From such comparison of densities the rate of admission of liquid to the particular vapor generating path is controlled, to maintain the outlet density at or near predetermined value.

No such heat and/or temperature equalizing

tendency is obtained with flow restrictors. When they alone are used, one must depend upon the total resistance; that is, resistors plus tube resistance must be near enough alike in the different circuits to tend to equalize flow therethrough. Through our invention, by the substitution of equalizing valves for flow restrictors, there is a greater tendency toward circuit equalization of flow, heat, temperature, and density, since we have not lost the action of pressure drop in equalization of flows, and at the same time we have gained an equalization of thermal conditions of the fluid leaving the circuit.

It does not appear necessary to go into the reasons for employing a plurality of long small-bore tubes for the forced flow path, inasmuch as this is well recognized in the art. Suffice it to say that having such construction, it is of prime importance that the plurality of circuits be equalized insofar as flow, heat, temperature, density, etc., are concerned.

In the drawings:

Fig. 1 diagrammatically illustrates a drumless forced flow vapor generator to which the present invention is directed.

Fig. 2 is a sectional elevation of an equalizing valve incorporating our invention.

Fig. 3 is a sectional elevation of another form of equalizing valve.

Fig. 4 is a flow diagram including the valve of Fig. 3.

Fig. 5 is a sectional elevation of a further arrangement of equalizing valve.

Fig. 6 is a flow diagram including the equalizing valve of Fig. 5.

The drumless forced flow vapor generator to which the present invention is directed is diagrammatically illustrated in Fig. 1 to indicate gas flow, working fluid flow, and heat absorbing surface, arranged as contained within the enclosure represented by the dot and dash lines.

The flow path for the working medium is comprised of long small-bore tubes brought together at suitable headers. The generator includes an economizer 1 at the cooler end of the gas passage and which receives liquid from a pump which may be connected to a hot well. The pump may be of any suitable type or characteristic for the service.

The liquid from the economizer outlet header 2 is conveyed by a tube 3 to a manifold tube 4 from which the liquid is distributed to the generating section through, in this instance, three equalizing valves 5, whereby the liquid is proportionately distributed to the tubular fluid flow passages 6, 7 and 8 constituting the vapor generating section of the assembly.

These three flow circuits comprising the vapor generating surface tangentially enter a bulge in the fluid flow path which is in the form of a separating chamber 9 for dividing the fluid into liquid and vapor, the vapor passing to a superheater 10 and the excess liquid being diverted from the fluid flow path through a pipe 10A to the hot well, or to waste.

The "heat source" is illustrated as having an oil burner with adequate air admission facilities, but may comprise any well known fuel burning arrangement and have ordinary provision for initial ignition, safety features, etc.

The direction of flow of fluid from the header 4 through the equalizing valves 5, the vapor generating passages 6, 7 and 8, the valves 5, and to the separator 9, is indicated in Fig. 1 by arrows

and with single line diagram representing the tubular flow path.

It will be understood that while the vapor generating surface is shown as three parallel flow paths, this is representative only and the flow paths may be a single path or any desired number of paths in parallel.

In Fig. 2 we illustrate in sectional elevation a preferred form of the equalizing valve 5, as for example the valve 5 in connection with the flow path 8 of Fig. 1. In both Figs. 1 and 2 the pipe 11 joins the header 4 with the equalizing valve 5. This flow of water leaves the valve 5 through a pipe 12 to the vapor generating path 8, from which it returns through the pipe 13 to the valve 5, thereafter leaving through the pipe 14 to the separator 9. In Fig. 1 we have indicated a shut-off valve 15 in the pipe 11 and a needle control valve 16 joining the pipes 11 and 12 and bypassing the valve 5. The purpose of the valves 15 and 16 will be explained more in detail hereinafter.

Referring now specifically to Fig. 2, it will be observed that the heated water from the economizer 1 enters the valve assembly through the pipe 11 below a movable valve member 17 having guide fins 18 and seating normally on a seat member 19. When the valve member 17 is moved upwardly (on the drawings) water from the pipe 11 passes between the valve member 17 and the seat 19 to the pipe 12 in quantity determined by the amount of opening.

Fluid from the heated flow path 8 may be all water, all steam, or a mixture of water and steam, and enters the valve 5 through the pipe 13 below a movable valve member 20 having guiding fins 21 and adapted to seat against a seat member 22.

The movable valve members 17, 20 are interrelated by a push rod 23 slidable through a partition member 24. The valve members 17, 20 and push rod 23 are urged together and downwardly by a compression spring 25 adjustable through the agency of a screw 26 in well known manner. Normally then the valve members 17 and 20 are urged against the seat members 19 and 22 by the spring 25.

When water under pressure is available in the header 4 the pressure thus effective upon the underside of the valve member 17 causes it to move upwardly to unseat and allow flow from the pipe 11 to the pipe 12. Such upward positioning moves the push rod 23, the valve 20, and compresses the spring 25. The result is a flow of liquid through the fluid path 8, the pipe 13, and the pipe 14 to the separator 9. When the path 8 is heated and vapor begins to be generated therein, the fluid entering the valve assembly 5 through the pipe 13 constitutes a mixture of liquid and vapor at greater specific volume and lower density than the liquid passing through the pipes 11 and 12. For a condition of equilibrium this flow of liquid-vapor mixture requires a greater valve opening between the member 20 and the seat 22, and thus the area of the member 20 is greater than that of the member 17. The design of these relative areas, as well as the initial scale of the spring 25, and adjustment of the screw 26, depends upon the desired density of the fluid leaving the section 8 through the pipe 13. In other words, in a forced flow vapor generator of the type being described, and having a separator 9, it is desired to admit more water through the pipe 12 than can be evaporated in a single passage through the path 8.

and the liquid-vapor mixture leaving through the pipe 13 will consist of the vapor which has been generated plus the excess liquid. This excess liquid may desirably be from 10% to 50% of the amount entering the pipe 12, and is adjustable within certain limits through the agency of the screw 26. For wider operating changes it may be desirable to replace the valve members 17, 20 with valve members of different cross-sectional area, or to change the spring.

We have provided an arrangement which is continuous and automatic in function to control the admission of liquid to a flow path, such as the heated path 8, to continuously maintain a desired density condition of the fluid leaving said flow path and with adjustment possibilities whereby said desirable density may be the density of the entering liquid, or the density of its vapor, or of a mixture of the liquid and vapor. This result is obtained in general by utilizing the differential across a valve of variable opening for the control of flow to maintain a practically constant density. Its utility and advantage in connection with a vapor generator of the type herein disclosed will be apparent, for regardless of the care taken in design of the proportioning and location of the various flow paths, as well as of the heating, there is a possibility that one path may be subjected to greater or more direct heating than another path and some means must desirably be provided to proportion the liquid among the various paths in accordance with the heat applied thereto and the heat absorbing capability of the paths. Furthermore, it is essential that such an arrangement be continuous in operation and entirely automatic in action. The arrangement, such as we have disclosed, satisfies these demands.

We desire it to be understood that in speaking of density in our description and claims we use the term in its well understood and generic definition and meaning such as established by the International Critical Tables, Bureau of Standards, and other authorities, as follows:

Density of any substance (a liquid, gas, liquid-gas mixture, or a solid) is expressed in units of weight per unit of volume, as for example, pounds per cubic foot. It is an absolute or concrete value and therefore quite independent of temperature, pressure, location, etc.

Inasmuch as the valve arrangement works primarily on a density, or a density plus kinetic energy basis, the operation will be in the direction of having a larger percentage of spillover water from the separator (unvaporized excess) at low pressures than at high pressures. In speaking of high and low pressures it will be understood that we refer to static pressure of the fluid at any referred to location in the path, i. e., that pressure existing within a confined space relative to the pressure of the atmosphere adjacent the space.

The unbalanced area and the size of the ports of the two valves are arranged so that with the correct steam and water mixture entering the separator drum substantially equal water flows are admitted to each circuit. In case any one circuit becomes unbalanced and tends to produce superheated steam, the volume increases and the pressure drop across the upper valve member increases, opening both valves and admitting more water to that circuit. Similarly the valves will be moved in a closing direction whenever there is a smaller percentage of steam

in the mixture entering the separator 9, due to the decrease in volume and pressure drop across the upper valve member.

In Fig. 1 we show a valve 27 located in a by-pass between the pipes 13 and 14. By means of the valves 15, 16 and 27 the equalizing valve 5 may be disconnected completely from the flow circuit 8 so that work may be done thereon. If the valve 15 is closed, and the valves 16, 27 are opened, then the equalizing valve 5 is completely by-passed insofar as the flow pipes 11, 12, 13, 14 are concerned. If under this condition the needle valve 16 is positioned by hand to a partly throttled condition, this will introduce an adjustable pressure drop similar to the known restrictors or restrictions and regulation of the circuit may be carried on by hand, while the assembly 5 is out of service.

Under certain conditions it may be desirable (with the valve 15 opened and the valve 27 closed) to have the valve 16 slightly cracked and allow a certain amount of liquid to by-pass the assembly 5. In other words, the combination of the assembly 5 in automatic functioning and an adjustable by-pass 16 allows a wide latitude of regulation of the liquid passing through the passage 8. It will be appreciated that the same arrangement of valves, such as 15, 16 and 27, may be incorporated with the equalizing valves 5 of the circuits 6 and 7, or of any number of circuits that may be employed in the vapor generating section.

As a specific example of the design of a valve assembly 5, the ports may be designed so that at minimum flow of 1000 lb. of water per hour for the circuit, and with water only going through both valve members, i. e., with no steam generation, the water flow going completely to the separator or spillover, there will be a differential pressure of approximately 36 lb. per square inch across the valve member 17, and approximately 6 lb. per square inch across the valve member 20. At the maximum flow rate of approximately 8000 lb. of water per hour past the valve member 17, and of say for example 7200 lb. of steam and 800 lb. of water past the valve member 20, there will be a differential pressure of approximately 100 lb. per square inch across the valve member 17, and approximately 10 lb. per square inch across the valve member 20. These values are obtained with a spring having a scale of 25 lb. per inch and an initial compression at zero flow of approximately 40 lb. The general design is such that the valve members will lift approximately uniformly with flow increase, although it will be appreciated that the shape and design of the valve members and their seats may be such that any desired characteristic of flow-with-positioning may be attained. In other words, this characteristic may be a lineal or straight line relation, or may be curved, as desired.

The upper valve is designed so that it has an unbalanced area of approximately ten and one-half times that of the lower valve member, so that even though the pressure drop is less, the actual force exerted by the upper member is always greater than that exerted by the lower member. The reason for this arrangement is in order that relatively small changes in density of the steam and water mixture, which in turn produces a change in differential pressure across the upper valve member, will cause considerable motion of both members, and thus affect the water flow through the lower member materially.

The lower, or water valve member, is inten-

tionally designed for a fairly high pressure drop, so as to get a similar effect as the balancing resistors or restrictors previously used, though of course a materially smaller pressure drop is possible with the present arrangement at maximum flow. The initial and final pressure drop can be altered materially by changing the scale or initial tension of the loading spring. Furthermore, the characteristic of the valve can be materially altered by changing the ports or shape of the valve members and seat members.

Referring now in particular to Fig. 3, we show therein a somewhat diagrammatic sectional elevation of another embodiment of the valve assembly 5 and indicated therein as 5A. Fig. 4 is a schematic drawing showing the location of valve assembly 5A in relation to the other parts in manner similar to Fig. 1.

Liquid from the economizer header 4 enters the valve 5A through the pipe 11 below a valve member 28 movable relative to a seat 29 and carried by a stem 30, which also carries a movable valve member 31 relative to a seat 32. The lower end of the valve stem 30 is fastened to a diaphragm 33, while the upper end is fastened to a diaphragm 34. The assembly comprising the valve stem 30, the valve members 28, 31, and the diaphragms 33, 34, are movable together, and movement is opposed in one direction by a compression spring 35 adjustable through the screw 36. A stop screw 37 is provided at the lowermost end of the assembly to limit travel.

The pressure of the water from the pipe 11 is effective upon the upper side of the diaphragm 33, while the pressure of the water after it has passed the valve 28 is effective upon the lowermost side of the diaphragm 33. Thus, the diaphragm 33 is subjected to the pressure drop across the valve 28. In similar fashion the diaphragm 34 is subjected to the pressure drop across the valve member 31.

Fig. 3 shows an unbalanced valve having the advantage that if anything happens to either diaphragm the prepondering unbalanced force of the steam and water mixture at the outlet will tend to open wide the water inlet valve, so that there will be no danger of starving the circuit.

The differential pressures across the two diaphragms are opposed to each other and the differential across diaphragm 34 is in such a position that a lower percentage of spillover results in high specific volume and correspondingly high differential across the valve 31, and diaphragm 34. The unbalance between the diaphragms 34 and 33 will open the valves further. The flow impact or pressure drop across the valves 28, 31 will tend to open the valves and if the diaphragms 33, and 34 are balanced, then the spring 35 is the opposing force. The resulting action is not one of exactly constant differential across the diaphragms, but will be one of increasing differential with flow; but not nearly as fast as if the valves had a fixed opening and the differential increasing as the square of the flow.

This present showing is with the valve areas 28, 31 approximately 1-3, or in a relation approximating the square root of specific volume, so that for 10% excess liquid going to the spillover and at approximately 1500 lb. pressure operation, these specific volumes will be in the ratio of approximately 10 to 1. The characteristics of the spring loading on the valve may be so arranged that the pressure drops do not go below a certain value at minimum rating, and with the adjustable stop 37 this permits a definite water flow even

with an unbalance of the diaphragms and when no steam is being generated, as during starting.

In Fig. 5 we show a further embodiment in somewhat diagrammatic sectional elevation and in relation to the schematic showing of Fig. 6. It will be observed that the valve assembly 5B is inserted in the flow path between the pipes 11 and 12, but that the flow path 8 does not return to the valve 5B, but goes directly (as through the pipe 14) to the separator 9. The water entering the pipe 11 passes the valve members 38 and leaves to the pipe 12 through a fixed orifice 39. This orifice measures the water flow in the solid water condition. The pressure at the inlet side is effective upon one side of the diaphragm 40, while the pressure at the outlet side of the orifice 39 is effective upon the other side of the diaphragm 40. Thus the valve stem 41, to which the valve members 38 are fastened, is positioned according to the differential pressure across the orifice 39.

In Fig. 6 we illustrate a flow measuring orifice 42 at the entrance to the separator 9 and through which the steam and water mixture passes on its way to the separator. Pressure pipes 43, 44 lead from opposite sides of the orifice 42 to the valve assembly 5B at opposite sides of a diaphragm 45. The diaphragm 45 is also fastened to the valve stem 41 and thus the valve members 38 are jointly positioned by the diaphragms 40, 45. So long as the ratio of the two differentials is constant, the density at the outlet pipe 14 remains constant at all loads. A stop 46 is provided to give a minimum valve opening for low ratings. The loading spring 47 is provided with an adjustable screw 48.

As illustrated in Figs. 5 and 6 the two diaphragms are balanced as long as the proper density is obtained in the outlet mixture line. The orifice 42 in the mixture line is designed larger than the orifice 39 in the water line to give an equal differential, based on the different desired densities. As the quantity of spillover or excess water becomes less than predetermined value, the specific volume of the mixture increases and its differential increases, thus opening the valve until equilibrium is restored.

In general, we have provided an arrangement wherein the rate of flow of liquid entering the circuit, such as the heated path 8, is controlled in accordance with the density of the fluid leaving the circuit, or in accordance with the relation of densities between the inflow and outflow fluid. Through such an arrangement, inequalities in flow resistance, heating, heat absorption capability, and other irregularities in parallel boiler circuits and similar passages are compensated for.

While we have chosen to illustrate and describe certain embodiments of our invention we are not to be limited thereto but only as to the claims in view of prior art.

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

1. The method of operating a vapor generator of the forced flow type having a plurality of parallel heated paths in the generating portion and having a liquid-vapor separator between the generating and superheating portions of the fluid flow path, which includes the steps of, normally supplying liquid to the inlet of the generating portion in excess over vapor generated therein, discharging the resulting liquid-vapor mixture into the separator, and regulating the rate of liquid supply in accordance with a comparison

of the density of the liquid supply and the density of the fluid entering the separator.

2. The method of operating a vapor generator of the forced flow type having a liquid-vapor separator between the generating and superheating portions of the fluid flow path, which includes the steps of, normally supplying liquid to the inlet of the generating portion in excess over vapor generated therein, discharging the resulting liquid-vapor mixture into the separator, and regulating the rate of liquid supply in accordance with a comparison of the density of the liquid supply and the density of the fluid mixture entering the separator.

3. The method of operating a vapor generator of the forced flow type having a plurality of parallel heated paths in the generating portion and having a liquid-vapor separator between the generating and superheating portions of the fluid flow path, which includes the steps of, normally supplying liquid to the inlet of the generating portion in excess over vapor generated therein, discharging the resulting liquid-vapor mixture into the separator, and proportioning the liquid supplied to the plurality of parallel generating paths in accordance with a comparison of the density of the liquid supply and the density of the fluid entering the separator.

4. The method of operating a vapor generator of the forced flow type having a plurality of parallel heated paths in the generating portion and having a liquid-vapor separator between the generating and superheating portions of the fluid flow path, which includes the steps of, normally supplying liquid to the inlet of the generating portion in excess over vapor generated therein, discharging the resulting liquid-vapor mixture into the separator, and proportioning the liquid supply to the parallel generating paths in accordance with the density of the fluid leaving the generating portion.

5. In combination, a vapor generator of the forced flow type having a plurality of parallel tube circuits in the vapor generating portion of the flow path and discharging into a liquid-vapor separator, means supplying liquid to the generating portion at a rate in excess over vapor generated therein, and means at the entrance of each of said tube circuits controlling admission of liquid thereto in accordance with density of the liquid-vapor mixture leaving that tube.

6. A method of operating a vapor generator of the forced flow type having a liquid-vapor separator between the generating and superheating portions of the fluid flow path, which includes, normally supplying liquid under pressure at the inlet of the generating portion in predetermined excess to vapor discharged to the separator, and utilizing density of the mixture entering the separator to modify rate of liquid supply.

7. The method of operating a vapor generator of the forced flow type having a liquid-vapor separator between the generating and superheating portions of the fluid flow path, which includes, normally supplying liquid under pres-

sure at the inlet of the generating portion in excess to vapor generated, and utilizing a manifestation of density of the liquid-vapor mixture discharged to the separator to regulate rate of liquid supply.

8. The method of operating a vapor generator of the forced flow type having a generating and a superheating portion of the path, which includes, normally supplying liquid under pressure continuously to the inlet of the generating portion in excess over vapor generated therein, continuously diverting the excess liquid from the fluid flow path adjacent the division zone between liquid and vapor, and regulating the supply of liquid in accordance with the density of the liquid-vapor mixture adjacent the zone of diversion.

9. The method of operating a vapor generator of the forced flow type having a generating and a superheating portion of the path, which includes, normally supplying liquid to the generating portion in excess to vapor generated, discharging the liquid-vapor mixture to a separator, passing the vapor from the separator to the superheating portion of the path, regulating the rate of liquid supply in accordance with the density of the liquid-vapor mixture, continuously diverting excess liquid from the separator, and maintaining a predetermined amount of liquid in the separator through additional regulated diversion therefrom.

10. The method of operating a vapor generator of the forced flow type having a liquid-vapor separator between the generating and superheating portions of the fluid flow path, which includes, continuously supplying liquid to the generating portion in excess over vapor discharged to the separator, and regulating the excess of liquid inversely proportional to static pressure past the generating portion of the path.

11. Apparatus for controlling the operation of a fluid treating system of the forced circulation type, comprising in combination, means continuously supplying liquid under pressure to the entrance of the path in excess over vapor discharged from the exit, a relatively quiescent separator zone to which the resultant liquid-vapor mixture is discharged, and a regulator of said first named means responsive to a condition of density of the mixture.

12. In a vapor generating system of the forced circulation type having a liquid-vapor separator between generating and superheating portions of the fluid flow path, the improvement which includes, means continuously supplying liquid to the inlet of the generating portion in excess over vapor leaving that portion and discharged to the separator, means sensitive to static pressure of the fluid in the path, and means responsive to the sensitive means adapted to control the supply means in such manner as to continuously maintain the percentage excess inversely proportional to the static pressure past the generating portion of the path.

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