Dec. 28, 1943. R. D. JUNKINS 2,337,851

CONTROL SYSTEM

Filed Jan. 5, 1940 6 Sheets-Sheet 1

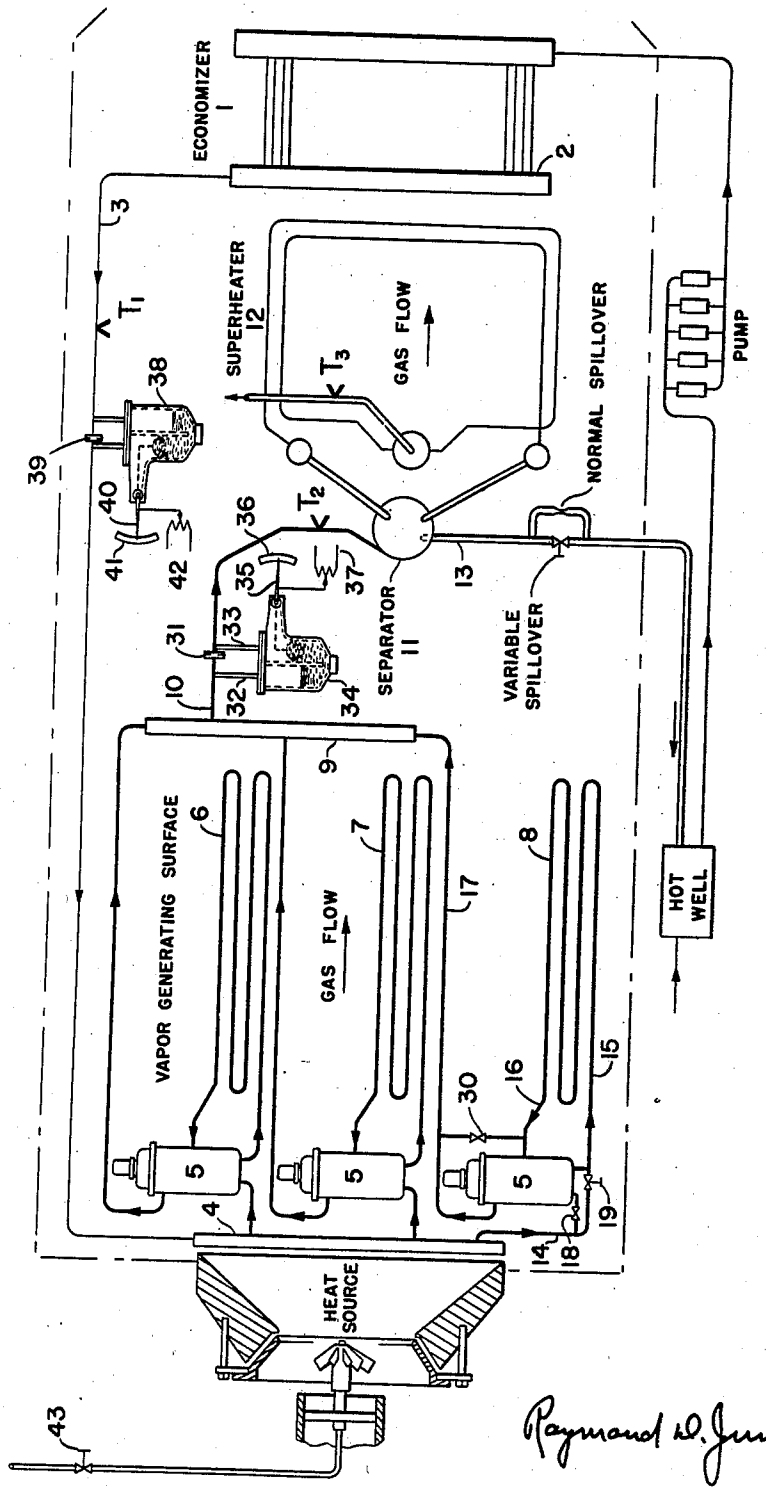


FIG. 1

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CONTROL SYSTEM

Filed Jan. 5, 1940 6 Sheets-Sheet 2

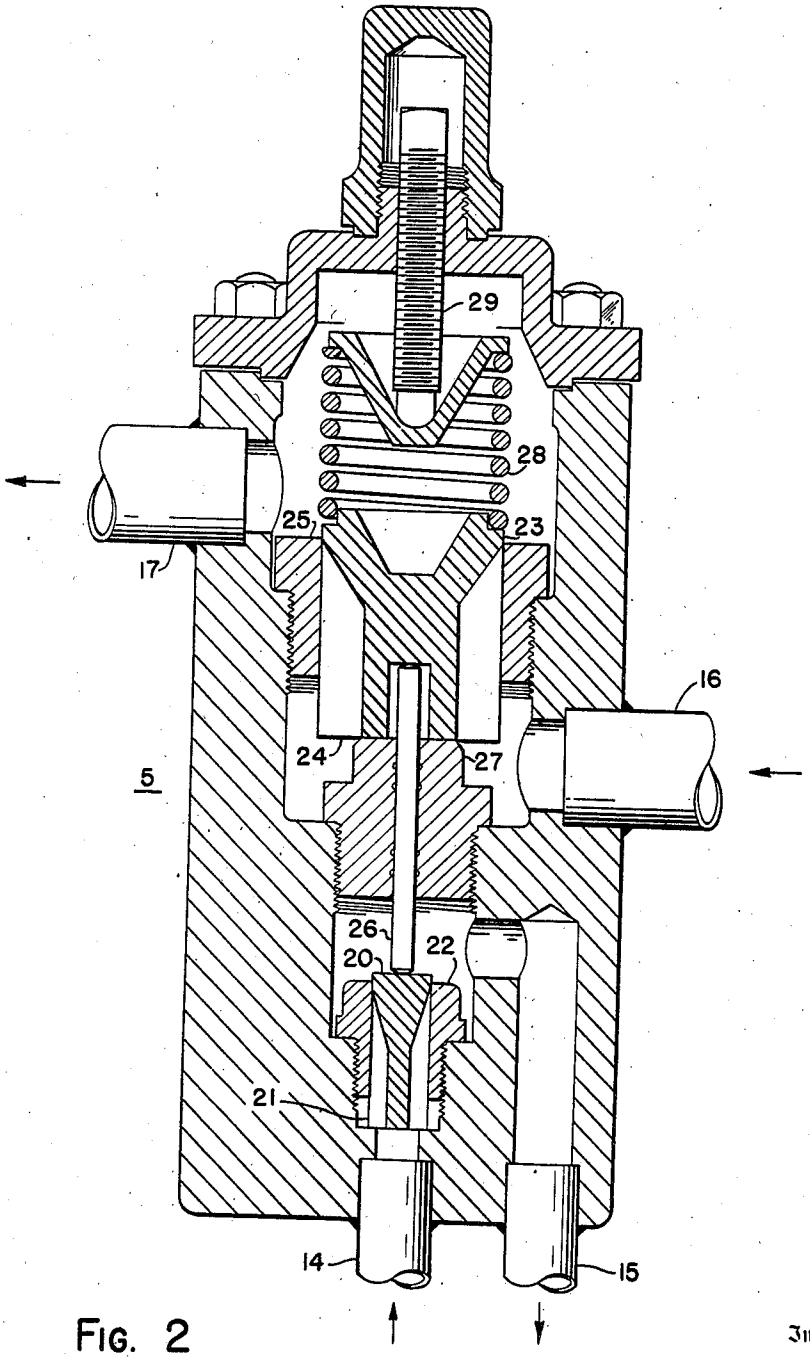


FIG. 2

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CONTROL SYSTEM

Filed Jan. 5, 1940 6 Sheets-Sheet 3

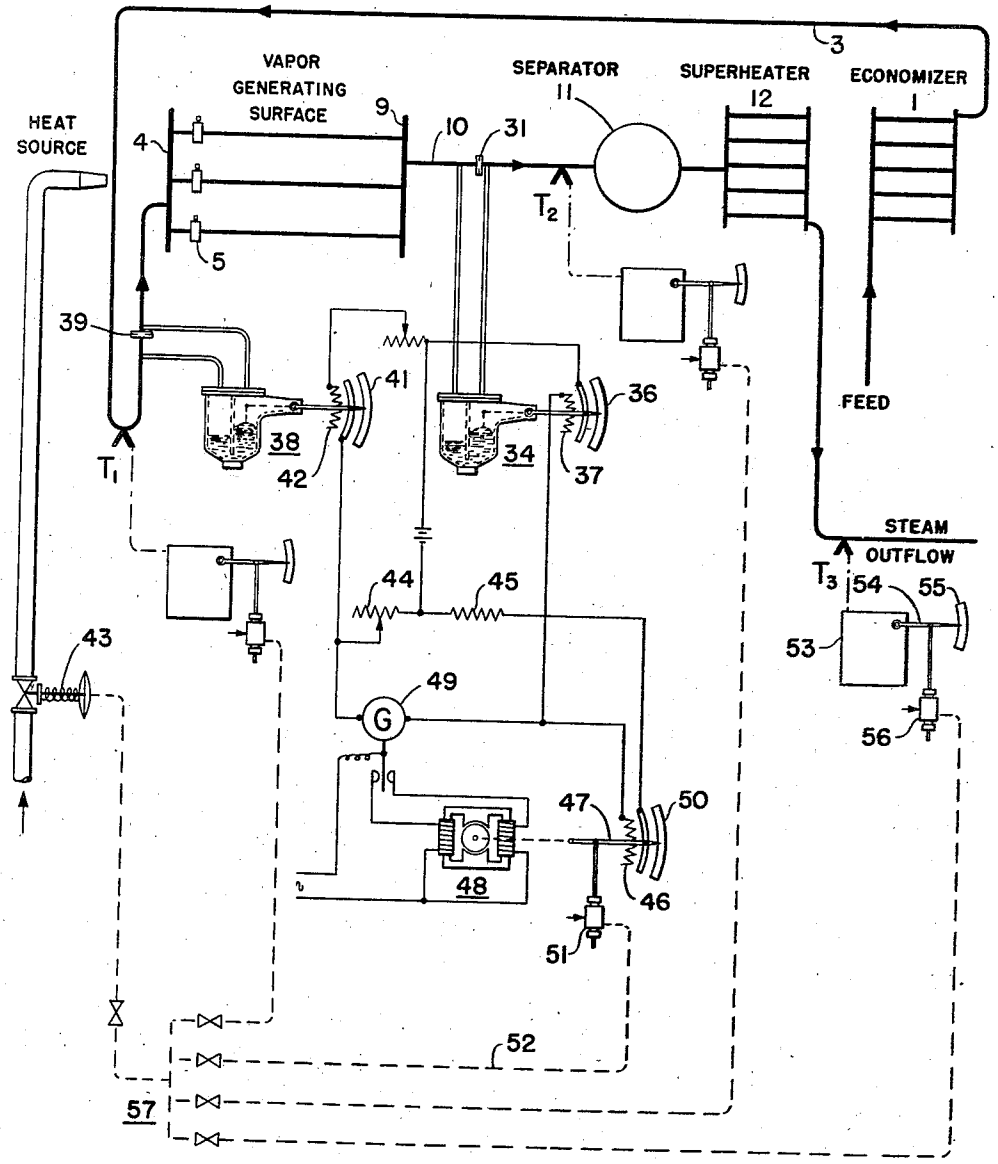


FIG. 3

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CONTROL SYSTEM

Filed Jan. 5, 1940 6 Sheets-Sheet 4

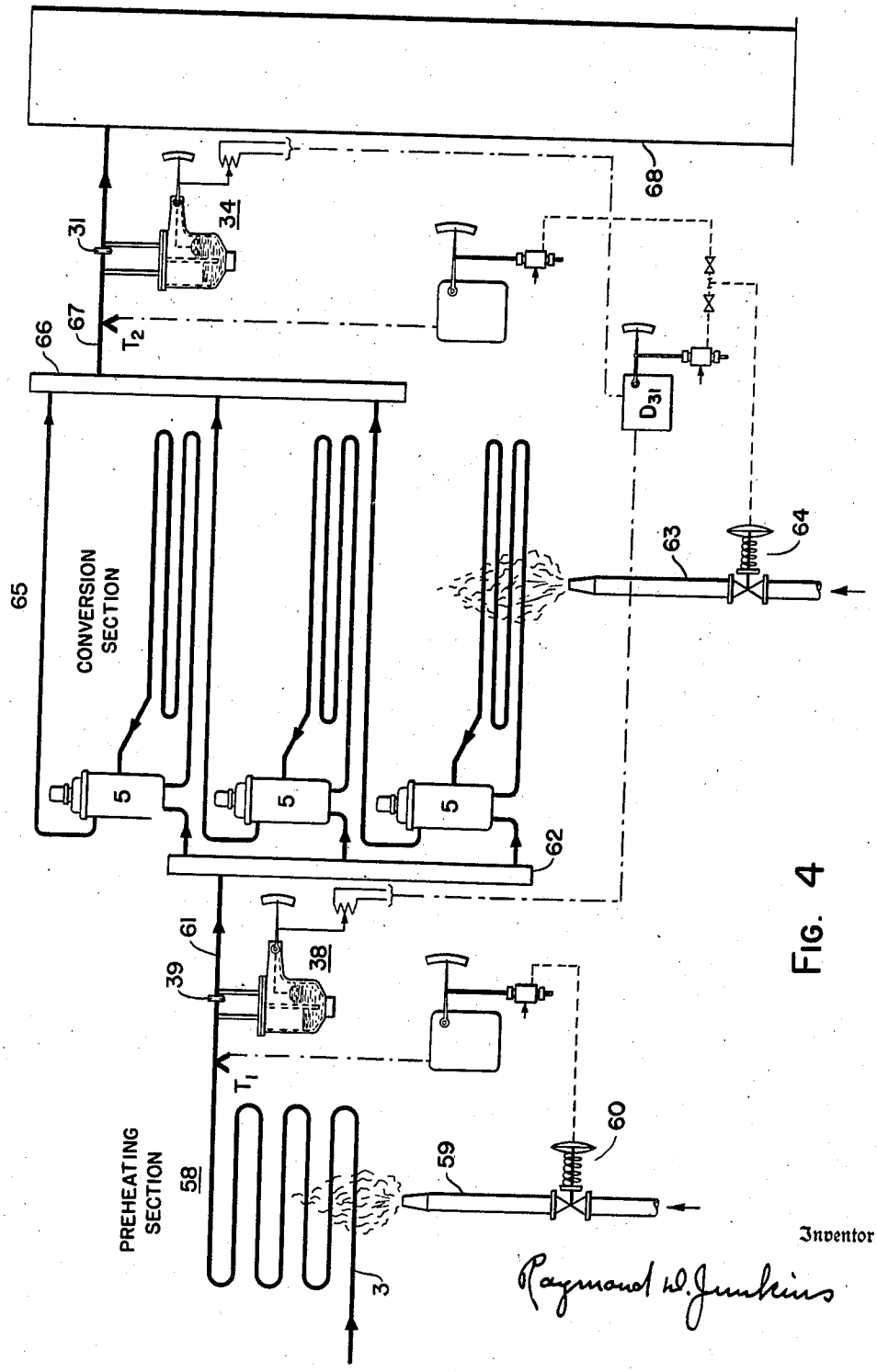


FIG. 4

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CONTROL SYSTEM

Filed Jan. 5, 1940 6 Sheets-Sheet 5

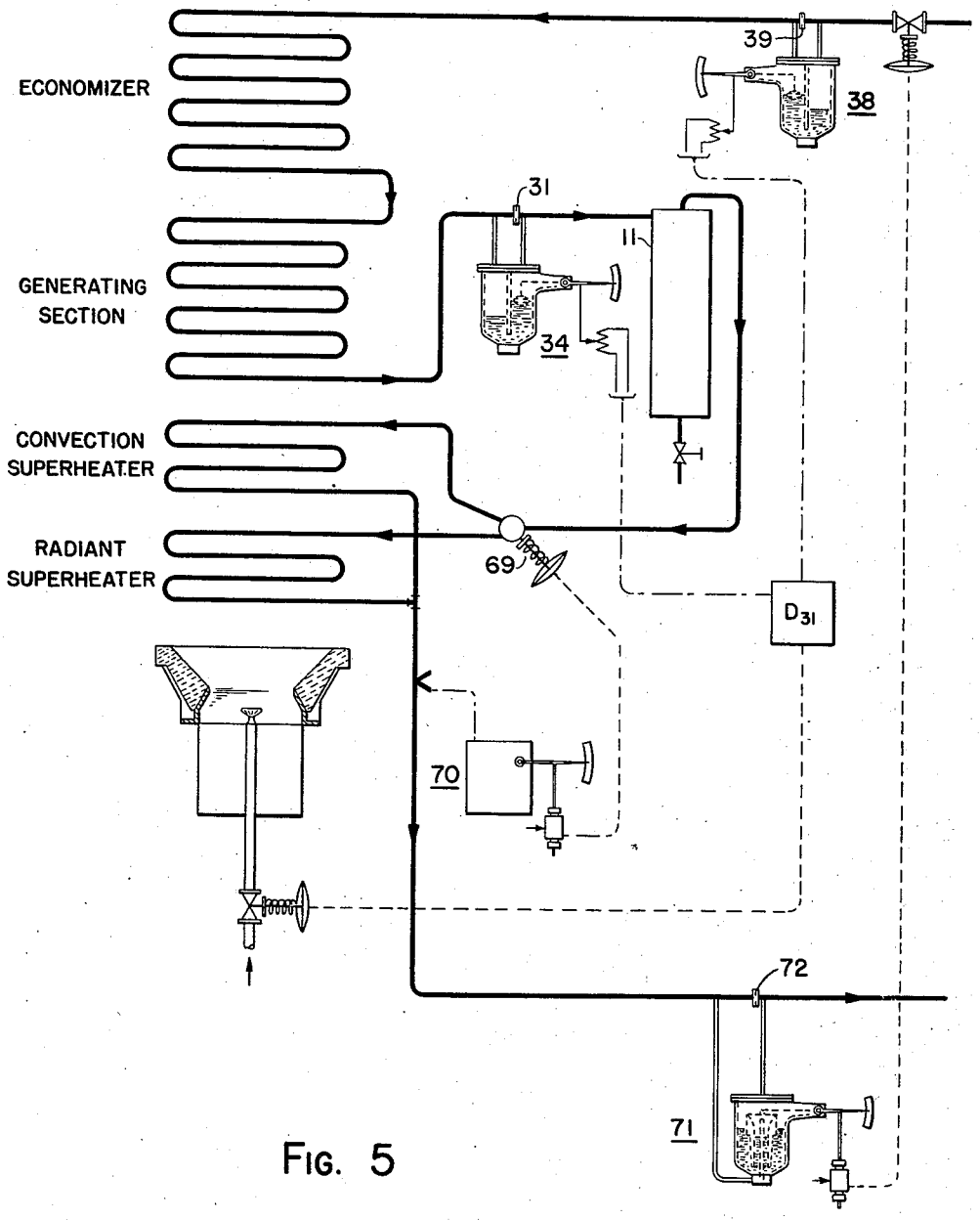


FIG. 5

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Filed Jan. 5, 1940 6 Sheets-Sheet 6

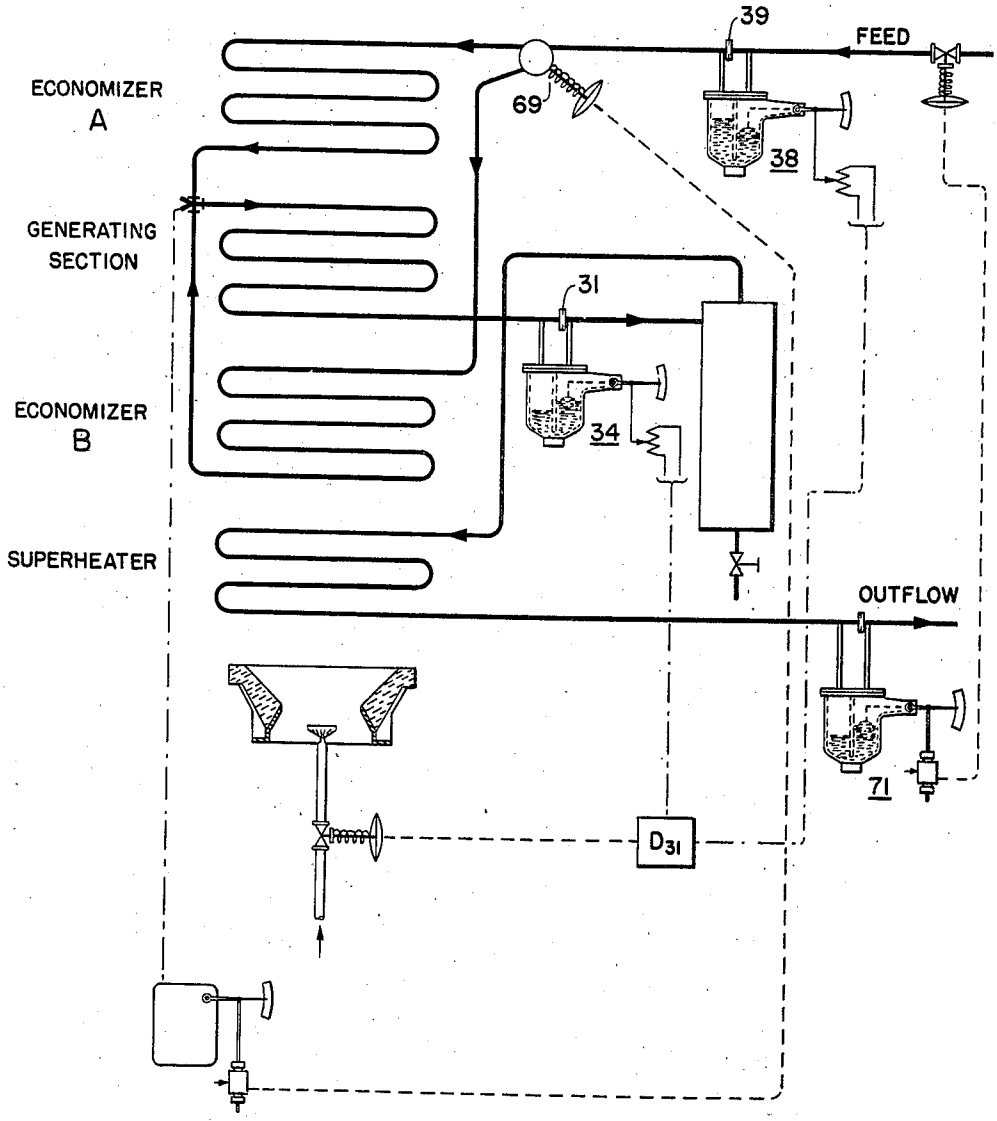


FIG. 6

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Patented Dec. 28, 1943

2,337,851

UNITED STATES PATENT OFFICE

2,337,851

CONTROL SYSTEM

Raymond D. Junkins, Cleveland Heights, Ohio, assignor to Bailey Meter Company, a corporation of Delaware

Application January 5, 1940, Serial No. 312,515

10 Claims. (Cl. 196—132)

This invention relates to methods of and apparatus for fluid processing or treating systems, particularly of the forced circulation type wherein the fluid to be processed or treated is supplied to the inlet of a heated path under pressure and discharges at the other end of the path either as a liquid, a vapor, or a liquid-vapor mixture. Such systems contemplate the generation of steam from water, the processing of petroleum hydrocarbons, or any analogous fluid treating or processing.

While I have chosen to illustrate and describe as a preferred embodiment of my invention the generation of steam in a forced flow vapor generator, it is to be understood that this is by way of example only and that the invention is equally applicable to the processing of petroleum hydrocarbons or of any fluid in forced flow through a heated path.

The particular vapor generators here under consideration are 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 and characterised 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 or marine 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 or other usage. 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 enter into the present invention.

The excess of liquid over vapor generated, and which may be completely or partially recirculated, may comprise twenty, thirty, or even fifty percent of the liquid entering the flow path under pressure. The same is true in the case of a processing of petroleum hydrocarbons, in which in fact the percentage by weight of liquid leaving the heated path may be as much as or greater than the weight rate of vapor.

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 overheating of one tube as compared to another. Flow restrictors are usually sections of tubing of relative 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.

I 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 distributions between the different tube paths is concerned. Any generating tube which has a 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 my 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 generating 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 therebetween. Through my invention, by the substitution of equalizing valves for flow resistors, there is a greater tendency toward circuit equalization of flow, heat, temperature, and density, since I have not lost the action of pressure drop in equalization of flows, and at the same time I 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.

While it is true that I am principally describing my invention in connection with a forced circulation vapor generator, it must be remembered that other treating and processing systems, such for example as the processing of a petroleum hydrocarbon, also employ a plurality of long small-bore tubes for the forced flow path, and here again the necessity of equalization of flow, heat, temperature, density, etc. is of prime importance. Again the problem is of great importance in equalization between parallel superheater circuits and parallel economizer circuits, etc.

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 my invention.

Fig. 3 is similar to Fig. 1, but more completely discloses the determination and utilization of density of a mixture of liquid and vapor.

Fig. 4 is a diagrammatic illustration of the application of my invention to a petroleum processing system.

Fig. 5 diagrammatically illustrates the invention applied to a forced flow vapor generator with a plurality of superheater sections.

Fig. 6 diagrammatically illustrates the application of the invention to a forced flow vapor generator having a plurality of economizer sections.

The drumless forced flow vapor generator to which the present invention is particularly directed is diagrammatically illustrated in Fig. 1 to indicated 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 adapted for the service.

The liquid from the economizer outlet header 2 is conveyed by a tube 3 to a manifold 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 join in a header 9, from which a tube 10 enters a bulge in the fluid flow path which is in the form of a separating chamber 11 for dividing the fluid into liquid and vapor, the vapor passing to a superheater 12 and the excess liquid being diverted from the fluid flow path through a pipe 13 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 provisions 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 header 9, and to the separator 11, 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 comprising 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 I 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 14 joins the header 4 with the equalizing valve 5. This flow of water leaves the valve 5 through a pipe 15 to the vapor generating path 8, from which it returns through the pipe 16 to the valve 5, thereafter leaving through the pipe 17 to the header 9. In Fig. 1 I have indicated a shutoff valve 18 in the pipe 14, and a needle control valve 19 joining the pipes 14 and 15 and by-passing the valve 5. The purpose of the valves 18 and 19 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 14 below a movable valve member 20 having guide fins 21 and seating normally on a seat member 22. When the valve member 20 is moved upwardly (on the drawing) water from the pipe 14 passes between the valve member 20 and the seat 22 to the pipe 15 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 16 below a movable valve member 23 having guiding fins 24 and adapted to seat against a seat member 25.

The movable valve members 20, 23 are interre-

lated by a push rod 26 slideable through a partition member 27. The valve members 20, 23 and push rod 26 are urged together and downwardly by a compression spring 28 adjustable through the agency of a screw 29 in well known manner. Normally then the valve members 20 and 23 are urged against the seat members 22 and 25 by the spring 28.

When water under pressure is available in the header 4 the pressure thus effective upon the underside of the valve member 20 causes it to move upwardly to unseat and allow flow from the pipe 14 to the pipe 15. Such upward positioning moves the push rod 26, the valve 23, and compresses the spring 28. The result is a flow of liquid through the fluid path 8, the pipe 16, and the pipe 17, to the header 9. When the path 8 is heated and vapor begins to be generated therein, the fluid entering the valve assembly 5 through the pipe 16 constitutes a mixture of liquid and vapor at greater specific volume and lower density than the liquid passing through the pipes 14 and 15. For a condition of equilibrium this flow of liquid-vapor mixture requires a greater valve opening between the member 23 and the seat 25, and thus the area of the member 23 is greater than that of the member 20. The design of these relative areas, as well as the initial scale of the spring 28, and adjustment of the screw 29, depends upon the desired density of the fluid leaving the section 8 through the pipe 16. In other words, in a forced flow vapor generator of the type being described, and having a separator 11, it is desired to admit more water through the pipe 15 than can be evaporated in a single passage through the path 8, and the liquid-vapor mixture leaving through the pipe 16 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 15, and is adjustable within certain limits through the agency of the screw 29. For wider operating changes it may be desirable to replace the valve members 20, 23 with valve members of different cross sectional area or to change the spring 28.

I 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 I have disclosed, satisfies these demands.

I desire it to be understood that in speaking of density in this description and in the claims I use the term in its well understood and generic definition and meaning such as has been 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, i. e. unevaporated excesss, at low pressures than at high pressures.

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 particular circuit. Similarly the valves will be closed whenever there is a smaller percentage of steam in the mixture entering the drum, due to the decrease in volume and pressure drop across the upper valve member.

In Fig. 1 I show a valve 30 located in a by-pass between the pipes 16 and 17. By means of the valves 18, 19 and 30 the equalizing valve 5 may be disconnected completely from the flow circuit 8 so that work may be done thereon. If the valve 18 is closed, and the valves 19, 30 are opened, then the equalizing valve 5 is completely by-passed insofar as the flow pipes 14, 15, 16 and 17 are concerned. If under this condition the needle valve 19 is positioned by hand to a partly throttled condition, this will introduce an adjustable pressure drop similar to the known resistors 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 18 opened and the valve 30 closed) to have the valve 19 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 19 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 18, 19 and 30, may be incorporated with the equalizing valves 5 of the circuits 6 and 7, or 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 say 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 20, and approximately 6 lb. per square inch across the valve member 23. At the maximum flow rate of approximately 8000 lb. of water per hour past the valve member 20, and of say for example 7200 lb. of steam

and 800 lb. of water past the valve member 23, there will be a differential pressure of approximately 100 lb. per square inch across the valve member 20, and approximately 10 lb. per square inch across the valve member 23. These values are obtained with a spring having a scale of 25 lb. per square 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 of 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 member 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 intentionally 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.

I have so far explained the functioning of the equalizing valves 5 in controlling the admission of water from the header 4 to the vapor generating surfaces 6, 7 and 8, and in proportioning the water to the various surfaces, from manifestations of density at the exit of each of the circuits 6, 7 and 8, as well as from a comparison of such densities individually with the density of the feed liquid. A further particular feature of the present invention is a control of the heating responsive to a determination of the density of the liquid-vapor mixture leaving the header 9 through the conduit 10 and passing to the separator 11.

In the conduit 10 I have located an orifice or similar restriction 31, which may be a Venturi tube, flow nozzle, or any suitable and well known device for creating a pressure differential representative of the volume rate of flow of the fluid therethrough.

Connected to the conduit 10 at opposite sides of the orifice 31 by means of the connecting pipes 32, 33, is a differential pressure responsive device 34 comprising a mercury U-tube on the surface of one leg of which is a float positioned responsive to, and representative of, the differential in pressure existing across the orifice 31. The float is adapted to position an indicator arm 35 relative to an index 36, and at the same time to position a contact arm along a resistance 37.

In similar manner a pressure differential responsive meter 38 is connected across an orifice 39 in the liquid feed line 3, adapted to position an indicator 40 relative to an index 41, and to position a contact relative to a resistance 42. As will be explained hereinafter, the resistances 37, 42 comprise legs in a Wheatstone bridge circuit for determining the density of the fluid mixture passing the orifice 31; and such determination of density is utilized in automatically controlling the opening of a fuel regulating valve 43.

I have also indicated in Fig. 1 a thermocouple T_1 for determining the temperature of the fluid passing through the conduit 3, a thermocouple T_2 sensitive to temperature of the mixture entering the separator 11, and a thermocouple T_3 sensitive to temperature of the steam leaving the superheater.

In Fig. 3 I show in more diagrammatic fashion the vapor generator of Fig. 1, and have clearly illustrated how the differential pressure meters 34, 38 are interconnected to determine the value of density of the mixture passing through the conduit 10 to the separator 11. I have previously stated that the resistance values 37, 42 are continuously representative of differential pressure across the orifices 31, 39 respectively.

The relation between volume flow rate and differential pressure is:

$$Q=cM\sqrt{2gh} \qquad (1)$$

Where

Q=cubic feet per second
c=coefficient of discharge
M=meter constant (depends on pipe diameter and diameter of orifice hole)
g=acceleration of gravity=32.17 ft. per sec. per sec.
h=differential head in feet of the flowing fluid

The coefficient of discharge remains substantially constant for any one ratio of orifice diameter to pipe diameter, regardless of the density or specific volume of the fluid being measured. With c, M and $\sqrt{2g}$ all remaining constant, then Q varies as the $\sqrt{h}$. Thus it will be seen that the float rise of the meters 34, 38 is independent of variation in density or specific volume of the fluid at the two points of measurement and that the reading on the indexes 36, 41 of differential head is directly indicative of volume flow rate. If the conduit size and orifice hole size are the same at both meter locations, then the relation of meter readings is indicative of the relation of density and specific volume. Thus for the same weight rate of flow past the two metering locations, and with a constant water density at orifice 39, the differential pressure at location 31 will increase with decrease in density of the fluid, and vice versa.

This may readily be seen, for if it were desired to measure the flowing fluid in units of weight, Formula 1 becomes:

$$W=cM\times\sqrt{2ghd} \qquad (2)$$

Where

W=rate of flow in pounds per second
d=density in lb. per cu. ft. of the flowing fluid
h=differential head in inches of a standard liquid such as water
M=meter constant now including a correction to bring h of Equation 1 into terms of h of Equation 2

Assuming the same weight rate of flow passing successively through two similar spaced orifices 39, 31 and with a change in density as may be caused by the heating means, then the density

at the second orifice 31 may be determined as follows:

$$W_{31}=W_{39}$$
$$\sqrt{2gh_{31}d_{31}}=\sqrt{2gh_{39}d_{39}}$$
$$\sqrt{h_{31}d_{31}}=\sqrt{h_{39}d_{39}}$$
$$d_{31}=d_{39}\times\frac{h_{39}}{h_{31}} \quad (3)$$

Thus it will be observed that, knowing the density of the fluid passing the orifice 39 (in this case water, although it may be any other selected fluid), I may readily determine the density of the fluid passing the orifice 31 from the relation of differential pressures indicated by the meters 34, 36.

Referring now to Fig. 3 it will be observed that the adjustable resistances 37, 42 comprise two arms of a Wheatstone bridge. A third arm includes a hand adjustable resistance 44, while a fourth arm includes a fixed resistance 45 and an adjustable balancing resistance 46. The adjustable resistance 46 (for balancing the bridge) is varied by movement of an arm 47, through the agency of a reversible synchronous motor 48, under the control of a galvanometer 49.

The motor 48 is of the self-starting synchronous type of alternating current motor and is shown as having normally deenergized opposed fields. Should the Wheatstone bridge become unbalanced, then the needle of the galvanometer 49 will move either clockwise or counterclockwise (Fig. 3), thereby energizing one of the fields of the motor 48, resulting in a positioning of the arm 47 in direction and amount over the resistance 46 to balance the bridge and cause the galvanometer needle to return to neutral position. It will be understood that the necessary gear reduction is incorporated between the motor 48 and the arm 47 so that the arm 47 moves at a relatively slow speed.

The Wheatstone bridge thus serves to continuously determine the density of the fluid at the orifice 31 through solving Equation 3. Such density is continuously indicated on an index 50 by the movable arm 47.

Solving Equation 3

$$d_{31}=d_{39}\times\frac{h_{39}}{h_{31}}$$

Resistance $37\propto h_{31}$
Resistance $42\propto h_{39}$

And it is expected that:

$$d_{39}>d_{31}$$
$$h_{39}<h_{31}$$
$$42<37$$

It is known that the law of the Wheatstone bridge is:

$$\frac{R42}{R46+R45}=\frac{R37}{R44}$$

$$R46=\left(R44\times\frac{R42}{R37}\right)-R45$$

and R46 represents d_{31}.

Thus the actual density of the liquid-vapor mixture passing through the conduit 10 to the separator 11 is determined and indicated upon an index 50. At the same time the arm 47 positions the stem of a pilot valve 51, which may be of the type disclosed and claimed in the patent to Clarence Johnson 2,054,464, and wherein a fluid loading pressure is established in the pipe 52 continuously representative of the value of density of the fluid in conduit 10.

I have also illustrated that each of the temperature responsive thermocouples T_1, T_2 and T_3 is associated with a known potentiometer device such as 53 for positioning an indicator 54 relative to an index 55 to advise the value of the temperature and at the same time position the stem of a pilot valve such as 56 for establishing a fluid loading pressure representative of temperature.

The loading pressures representative respectively of T_1, T_2, T_3 and density in conduit 10 are manifolded as at 57 and connected to the fuel supply valve 43 in such a manner that the fuel supply valve may be selectively under the control of any one of the three mentioned temperatures or of density of the fluid in conduit 10.

A particular feature of my present invention is in the control of the heating responsive to the value of density of the liquid-vapor mixture entering the separator 11 and for the purpose of maintaining such density at a predetermined value.

Thus considering the disclosure of Fig. 3, it will be observed that the plurality of parallel circuits in the vapor generating portion of the forced flow path are each provided with an equalizing valve 5 serving to regulate the total feed of liquid to the generating surface and to properly proportion it between the different brancnes of the parallel circuits. The heating of the unit however is under control of the total liquid-vapor mixture leaving the generating surfaces and passing to the separator and from an indication of density thereof. Thus while the equalizing valves 5 proportion the total feed of liquid to and between the circuits, the final value of density of the mixture entering the separator is used in controlling the heating to maintain said density as desired.

While in connection with Fig. 3 I have explained in detail the manner in which I determine the density of a liquid-vapor mixture, I do not believe that it is necessary to repeat such disclosure, either in the other figures of the drawings or in the description pertaining individually thereto. It will thus be understood that in Figs. 1, 4, 5 and 6 the determination of density of the liquid-vapor mixture may be as explained in connection with Fig. 3.

In Fig. 4 I illustrate in diagrammatic fashion the application of my invention to the processing of a petroleum hydrocarbon, as for example in the cracking of oil. Here again in general I illustrate a regulation and proportioning of the feed liquid to the various circuits in the conversion or vaporizing section of the fluid flow path, and furthermore a regulation of the firing in accordance with a determination of the density of the liquid-vapor mixture leaving the conversion section.

The charge liquid enters through a conduit 3 to a preheating section 58 of the flow path, which is heated by a burner or burners 59 having fuel controlled thereto by means of a regulating damper or valve 60. The heated liquid passes from the section 58 through a conduit 61 having positioned therein an orifice 39 across which is connected a differential pressure meter 33 for positioning a resistance representative of the differential pressure.

The heated petroleum hydrocarbons pass from the conduit 61 to a header 62, splitting to three or more parallel circuits comprising a conversion

section heated by a burner or burners 63 to which fuel is supplied under regulated control of a valve or damper 64. The conversion section 65 feeds its parallel circuits to a header 66 from which a conduit 67 leads to a tower, reaction chamber, vapor separator, or other relatively quiescent zone 68 where liquids and vapors may separate.

The forced flow path is so arranged and proportioned that preferably no vaporization or liberation of gases or vapors occurs in the heating section 58; and all vaporization or liberation occurs within the conversion section 65. Thus it is normally expected that liquid only will enter the header 62 and that a liquid-vapor mixture will leave the header 66 through the conduit 67.

The density of the liquid-vapor mixture in the conduit 67 is continuously determined, or a manifestation thereof is determined, through the agency of the differential pressure meters 34, 38 and the Wheatstone bridge measuring system described in connection with Fig. 3.

In the present embodiment I preferably control the fuel valve 60 either manually in accordance with an observation of T_1 or automatically therefrom. I preferably control the fuel supply valve 64 to the conversion section in accordance with density D_{31} of the liquid-vapor mixture leaving the conversion section, or selectively in accordance with temperature thereof.

It should be quite clear that the invention is equally applicable to the vaporization of water, the cracking or other treatment of a petroleum hydrocarbon, or the processing of any fluid.

In Fig. 5 I illustrate a further embodiment of my invention in connection with a forced flow vapor generator having parallel circuits in the superheater, one of which may be a radiant superheater and the other a convection type. The feed liquid enters an economizer section after passing through an orifice 39 across which is connected the differential pressure meter 38. From the economizer section the heated liquid enters a generating section from which the liquid-vapor mixture passes to a separator 11. The density of the mixture entering the separator is determined as previously herein disclosed.

Vapor from the separator 11 passes to the convection and radiant superheaters through a proportioning valve 69 under the control of a temperature sensitive device 70 for maintaining the final temperature of the steam leaving the unit as desired irrespective of variations in load.

It will be understood that vapor generators equipped with radiant superheaters have a superheat-load characteristic differing from the characteristic of the convection superheater relative to load. Various combinations of superheaters having convection heating surface and having radiant heating surface have been made in an attempt to obtain a uniform superheat irrespective of load variations. Some attempts have been made to proportion the surfaces and/or the amount of steam passing therethrough in accordance with a measure of load to predetermine the proportionality of superheating work done by the convection and by the radiant superheater in an attempt to result in uniform superheat with varying load.

I have found however that a proportioning valve 69 may readily be designed and arranged to control from temperature of the total superheat leaving the convection and radiant superheaters to maintain said superheat substantially constant irrespective of load variations.

In Fig. 5 I control the firing in accordance with a determination of or manifestation of the density of the mixture of liquid and vapor entering the separator 11, and control the total feed of liquid to the unit in predetermined excess to measured vapor outflow, the excess liquid being discharged from the separator 11. The flow meter 71 is a weight rate of flow meter rather than a volume flow meter and has a mercury sealed inverted bell of designed cross sectional area such that the positioning of the indicator and of the air pilot valve is directly in accordance with weight rate of flow of steam leaving the unit, rather than in accordance with differential pressure across the orifice 72.

In general then in Fig. 5 the total feed of liquid to the forced circulation path is in predetermined excess over measured vapor outflow, which latter of course is determined by the load upon the unit. The total fluid passing to the separator 11 will be in liquid-vapor proportion determined by the heat applied to the unit and thus I utilize a measurement of density of the liquid-vapor mixture in controlling said heating to maintain the density as desired. The superheated steam leaving the separator 11 is then proportioned to the convection and radiant superheaters so that the temperature of the vapor outflow is as desired irrespective of load and other fluctuations.

In Fig. 6 I illustrate an embodiment of my invention wherein the circuits of a forced circulation vapor generator are arranged with a plurality of economizer sections in parallel. The various parallel circuits in the economizer section may be located relative to the heating as desired, and the location forms no particular part of the present invention. I do however desirably proportion the feed liquid to the economizer sections in accordance with means similar to that explained in connection with Fig. 5. Thus irrespective of the location of the economizers relative to radiant or convection firing, and irrespective of the proportionality of duty upon the economizers, I properly proportion the liquid feed to the economizers through the agency of the proportioning valve 69 by an indication of total temperature of the liquid leaving the economizers.

From the economizers the fluid passes through a generating section and to a separator. The density D_{31} of the liquid-vapor mixture entering the separator is used to control the firing or heating of the unit, while the total feed is in predetermined excess to measured vapor outflow.

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

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

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

3. The method of processing a fluid, which includes, flowing the fluid in a confined flow path under pressure and subjected to heat, then dividing the flow into a plurality of parallel paths, heating the plurality of parallel paths, normally vaporizing a part only of the liquid entering the parallel paths, utilizing a comparison of the density of the liquid entering the parallel paths and the density of the liquid-vapor mixture leaving the paths to proportion the liquid to the parallel paths, and utilizing the density of the mixture to regulate the heating of the parallel paths.

4. In a forced flow vapor generator, in combination, a flow path having a generating portion and a superheating portion, a liquid-vapor separator between said portions, means for heating the path, liquid supply means normally supplying liquid to the entrance of the generating portion in excess of vapor generated, means continuously determining density of the liquid-vapor mixture entering the separator, and means controlling the heating means responsive to said density determining means.

5. The method of operating a forced flow vapor generator, which includes, supplying liquid to the generating portion of the path in excess over vapor discharged therefrom, passing the liquid-vapor mixture to a relatively quiescent separator zone, diverting the excess liquid, regulating the heating of the path responsive to density of the mixture, and proportioning the vapor from the separator through parallel superheating paths responsive to temperature of the vapor leaving the superheater.

6. The method of operating a forced flow vapor generator, which includes, supplying liquid to the unit in excess over vapor discharged therefrom, proportioning the liquid through a plurality of parallel preheating paths responsive to temperature of the liquid leaving such paths, passing the liquid through a generating portion of the path wherein a part only of the liquid is vaporized, discharging the liquid-vapor mixture to a relatively quiescent separator zone, and controlling the heating of the zone responsive to density of the mixture.

7. The method of processing petroleum hydrocarbon, which includes, serially flowing the fluid through a preheating and a conversion portion of a confined path under pressure and where the conversion portion of the path is comprised of a plurality of parallel circuits, continuously supplying liquid to the preheateing portion in excess over vapor leaving the conversion portion, separately heating the portions of the path, regulating the heating of the preheating portion responsive to temperature of the fluid leaving such portion, proportioning the fluid leaving the preheating portion to the several parallel circuits of the conversion portion of the path in accordance with a comparison of density of the fluid entering each circuit with the density of the fluid leaving each circuit, and regulating the heating of the conversion portion responsive to density of the liquid-vapor mixture leaving the conversion portion.

8. The combination with a petroleum hydrocarbon processing system having a confined path including a preheating and a conversion portion serially arranged, said conversion portion being comprised of a plurality of parallel circuits, of means for continuously supplying liquid to the preheating portion in excess over vapor leaving the conversion portion, means for separately heating the preheating and conversion portions of the path, means responsive to the temperature of the fluid leaving the preheating portion and adapted to regulate the heating of such portion in accordance therewith, means for comparing the density of the fluid entering each circuit of the conversion portion with the density of the fluid leaving each of said circuits and adapted to proportion the fluid leaving the preheating portion to the several parallel circuits in accordance with such comparison of densities, and means responsive to density of the liquid-vapor mixture leaving the conversion portion and adapted to regulate the heating of the conversion portion in accordance therewith.

9. In combination with a forced flow vapor generator having a generating portion of the flow path and parallel superheating portions of the flow path serially connected to the generating portion, a vapor-liquid separator between the generating and superheating portions, means supplying liquid to the generating portion in excess over vapor discharged therefrom, means diverting unevaporated liquid from the separator, heating means for the path, means responsive to the density of the vapor-liquid mixture leaving the generating portion of the path and adapted to control the heating means, means sensitive to temperature of the vapor leaving the superheater, and means proportioning the vapor from the separator through the parallel superheating paths responsive to said temperature sensitive means.

10. In combination with a forced flow vapor generator having a generating portion of the flow path and parallel preheating paths connected to the inlet of the generating portion, a relatively quiescent separator zone to which the generating portion discharges, means supplying liquid to the parallel preheating paths in excess over vapor discharged to the separator, heating means for the paths, means sensitive to the temperature of the liquid leaving the preheating paths, means proportioning the liquid through the parallel preheating paths responsive to said temperature sensitive means, and means responsive to the density of the liquid-vapor mixture entering the separator and adapted to control said heating means.

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