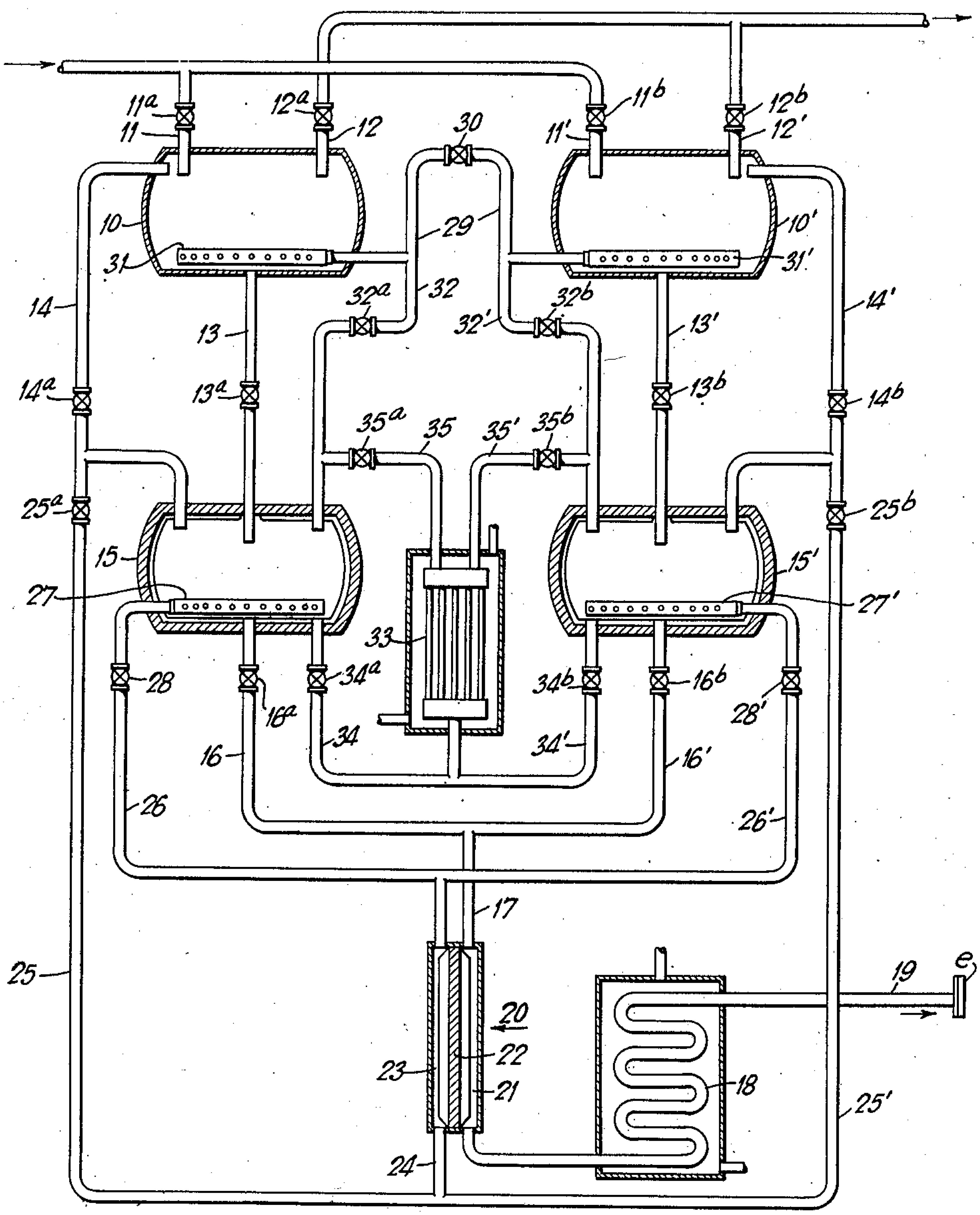
April 21, 1936. J. M. GAINES, JR 2,037,714

METHOD AND APPARATUS FOR OPERATING CASCADE SYSTEMS WITH REGENERATION

Filed March 13, 1935 3 Sheets-Sheet 1

Fig. 1.



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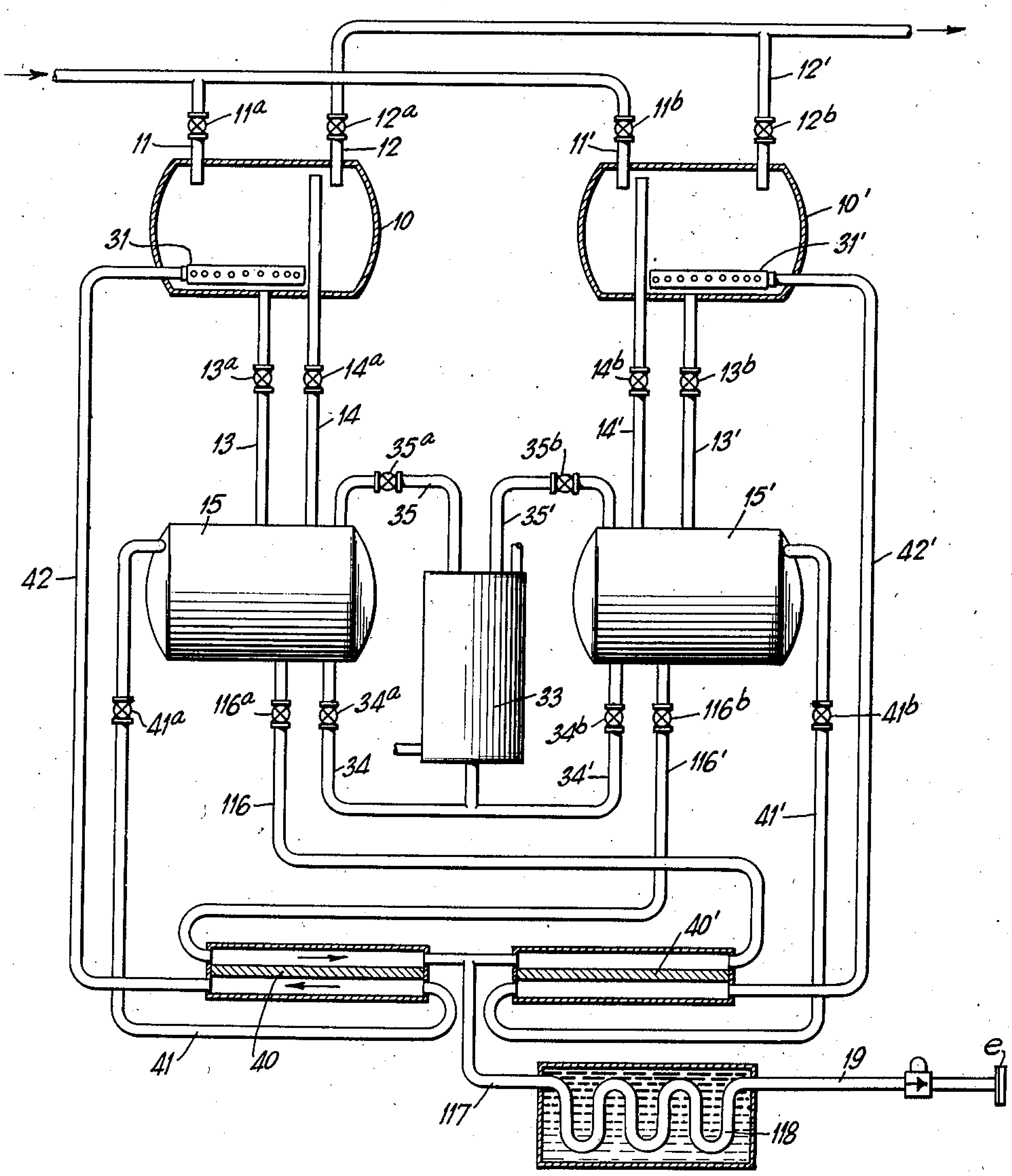
Filed March 13, 1935 3 Sheets-Sheet 2

Fig. 2.



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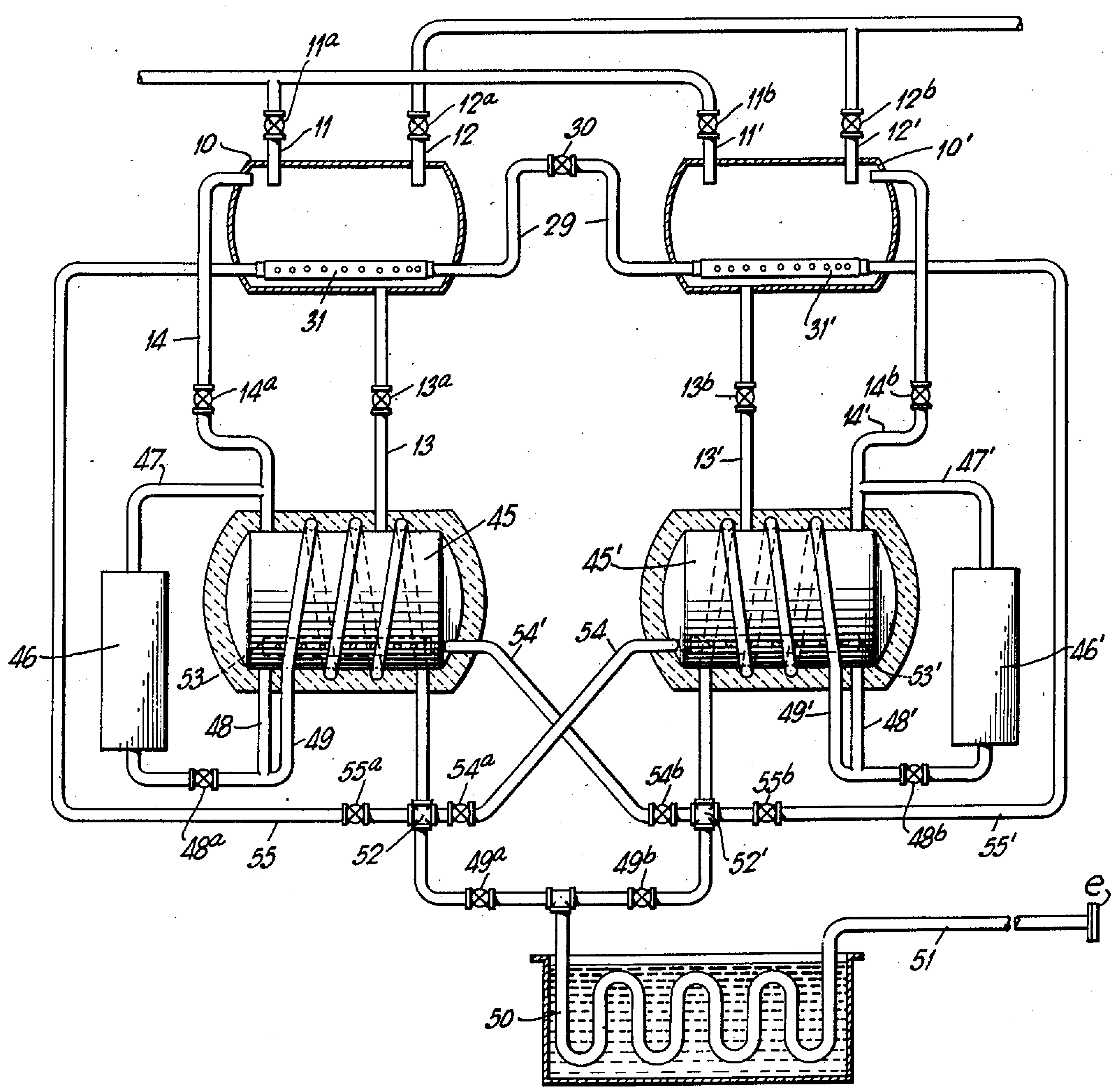
Filed March 13, 1935 3 Sheets-Sheet 3

Fig. 3



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METHOD AND APPARATUS FOR OPERATING CASCADE SYSTEMS WITH REGENERATION

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Application March 13, 1935, Serial No. 10,793

20 Claims. (Cl. 62—1)

This invention relates to a method and apparatus for operating a cascade system with regeneration to effect the transfer of a precious volatile liquid which tends to gasify under the conditions of ordinary transfer; the cascade principle being employed to reduce vaporization losses. More specifically, it relates to an advantageous method and apparatus for rejecting heat from a cascade system when arranged for rapidly transferring a liquefied gas or like volatile material from a region of relatively low pressure to a region of relatively high pressure.

The invention has for its object generally an improved method utilizing the cascade principle for reducing loss of material in the gas phase when effecting the desired transfer, by which heat is controllably supplied for accelerating the transfer in a manner that conserves the refrigerating effect of the material being transferred and by which the refrigerating effect conserved is used when rejecting heat from the cascade system to reduce the internal energy of the material transferred in the gas phase to a relatively small value.

More specifically, it is an object of the invention to provide a cascade system with an improved arrangement of transfer vessels for transferring liquids having boiling points below 273° K., such as certain liquefied hydrocarbon gases, liquid oxygen, liquid nitrogen and the like, from regions of relatively low pressure to regions at higher pressure together with a method and means for conserving the refrigerating effect of material discharged from a final transfer vessel, whereby such refrigeration is utilized for rejecting heat from material in the gas phase being transferred in the system.

Another object of the invention is to provide a method and means for utilizing in greater degree than heretofore the condensing capacity of the liquid passed through transfer vessels for the reduction of the internal energy of the material being transferred in the gas phase whereby heat in the gas phase is carried away from the system in a manner that conserves both internal energy and gas material.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the several steps and the relation of one or more of such steps with respect to each of the others, and the apparatus embodying features of construction, combinations of elements and arrangement of parts which are adapted to effect such steps, all as exemplified in the following detailed disclosure, and the scope of the invention will be indicated in he claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings, in which:

Fig. 1 is a view partly in elevation and partly in section showing a mixed cascade system, i. e., one having transfer vessels connected partly in series and partly in parallel to embody the cascade principle, arranged for conserving the refrigerating effect of the material discharged and rejecting heat from gas material transferred in accordance with the present invention;

Fig. 2 is a similar view of a modified form of apparatus according to the invention wherein heat is rejected from material in the gas phase transferred between other vessels of the system; and

Fig. 3 is a similar view of another modification of apparatus according to the invention.

When transferring volatile liquids of low boiling point from regions of relatively low pressure to receiving vessels at higher pressure by a system of transfer vessels employing the cascade principle as set forth in the co-pending application, Serial No. 752,993, filed in the name of J. J. Murphy, loss of material in the gas phase is reduced by transferring a portion of the internal energy contained in the gas phase remainder to liquid being transferred within the system. Since the gas remaining after the discharge of liquid from a final vessel is to be recondensed, it is advantageous that the internal energy of material in the gas phase be either kept at a low value or brought to a low value before the recondensation is effected.

In the copending application, Serial No. 3,249, filed in the name of G. H. Zenner, it is shown how thermal energy alone, by means of a so-called "thermal leg", is applied to accelerate the discharge of liquid from the final vessel of a cascade system and to reduce the total internal energy contained in the gas remaining after discharge by rapidly heating a segregated portion in the thermal leg to a relatively high temperature.

In the copending application, Serial No. 3,219, filed in the name of L. I. Dana, there is shown a method and means for transferring a portion of the internal energy contained in the gas phase remainder of a warm converter that is used as the final vessel of a cascade system, to material of another charge when being discharged; the transfer of heat being effected by means of a heat storage and exchanging device or so-called "regenerator". Only a portion of the discharge in such case is useful for refrigerating the regenerator, since the after portions of each discharge have too high a temperature and are therefore by-passed around the regenerator.

By the present invention the final vessel of a cascade system is discharged by means of a thermal leg whereby the material in the gas phase is quickly heated to a relatively high temperature so as to keep the total internal energy contained in it to a value that is low compared to the internal energy that it would contain at a lower temperature but equal to discharge pressure while at the same time maintaining substantially unimpaired refrigerating capacity of the material of the liquid phase discharged. This is accomplished by providing a suitable regenerator in operative conjunction with the thermal leg, whereby advantage is taken of the refrigerating capacity of the total discharge for reducing the internal energy of the material in the gas phase to a relatively low value.

By such means, the conserved refrigeration of the liquid phase discharge is transferred to the gas phase already discharged from the cascade system, and the desired reduction of the internal energy of the gas to be recondensed is accomplished. This reduction, however, has a cumulative effect on succeeding charges passed through the cascade system until a balance is reached. This cumulative effect follows because the gas which is passed into and condensed in the next succeeding charge of liquid carries less internal energy by an amount equivalent to the heat transferred to the heat storage and exchanging device. Therefore the second charge of liquid is not heated to as high a temperature as the previous charge and cools the exchanging device to a lower temperature than the temperature level imparted to it by the previous charge.

The gas phase remainder of succeeding charges is therefore more effectively cooled to lower temparatures which in turn tends to preserve the refrigerating capacity of the material in the liquid phase at still lower temperatures. The cumulative effect grows smaller with each cycle until a balanced condition is reached. Under certain conditions liquefaction of some of the gas which is cooled in the exchanging device may occur, depending upon the temperature and pressures involved.

The present arrangement applied to the improved cascade system effects a reduction of the blowdown loss to a very small amount, since the refrigerating capacity of the material that may be under a pressure well above its critical pressure is used for reduction of the internal energy of the gas recycled for condensation in liquid. For a predetermined commercially allowable blowdown loss fewer steps of cascade equalization need be provided which results in a simplification of apparatus and a reduction in the total weight of the system which is desirable when the apparatus is mounted on rolling stock for servicing storage and consuming devices located at points distant from a centrally located liquefied gas production or storage plant.

Referring now to the drawings, and particularly to Fig. 1, there is shown a cascade system having four transfer vessels connected as parallel groups of two which are in series, so that the discharge of successive charges of the volatile material takes place alternately from the final vessel of each series. As illustrated, the parallel groups each comprise a low pressure initial transfer vessel shown at 10 and 10′. The low pressure vessels each have a liquid inlet connection shown at 11 and 11′, a gas phase discharge connection shown at 12 and 12′, and a liquid phase discharge connection shown at 13 and 13′. The latter are arranged for transferring the liquid material into final vessels 15 and 15′ which are disposed in succession below the initial transfer vessels; gas phase displacement connections 14 and 14′ being arranged to lead respectively from each final vessel to the corresponding initial vessel for controlling the transfer. The vessels 15 and 15′ are preferably provided with liquid holding linings or "baskets" spaced from the heavy pressure resistant walls whereby heat contained in or passing through the walls is substantially excluded and the liquid protected. Leading from the bottom of vessels 15 and 15′ are connections 16 and 16′ which lead to the common connection 17 communicating with one pass of a regenerator shown generally at 20. This pass leads to the liquid receiving and vaporizing device 18 which discharges gas at high pressure to consuming devices through the service connection 19.

The regenerator 20 is shown as of the separate-pass type having passages 21 and 23 separated by a heat storage wall 22. Passage 21 has its inlet communicating with the connection 17 and its outlet connected to the device 18. The second passage 23 has its inlet 24 communicating with a connection 25 that leads from the gas space of the vessel 15 and a similar connection 25′ leading from the gas space of vessel 15′; these connections being controlled by valves 25a and 25b, respectively. The outlet of passage 23 has a common communication with the connections 26 and 26′ which lead respectively to the gas distributing devices 27 and 27′ disposed respectively in the vessels 15 and 15′. Suitable means, for example, check valves, as shown at 28 and 28′, are preferably disposed in each of the connections 26 and 26′ for preventing gas pressures in vessels 15 and 15′ from forcing the flow of liquid through the connections 26 and 26′ into the passage 23.

While the regenerator, shown diagrammatically at 20, is illustrated as having two passages separated by a heavy wall of heat storage material, it is contemplated that in actual practice the regenerator may have any suitable form known to the prior art adapted for heat exchange in the manner desired between fluids of the character here transferred. An advantageous form of regenerator, adapted for use when liquid oxygen is to be transferred, comprises a bundle of relatively small bore heavy walled copper tubes joined at each end to headers for the liquid phase discharge pass, and a jacket surrounding the bundle to provide a pass for the gas to be cooled. Provision is also made in the construction for temperature and pressure effects and for efficient heat exchange as well as the presence of the desired amount of metal in the tubing walls for the storage and exchange of heat, in the manner here set forth, between predetermined temperature levels. A detailed showing of such form is, however, omitted in the interest of clearness of illustration in the drawings, the form of the regenerator here employed being no part of the invention.

Means are also provided for effecting cross equalization between vessels 10 and 10′ in the form of a conduit 29, controlled by valve 30, connecting distributors 31 and 31′; similar means being provided for effecting equalizations between vessels 15 and 10 and between vessels 15′ and 10′ in the form of conduits 32 and 32′ which connect distributors 31 and 31′ with the upper portions of vessels 15 and 15′, respectively.

A common thermal leg is provided, as shown at 33, for accelerating the discharge from vessels 15 and 15′. This leg is connected in such manner as to heat a withdrawn portion of the charge without heating the major portion that is discharged, and comprises lower and upper headers connected by a plurality of tubular conduits of heat conducting material, the whole being exposed to the action of a suitable heating medium, for example, steam.

In such arrangement, the lower header is connected with the lower portions of vessels 15 and 15' by connections 34 and 34' while the upper header is connected to the upper portions of the vessels by conduits 35 and 35', respectively.

Each of the conduits or connections is controlled by valves interposed therein as follows: Conduits 11, 12, 13, 14, 16, 25, 32, 34 and 35 are controlled by valves 11*a*, 12*a*, 13*a*, 14*a*, 16*a*, 25*a*, 32*a*, 34*a* and 35*a*, respectively, while conduits 11', 12', 13', 14', 16', 25', 32', 34' and 35' are controlled by valves 11*b*, 12*b*, 13*b*, 14*b*, 16*b*, 25*b*, 32*b*, 34*b* and 35*b*, respectively.

In the operation of this four vessel system, the passage of liquid and gas through the passes 21 and 23 is more or less continuous by virtue of the alternate discharge of vessels 15 and 15' and in consequence the heat transfer surfaces are efficiently used. Assuming that vessel 15 has just been filled with liquid and that vessel 15' is full of gas (which may be termed "hot gas" by reason of its relatively high temperature with reference to the liquid, although in the case of liquid oxygen, the gas temperature may be in the neighborhood of atmospheric temperature), discharge of liquid is effected through the connection 16 only after an equalization of pressures between the vessels 15' and 15 is accomplished. To this end valves 25*b* and 28 are first opened in their respective connections 25' and 26 and gas passed through the pass 23 to flow from vessel 15' to 15 where its heat is transferred to and stored in the wall 22. When equalization is substantially completed, valves 25*b* and 28 are closed and liquid withdrawal from vessel 15 through the connection 16 is initiated when the thermal leg 33 is opened to communication with vessel 15. To this end, valves 34*a* and 35*a* are opened, and gas material is circulated through thermal leg 33 where it becomes heated to a relatively high temperature, whereby pressure is rapidly built, so that when valve 16*a* is open the relatively cold gas material in vessel 15 is discharged through passage 21 of the regenerator 20 and through heating device 18 to receiving devices coupled to the line 19 at *e*. It is seen that practically all of the material discharged is at a low temperature since the major portion of the heat introduced by the thermal leg will remain in the gas left in vessel 15 after discharge.

This gas phase remainder is first cooled by the regenerator 20 when vessel 15 and vessel 15' containing a new charge of liquid are pressure equalized. In accordance with the cascade principle, the remainder, after the cross equalization, is conducted into a charge of liquid in vessel 10 by opening valve 32*a* for a second step of equalization with further condensation. A third step of equalization is practised by cross equalizing between vessels 10 and 10' by opening valve 30 after the liquid charge of vessel 10 has been transferred to vessel 15 and vessel 10' filled with a new charge of liquid from the supply source, such transfer being preceded by a transfer of residual gas to vessel 10 as well as liquid from vessel 10 to vessel 15.

In Fig. 2 is shown another four vessel system in which the gas conducted into a succeeding charge for condensation in a vessel in series relation with one final vessel is cooled by countercurrent flow in heat exchanging relation with material being discharged from the other final vessel.

The transfer vessels here are of similar construction to those shown in Fig. 1 and are similarly connected, equivalent parts being designated by the same numerals. Cross equalizing connections, however, are omitted in the interests of clearness of illustration in the drawings. Material of the liquid phase discharged from the final vessel 15 through discharge conduit 116 is caused to pass through one pass of countercurrent regenerator or heat exchanger 40' whose warm end is connected to common conduit 117 which conducts to heater 118. From the gas space of vessel 15 a conduit 41 conducts gas to be cooled to the warm end of the return pass of a similar regenerator or heat exchanger 40 from the cold end of which the gas is conducted to the distributor 31 in vessel 10 by conduit 42. Similar conduits are provided for the discharges from vessel 15', conduit 116' conducting from the liquid phase to exchanger 40 while conduit 41' conducts from the gas phase to exchanger 40'. Valves for controlling the respective conduits are provided at 116*a*, 116*b*, 41*a*, and 41*b*.

If desired, a single countercurrent heat exchanger may be provided instead of the two individual exchangers. This is readily accomplished by suitable arrangement of the connections and the control valves.

The heat exchangers in this form of the invention need not be provided with any substantial amount of heat storage material since the flow of the two fluids between which heat is exchanged occurs substantially simultaneously. Thus when vessel 15 is being discharged of material in the liquid phase through conduit 116 and one pass of exchanger 40', gas is at the same time discharged from vessel 15' through conduit 41', the other pass of heat exchanger 40' and conduit 42' to vessel 10'. The flow of gas may be regulated by the adjustment of the control valve 41*b* so as to occur during the entire time of discharge from vessel 15. It will be seen that the residual gas in vessel 15' after the displacement of the charge is conducted into the initial vessel 10' and during its passage the gas is cooled by heat exchange in countercurrent flow with the liquid which is being discharged substantially simultaneously from the vessel 15. When the pressures are equalized, the augmented charge of liquid in vessel 10' is transferred to vessel 15' by opening valves 13*b* and 14*b* for the required period, after which vessel 10' is vented in preparation for refilling. Cross equalizations between vessels 10 and 10' and vessels 15 and 15' are dispensed with but may be practised if desired.

In the arrangement of the apparatus shown in Fig. 3, advantage is taken of the mass of the metal in the pressure retaining walls of the final vessels to provide the desired heat storage capacity. Here the final vessels of the transfer system, shown at 45 and 45', are of similar construction to vessels 15 and 15' and have heavy metal pressure resistant walls and baskets for holding liquid thermally insulated from the walls. The vessels 45 and 45' are connected with individual thermal legs 46 and 46' although they may be connected to a common thermal leg by suitable connections similarly to the arrangement shown in Figs. 1 and 2. Where individual thermal legs are provided as shown the control valve with its attendant restriction to gas flow may be and is omitted from the connections 47 and 47′ connecting the thermal legs to the gas space of vessels 45 and 45′. Communication of the thermal legs with the liquid space of vessels 45 and 45′ is had through connections 48 and 48′ when the respective control valves 48*a* and 48*b* are open.

Refrigeration is transferred to the walls of vessels 45 and 45′ by coiling extended portions of the discharge conduits 49 and 49′ disposed around the vessels and in thermal contact with the outer surface of the walls. Conduits 49 and 49′ lead from conduits 48 and 48′ and connect to a common heating coil or heater 50 which has a portion 51 leading to the receiving devices that are coupled at *e*.

Equalizing connections are provided as follows: at points 52 and 52′ after the conduits 49 and 49′ leave contact with the walls of their respective vessels, cross branch couplings are provided. One branch of coupling 52 is connected with a distributor 53′ in vessel 45′ by connection 54 and similarly one branch of coupling 52′ is connected with distributor 53 within vessel 45 by connection 54′. The other branches of couplings 52 and 52′ are connected by conduits 55 and 55′ to distributors 31 and 31′ in vessels 10 and 10′. Control valves 49*a* and 49*b* are provided in conduits 49 and 49′ in the portions between couplings 52, 52′ and the junction with heater 50. Control valves 54*a*, 54*b*, 55*a* and 55*b* are also provided in conduits 54, 54′, 55 and 55′ respectively.

In this form the discharge from the liquid phase of the final vessels and the outflow of gas when equalizing pressures between vessels both occur through the same conduits 49 or 49′. It is contemplated, however, that it may be desirable to provide a separate conduit also coiled in thermal contact with the vessel walls for conducting the gas to be cooled when equalizing pressures.

The operation of this latter form of apparatus takes place as a substantially continuously repeated cycle of events involving the alternate filling of the initial vessels with liquid to be transferred. As a convenient starting point in describing the sequence of events in the cycle, it will be assumed that vessels 45 and 10′ have been filled with charges of liquid. Thermal leg 46 is set in operation by opening valve 48*a* which produces a rapid building of pressure due to the unrestricted flow of the gas vaporized in the thermal leg through conduit 47 into vessel 45. The pressure, which soon exceeds that of the receiving devices, forces the major portion of the volatile material out through conduit 49 into the receiving devices including heater 50 when the valve 49*a* is open. The conserved refrigerating capacity of the material so discharged causes a removal of heat from the metal of the walls of vessel 45.

During discharge, gas and liquid are exchanged between vessels 10′ and 45′ after pressures are equalized between them. The pressure equalization is accomplished by opening valve 55*b* so that flow of gas occurs from vessel 45′, through conduits 49′ and 55′ to distributor 31′ and therefore the gas of the second step of equalization is also cooled by a stored refrigerating effect in the shell of vessel 45′. After the equalization, valves 13*b* and 14*b* are opened to drop the liquid charge from vessel 10′ into the basket in vessel 45′, at the same time transferring gas from vessel 45′ to vessel 10′.

When vessel 45 is discharged and vessel 45′ is charged, all valves are closed and the first step of cascade condensation is initiated by opening valve 54*a*. The gas phase remainder in vessel 45 having a relatively high temperature and pressure flows through conduits 49 and 54 to distributor 53′ disposed in the liquid in vessel 45′. This gas during flow through conduit 49 transfers heat to the metal of the walls of vessel 45 thereby losing a substantial amount of internal energy before it is passed in contact with the charge in vessel 45′. The charge in vessel 45′ condenses a larger portion of the gas and is heated to a smaller degree than if regeneration had not been practised. Therefore, the liquid charge after the equalization is a better refrigerating agent for cooling the heat storing material.

After the cross equalization, the second equalization, using the remainder of the warm gas in vessel 45, is practised by closing valve 54*a* and opening valve 55*a*. The gas in consequence flows, after heat exchange with the heat storing material, through conduit 55 to distributor 31 so that a large portion of it is condensed in the charge of volatile material in vessel 10.

By the methods and apparatus of the present invention, it is seen that the gas material transferred is self-compressed with a high degree of efficiency and economy. This is accomplished by the several methods of preserving the refrigerating capacity of the liquid charges and the efficient utilization of the refrigerating capacity for the reduction of the blow-down loss to commercially immaterial amounts.

The refrigerating capacity of the liquid charges is preserved by excluding heat therefrom by suitable means; for example, by insulating the charge from the heat of the walls of the transfer vessels by means of linings or baskets disposed interiorly and/or insulating jackets disposed exteriorly. Also, it is seen that by discharging the final vessels to the receiving devices by heating only a portion of the charge in a thermal leg, much heat is excluded; also, by precooling the gas which is to be condensed during either or both first and subsequent steps of pressure equalization, the internal energy of the gas material being transferred is kept at a low value.

The refrigerating capacity of the liquid charges is used first within the cascade system for recondensing the gaseous remainder in the final vessel after a discharge from the liquid phase and secondly for rejecting heat from the system by precooling the gas material beyond the final discharge vessel so as to carry away some of the heat otherwise contained in the gaseous material passing backwardly through the system.

Since certain changes in carrying out the above process and in the constructions set forth, which embody the invention may be made without departing from its scope, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

Having described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A method of transferring a volatile liquid material that evolves a gas phase on account of heat added during the transfer from a region

of relatively low pressure to a region of relatively high pressure, which comprises causing the passage of said material in a succession of metered charges in countercurrent relation to the gas phase through a succession of steps of increased pressures, excluding substantially all heat of external origin from said material prior to the passing of a predetermined point, controllably heating to a relatively high temperature a portion of each charge withdrawn after passage of said predetermined point while maintaining pressure equilibrium between the charge and the withdrawn portion whereby the pressure acting on the charge and the volume of the charge are raised to relatively high values without substantial impairment of the refrigerating capacity of said charge, flowing by the agency of increased pressure and volume the charge to said region of relatively high pressure, absorbing and storing refrigeration from the material flowed, utilizing the stored refrigeration for cooling after said flow the portions of material in the gas phase which were heated to relatively high temperature, and passing the material in the gas phase in countercurrent heat exchanging relation with the material being advanced through steps of increased pressures prior to the passage of said predetermined point.

2. A method of transferring a volatile liquid material that evolves a gas phase on account of heat added during the transfer from a region of relatively low pressure to a region of relatively high pressure, which comprises causing the passage of said material in a succession of metered charges in countercurrent relation to the gas phase through a succession of steps of increased pressures, excluding substantially all heat of external origin from said material prior to the passing of a predetermined point, controllably heating to a relatively high temperature a portion of each charge withdrawn after passage of said predetermined point while maintaining pressure equilibrium between the charge and the withdrawn portion whereby the pressure acting on the charge and the volume of the charge are raised to relatively high values without substantial impairment of the refrigerating capacity of said charge, flowing by the agency of increased pressure and volume the charge to said region of relatively high pressure, utilizing refrigerating capacity of the material flowed for cooling material in the gas phase which is passed countercurrent to and in heat exchanging relation with the liquid being advanced through said steps of increased pressures whereby so large a portion of the gas is condensed that the ultimate loss of material in the gas phase is reduced to an immaterial amount.

3. A method of supplying gas material to a receiving vessel at a predetermined superatmospheric pressure which comprises isolating a metered charge of liquefied gas in one of a plurality of transfer vessels into which it has been introduced at a pressure less than said predetermined pressure, raising the pressure environment of said charge to a value exceeding said predetermined pressure and simultaneously increasing the volume by separately heating a portion of said charge while in substantial pressure equilibrium with said charge without substantially impairing the refrigerating capacity of the portion not heated, discharging the portion of said charge not heated to said receiving vessel leaving a heated gas phase remainder in said transfer vessel having a pressure equal to said predetermined pressure, indirectly utilizing the refrigerating capacity of the portion discharged to cool the gas phase remainder when it is passed to another vessel, isolating a second charge of liquefied gas introduced at a pressure less than said predetermined pressure in a second transfer vessel where it is maintained substantially insulated against inflow of heat for a desired period of time, and conducting a cooled portion of said remainder into said second charge whereby a substantial portion is condensed in and augments said second charge.

4. A method of transferring volatile material that has a gas phase evolved due to heat gained in the transfer from one vessel to another in cascade relation, which method comprises introducing a metered charge of material in the liquid phase into one vessel while another vessel contains material in the gas phase at a relatively high pressure, equalizing the pressures between said vessels while effecting condensation of gas material drawn from the high pressure vessel and passed into the low pressure vessel, interchanging under the influence of gravity the liquid and gas phases between said vessels, controllably heating a portion of the charge of liquid in said high pressure vessel to increase the pressure and volume of the charge to values sufficient to enable said charge to enter the receiver while preserving the refrigeration capacity of the major portion of said charge, flowing said major portion to said receiver, and during said flow extracting and utilizing said refrigerating capacity for cooling gas transferred between vessels when effecting said equalization to aid the condensation.

5. A method of operating a volatile liquid transfer system having transfer vessels arranged in cascade, which comprises conserving the refrigerating capacity of a charge of volatile liquid when passed into a final transfer vessel by excluding substantially all heat inflow from the walls of said vessel, controllably heating to a relatively high temperature a sufficient portion of said charge for increasing the pressure and volume sufficiently to displace the balance from said final vessel at a desired pressure without substantially increasing the sensible heat of said balance, transferring a refrigerating effect from said balance being displaced from said final vessel to a heat storing material where it is held for a desired period of time, and bringing into thermal contact with said heat storing material gas remaining in said final vessel after displacement of the balance when said gas is being passed to other vessels of the system.

6. A method of operating a volatile liquid transfer system having transfer vessels arranged in cascade, which comprises conserving the refrigerating capacity of a charge of volatile liquid when passed into a final transfer vessel by excluding substantially all heat inflow from the walls of said vessel, controllably heating to a relatively high temperature a sufficient portion of said charge for displacing the balance from said final vessel at a desired increased pressure and volume without substantially increasing the sensible heat of said balance, and utilizing the refrigerating capacity of said balance for cooling gas which is transferred between vessels of the system.

7. A method of operating a volatile liquid transfer system having transfer vessels arranged in cascade, which comprises conserving the refrigerating capacity of a charge of volatile liquid when passed into a final transfer vessel by ex-

cluding substantially all heat inflow from the walls of said vessel, controllably heating to a relatively high temperature a sufficient portion of said charge for increasing the pressure and volume sufficiently to displace the balance from said final vessel against a predetermined pressure without substantially increasing the sensible heat of said balance, storing a refrigerating effect obtained from said balance during the displacement of said balance, and transferring said refrigerating effect to gas passed from a vessel at high pressure to a vessel at lower pressure in the system.

8. A method of operating a volatile liquid transfer system having transfer vessels arranged in cascade which comprises, conserving the refrigerating capacity of a charge of volatile liquid when passed into a final transfer vessel by excluding substantially all heat inflow from the walls of said vessel, controllably heating to a relatively high temperature a sufficient portion of said charge for increasing the pressure and volume sufficiently to displace the balance from said final vessel against a predetermined pressure without substantially increasing the sensible heat of said balance, transferring a refrigerating effect from said balance being displaced from said final vessel to gas being passed from another final vessel to a vessel containing a charge of liquid at a lower pressure.

9. In a method of transferring charges of volatile liquid material from a source at low pressure to a receiver at relatively high pressure by means of transfer vessels connected in cascade relation and having final transfer vessels arranged in parallel, the step which comprises cooling gas being passed from one final vessel at a relatively high temperature and pressure into thermal contact with a succeeding charge for partial condensation by passing said gas in simultaneous heat exchanging relation with the volatile material being discharged from another final transfer vessel to the receiver.

10. In a method of transferring charges of volatile liquid material from a source at low pressure to a receiver at relatively high pressure by means of transfer vessels connected in cascade relation and having final transfer vessels arranged in parallel, the step which comprises cooling gas being passed from a final vessel at a relatively high temperature and pressure into admixture with a succeeding charge at a lower pressure and temperature for partial condensation, by flowing said gas countercurrent to and in simultaneous heat exchanging relation with the volatile material being discharged from another final transfer vessel to the receiver.

11. In a cascade system for transferring volatile liquid material from a low pressure supply source to a receiver at higher pressure, the combination with a plurality of transfer vessels for holding charges of volatile liquid at successively higher pressures, of means for protecting said charges from the influence of heat of external origin, means for heating a portion of the charge in a final transfer vessel at the highest pressure to a relatively high temperature while maintaining the refrigerating capacity of the balance of the charge in the vessel relatively unchanged, means for conducting said balance to said receiver, means associated with said conducting means for transferring a refrigerating effect from said balance to gas of relatively high temperature discharged from a final vessel of the system, and means for passing said gas in heat exchanging relation with charges of volatile liquid at successively lower pressures.

12. In a cascade system for transferring volatile liquid material from a low pressure supply source to a receiver at higher pressure, the combination with a plurality of transfer vessels for holding charges of volatile liquid at successively higher pressures, of means for protecting said charges from the influence of heat of external origin, means for heating a portion of the charge in a final transfer vessel at the highest pressure to a relatively high temperature while maintaining the refrigerating capacity of the balance of the charge in the vessel relatively unchanged, means for conducting material of the liquid phase in heat exchanging relation with a heat storing material from a final vessel to said receiver, and means for passing gas from a final vessel in heat exchanging relation first with said heat storing material and then with charges of volatile liquid in other transfer vessels at lower pressures.

13. In a cascade system for transferring volatile liquid material from a low pressure supply source to a receiver at higher pressure, the combination with a plurality of transfer vessels for holding charges of volatile liquid at successively higher pressures, of means for protecting said charges from the influence of heat of external origin, means for heating a portion of the charge in a final transfer vessel at the highest pressure to a relatively high temperature to increase the pressure and volume while maintaining the refrigerating capacity of the balance of the charge in the vessel relatively unchanged, means for conducting material of the liquid phase in heat exchanging relation with a heat storing material from a final vessel to said receiver, and means for passing gas in heat exchanging relation with said heat storing material from a final vessel to another vessel of the system which contains a charge of liquid at lower pressure.

14. In a cascade system for transferring volatile liquid material from a low pressure supply source to a receiver at higher pressure, the combination with a plurality of transfer vessels for holding charges of volatile liquid at successively higher pressures, of means for protecting said charges from the influence of heat of external origin, means for heating a portion of the charge in a final transfer vessel at the highest pressure to a relatively high temperature to increase the pressure and volume while maintaining the refrigerating capacity of the balance of the charge in the vessel relatively unchanged, said final vessel having a heavy metal pressure retaining wall and a lining means for holding the charge of volatile liquid in relatively poor thermal contact with said wall, means for conducting material of the liquid phase discharged from a final transfer vessel in heat exchanging relation with said pressure retaining wall to said receiver, and means for passing gas from a final transfer vessel in heat exchanging relation first with said cooled pressure retaining wall and then with charges of volatile liquid in other transfer vessels at lower pressures.

15. In a cascade system for transferring a volatile liquid material from a supply vessel where it is held at a relatively low pressure to a receiver under a relatively high pressure, the combination with a plurality of transfer vessels adapted for holding a succession of charges of material in liquid phase and material in the gas phase evolved due to heat gained in the transfer and for effecting the countercurrent passage of liquid and gas

phases in heat exchanging relation, of means for discharging material from the liquid phase of a final transfer vessel by heating a sufficient portion of the volatile material in the vessel to a relatively high temperature for increasing the pressure and volume to desired values sufficient to insure expulsion without impairing the refrigerating capacity of the material which is discharged, and means for applying said refrigerating capacity for precooling material in the gas phase during said countercurrent passage.

16. In a cascade system for transferring a volatile liquid material from a supply vessel where it is held at a relatively low pressure to a receiver under a relatively high pressure, the combination with a plurality of transfer vessels adapted for holding a succession of charges of material in liquid phase and material in the gas phase evolved due to heat gained in the transfer and for effecting the countercurrent passage of liquid and gas phases in heat exchanging relation, of means for discharging material from the liquid phase of a final transfer vessel by heating a sufficient portion of the volatile material in the vessel to a relatively high temperature for increasing the pressure and volume to desired values without impairing the refrigerating capacity of the material which is discharged, and a heat storage and exchanging device having a pass for volatile material which is discharged from the liquid phase of a final transfer vessel and a pass through which flows material in the gas phase during said countercurrent passage.

17. In a cascade system for transferring a volatile liquid material from a supply vessel where it is held at a relatively low pressure to a receiver under a relatively high pressure, the combination with a pair of transfer vessels connected in series the first discharging into the second for holding charges of said material and gas evolved therefrom due to heat gained on discharge from the second of said vessels, of means associated with the second of said vessels for preserving the refrigeration of said charges of material in the liquid phase from impairment by inflow of undesired heat, means for equalizing the pressure of said first and second vessels by conducting gas from said second vessel in intimate contact with liquid in said first vessel whereby a desired portion of gas is condensed by the refrigeration of the liquid, means for causing an interchange of gas and liquid between said vessels, a thermal leg for increasing the pressure and volume of said liquid in said second vessel to values sufficient for effecting a discharge to said receiver without impairing the refrigerating capacity of the material discharged, means for taking up and temporarily storing a refrigerating effect from said material as discharged, and means for transferring said refrigerating effect to gas being conducted from said second vessel to said first vessel.

18. In a cascade system for transferring volatile liquid material from a supply vessel where it is held at relatively low pressure to a receiver under a relatively high pressure, the combination with a plurality of transfer vessels interposed between the supply vessel and receiver arranged as two parallel groups each consisting of a low pressure vessel and a high pressure vessel in series disposed to pass a succession of charges of said material, of means associated with said vessels for protecting said charges from the influence of heat of external origin, means associated exclusively with said high pressure vessels for heating a portion of the charge contained therein to a relatively high temperature while maintaining the refrigerating capacity of the balance of said charge relatively unchanged, withdrawal means arranged for conducting said balance to the receiver, passage means connected to said high pressure vessels for conveying gas collected therein at high pressure to a region of lower pressure and temperature where, by partial condensation, a portion of the gas is converted into liquid, and means associated with said withdrawal means and said passage means for causing the gas being conveyed to a region of low pressure to pass in countercurrent heat exchanging relation with the liquid being passed to said receiver.

19. In a cascade system for transferring volatile liquid material from a supply vessel where it is held at relatively low pressure to a receiver under a relatively high pressure, the combination with a plurality of transfer vessels interposed between the supply vessel and receiver arranged as two parallel groups each consisting of a low pressure vessel and a high pressure vessel in series disposed to pass a succession of charges of said material, of means associated with said vessels for protecting said charges from the influence of heat of external origin, means associated exclusively with said high pressure vessels for heating a portion of the charge in a high pressure vessel to a relatively high temperature, withdrawal conduits leading from each of said high pressure vessels having a common manifold leading to the receiver, equalization passages leading from the gas space of each of said high pressure vessels to the liquid space of another vessel whereby when at lower pressure a passage of gas into liquid takes place producing partial conversion by condensation of the gas into liquid, and a two-pass heat exchanging device associated with each withdrawal conduit, one pass of each device being interposed in the withdrawal conduit while its other pass is interposed in the equalization passage leading from the other high pressure vessel.

20. In a cascade system for transferring volatile liquid material from a supply vessel where it is held at relatively low pressure to a receiver under a relatively high pressure, the combination with a plurality of transfer vessels interposed between the supply vessel and receiver arranged as two parallel groups each consisting of a low pressure vessel and a high pressure vessel in series disposed to pass a succession of charges of said material, of means associated with said vessels for protecting said charges from the influence of heat of external origin, means associated exclusively with said high pressure vessels for heating a portion of the charge in a high pressure vessel to a relatively high temperature, withdrawal conduits leading from each of said high pressure vessels and having a common manifold leading to the receiver, equalization passages leading from the gas space of each of said high pressure vessels and discharging into the liquid space of the low pressure vessel of the series, and a two-pass heat exchanger associated with each withdrawal conduit, each of which has one pass interposed in its associated withdrawal conduit and the other pass in communication with the equalization passage leading from the other of said high pressure vessels; the communication to said passes being arranged to effect the countercurrent passage of the gas and liquid in said heat exchangers.

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